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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
GEODESY AND GEOMATICS PROGRAM

**GIS Based Network analysis for Locating Fire Stations and Emergency
Response: A Case of Addis Ababa City, Ethiopia**

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Approval sheet

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DECLARATION

I certify that this research work entitled “*GIS Based Network Analysis for Locating Fire Stations and Emergency Response: A Case of Addis Ababa City, Ethiopia*” is my own work and has not been presented for a degree in any other university. Where material has been used from other sources has been properly acknowledged.

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List of Abbreviations

AACFEPA	Addis Ababa City Fire and Emergency Prevention and Rescue Agency
AACRA	Addis Ababa City Road Authority
AHP	Analytical Hierarchy Process
AU	African Union
CMSGHS	Central Medical Stores of the Ghana Health Service
ESRI	Environmental System Research Institute
FPASA	Fire Protection Association of South Africa
GHS	Ghana Health Service
GIS	Geographic Information System
GPS	Global Positioning System
MCDMA	Multi-Criteria Decision-Making Analysis
NMA	National Metrological Agency
NDRMC	National Disaster Risk Management Commission
OSM	Open Street Map
WLC	Weighted Linear Combination
WHO	World Health Organization
NFPA	National Fire Protection Association
UNECA	United Nations Economic Commission for Africa
UN DESA Affairs	United Nations Department of Economic and Social Affairs
UTC	Coordinated Universal Time

Abstract

Urban fire is one of the most common problems not only for developing countries but also for developed countries. Particularly in Addis Ababa, Ethiopia. On this year ,2020/21 totally 274 incidents were occurred in the span of two years. Fire stations in Addis Ababa city is one of the major issues as most of increasing of population and urbanization expansion due to poor and inefficient access of fire services stations. This study aims GIS based network analysis for locating fire station and emergency response analysis. It was conducted in Addis Ababa city and it has a total area of 519.458 sq. km² and focused on two years fire incident report. The methodology of the study was integrated with roads network analysis and locating optimal fire stations for the study area using GIS software. The network analysis process has been applied and search optimal route between fire incident location and fire station by applying Dijkstra's algorithm to the road network of the addis ababa city in connection with this service area was applied. The served population from existing fire stations is 2,817,315 (66.62%) out of 3,689,001 estimated population which is distributed over the area 276.10km² (53.15 %) of the city are served out of a total of 519.458 km². The closest facilities from fire station to the fire incident eight minutes travel time, a total of 230 route was generated with maximum travel time of 7.99 min and length of 11890.42m as well as using travel time as an impedance factor this study determines the best route from fire stations to the incident location. And , multi criteria analysis model has been developed to choose suitable sites for the inaccessible place together with factor identifications. This study employed six different criteria are considered for selecting candidate sites . From them the more influenced criteria are inaccessible area, population density and land use with associated weights of 36% , 24% and 17% respectively and AHP method was used for selecting 35 candidate sites for the study area. Among of the location allocation problem type , maximize coverage has chosen ten new optimum location of fire stations to the study area. Finally, the present study suggests 10 new fire stations which helps to maximize the coverage of the city as well as provides services during emergency occurrence. After the suggested 10 new fire station location together with existing fire stations , the current service coverage the study area has increased into 87.44%.

Keywords: Urban fire, Network analysis ,GIS , AHP , Dijkstra's algorithm, and Location allocation

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Fire is a form of disaster that can occur anytime and anywhere and to some instances without notice (Edupta, 2011). Fire can be a great threat to human beings, the built-environment and nature, often resulting in injuries, deaths, economic loss and pollution Yao et al., (2019). According to the International Association of Fire and Rescue Services Brushlinsky et al., (2017) among the reported 31 countries there were on average about 3.5 fires per 1000 inhabitants in 2015, resulting in 18,454 deaths and over 44,000 injuries. Urban fire is one of the most common problems not only for developing countries but also for developed countries Nisanci., (2010). Particularly in Addis Ababa, Ethiopia. According to the Addis Ababa Fire and Emergency Prevention and Rescue Agency (AACFERA) report for the years of 2020 and 2021 a total of two hundred seventy-four (274) firehouse incident has occurred in the span of two years from this accident so many properties was damaged and there was also loss lives in the city. The main cause the accident was improper use of power line, poor installation of electric line , explosion of stoves that work with gas and oils. Firefighting and rescue services or fire stations are among the most crucial government services for protecting people , property ,and the environment from fire and other emergencies.

Fire stations are one of the most essential and necessary land uses in urban area that guarantee the life and safety of urban residents. So, the location and number of the stations is very significant for the efficient coverage of the area which intended to be protected. Furthermore, the expanded of urbanization growth has multiplied the increase in population of urban area in the developing countries which the risk of hazardous fire area its impact of the city became more obvious Habibi et al., (2008). As a result, emergency response services are critical, especially in the case of fire disasters, to prevent the country from losing valuable resources Forkuo and Quaye-ballard., (2013). The success of emergency response depends on procedures, resources, and Employees. Services are required during the response, preparedness, and rehabilitation times and must be defined according to the responding agencies and the types of emergencies experienced. In addition, the right resource control processes, such as the implementation of an emergency response plan, an incident. As a result of being trained to use the tools and practice

the systems in multiple emergency situations, the emergency management staff act as the link between the systems and resources. In other words, these professional workers are the ones that are on the site security problems and on the field at hand during crises. firemen and Ambulance staff are few examples of qualified emergency service personnel Subramaniam and Ali, (2012). Right now, in addis ababa city ten existing fire stations are found which provide a service for emergency response occurrence for the entry city. In order to determine the best location to the study area this study used GIS. Geographic information system (GIS) is one of the best techniques for determining the best location for a fire station, and it can integrate both spatial and non-spatial data Şen et al., (2011). There are two spatial data models being used in GIS today: vector and raster.

The present study was carried out to solve the problem of inequality distribution of fire stations throughout the city and develop a method of finding optimized routes for emergency response analysis. For that reason, an integrated method was used such as GIS techniques of Analytical Hierarchy Process(AHP) to propose additional candidate sites of fire stations to be added in the study area and network analysis techniques was conducted. Among of location allocation analysis, Maximize Coverage has been utilized to determine the best optimum location of fire stations service in the Addis Ababa City.

1.2 Statement of the problem

Fire incidents is a one of the key problems in Addis Ababa city which occurs frequently due to growth of population in parallel with the presence of dense housing which causes the number incident tends to increase year by year. On this year, in 2020 and 2021 one hundred twenty (120) and one hundred fifty-four (154) firehouse accidents occurred respectively.

Most of the time fire accident are caused by human carelessness, unexpected accidents and natural disasters. Fire is among the most destructive problem in Ethiopia. There is usually an incidence of fire in Ethiopia which is mainly in January, February and March before the onset of the rainy season (Yetmgeta, 2013) . The data from Addis ababa city fire and emergency prevention and rescue agency (AACFEPR) indicates that among 274 major fire house incidents occurred in 2020/21, 66 incidents are occurred in the above stated months. The cities need to enhance and upgrade emergency services and constantly improve on response time since seconds make differences in terms of saving lives and minimizing damage to property (Baloyi, 2017).

But the other is ,increased traffic flow in the city , inconvenience of roads will delay the response of time to reach the scene of fire this may result in economic failure of the victim.

Due to poor and inefficient access of fire stations service in Addis Ababa city as well as increasing of population and urbanization expands the fire incidents has increased year to year. Based on this it was discovered that unequal fire stations facilities distribution has been the problem in Addis Ababa city.

In the present day, Addis Ababa city has ten existing fire station services from the size of the city this is not enough to cover the entire city which is actually shown that the facilities are not equally distributed as per living population. The stipulated target response time of Addis Ababa city fire and emergency prevention and rescue agency is 8 minutes. However, most parts of Addis Ababa city fire stations cannot reach to the incident locations at the specified local standard time response. As the expansion of the city and growing population is increasing, the need for fire stations also increases. However, the number of fire stations has not increased yet accordingly. Therefore, to overcome this problem the study develops GIS based network analysis approach which is used for emergency response analysis. Additionally, Analytical hierarchy process was used to propose additional fire stations in order to minimize the deficiency of fire station service to the uncovered area which helps to reduce the huge property damage and loss of human lives.

1.3 Objective

1.3.1 General objective

The general objective of this study is GIS based network analysis for locating fire stations and emergency response analysis in Addis Ababa City.

1.3.2 Specific objective

- ❖ To evaluate the location of service area coverage of existing fire stations based on local deriving time response.
- ❖ To find the best route and closest facilities analysis from the nearest of fire station to the fire incident location.
- ❖ To choose optimum sites of fire stations to the study area by using location allocation problem types particularly maximize coverage.

1.4 Research questions

In parallel to these objectives, this study raised the following basic research questions.

- ✓ Which areas are there under the service coverage of existing fire stations based on local context deriving time response?
- ✓ What are the methods used for finding the shortest routes and closest facilities from fire station to the fire accident place?
- ✓ Which method is used for finding the optimum location of the fire station to maximize coverage of the study area?

1.5 Scope of the study

Addis Ababa is one of the biggest cities in Ethiopia and it has a total area of 519.458 sq. km². The scope of the study was GIS based network analysis for locating fire stations and emergency response analysis for Addis Ababa city. This study mainly performs finding additional candidate sites and using advanced network analysis extensions tools for emergency response analysis including service coverage, best route, closest facilities, and location allocation (Maximize coverage) in Addis Ababa city. In connection with this the study was focused in the year between 2020 & 2021 fire incident reports were used for further analysis.

1.6 Significance of the study

The importance of this study is not limited only for this paper but also the concerned stakeholders they look at will be beneficial. For example, the result of this study is very much useful for Addis Ababa city fire and emergency prevention and rescue agency(AACFEPPRA) and it will assist in finding well thought-out locations for constructing new fire stations in the city. In connection with this the information generated by this study is also believed to provide useful information for Addis Ababa city government plan and development commission while designing public facilities and infrastructure in relation to population growth. In addition to this the methodology and procedures used in the study will be used as a reference to conduct further research in other places for the other researcher.

1.7 Limitation of the study

In the study there was some limitation some of them are listed:

- ✓ The data obtained from Addis Ababa Fire and Emergency Prevention and Control Agency was not readily available in spatially compatible format. This made the study difficult to find and collect coordinate location of fire incident places.
- ✓ The climate condition during GPS data collection for the fire incident location was rainy season that made the study not to collect the data as per scheduled time.
- ✓ There was a shortage of data quality and it was very time consuming to clean the data .

1.8 Organization of the thesis

This thesis consists of five chapters which are arranged as follows: Chapter One : Introduction : this chapter includes introduction of the research , statement of the problem, research objective, research questions, significance of the study, limitation of the study, scope of the study and structure of thesis format. Chapter Two : present literature review of the previous literature appropriate for this study topic also discuss their common term and related terminology. Chapter Three: Methodology and Material: elaborate the data methodology and general implementation to achieve the objective of the study. Chapter Four: Data Analysis , Result and Discussion : shows that the main data analysis undertaken for the study, detailed discussion and interpretation of the result. The candidate site selection and advanced network analyst extension tools are applied in this chapter. The final section is Chapter Five: Conclusion and Recommendation : provide answers for research questions, generalizing the obtained results and indicate future work to another researcher. And Reference : a list of sources used in this study attached at the end of this paper.

CHAPTER TWO

REVIEW OF LITERATURE

In this section the study reviews the previous literature related with the present study of GIS based network analysis for locating fire stations and emergency response analysis are reviewed and presented under the following sections in addition to this some standard practiced across world has been reviewed. This chapter attempts to highlight various applications of ArcGIS integrated with Analytical Hierarchy Process for finding optimum location for fire stations to the study area. Along with this the reason for doing this study is in the city of Addis Ababa fire occurs frequently in order to save this event it is intended to establish a new fire station.

2.1 Definition of Terms and Concepts

2.1.1 Fire stations

Fire is among the causes of loss of life and property, therefore, to eliminate possible destructive outcomes there should be timely interventions. The fire service mission is to protect lives and property from fire. Therefore, emergency services in cities need to be planned in such a manner that they cater for all areas within their jurisdiction within the required response time. Traditionally, the purpose of the fire service departments has been to prevent fires and to respond to fires that do occur and to put them out. Although most fire departments are the primary providers of preventative fire protection, all fire departments are organized to react promptly to crisis situations such as road accidents and flooding Drake et al., (1972)

Worldwide, fire stations play the most important role in case of any type of emergency. the fire service mission is to protect life, property and natural resources from fire and other emergencies with the help of their existing vehicles and equipment and manpower skill ESRI, (2007). Fire station is an around the clock complement of a firefighter together with fire suppression vehicles such as an engine or a ladder Badri et al., (1998).

2.1.2 Fire incident

Fire incident is unexpected events can have its origin either in nature or in human activities. Whatever the case, it is a phenomenon that usually involves a process of occurrence, spreading, human countermeasures and then disappearance Haque, (2001). Fire usually occurs due to

improper use of utilities or unaware human behavior. It can spread in any direction if inflammable materials are present, and it can last anywhere from a few minutes to days or weeks depending on the fire load and successful countermeasures Maniruzaman and Haque, (2007).

2.1.2.1 Globally

Globally, Fire accidents have become very common in the world . Because of the health and climate impacts of fires and the fact that fire regimes have been changing, fire prediction has received increasing attention. Each year, fire causes about 300,000 deaths globally and most of these occur in the home Zhang et al., (2006). This can be mitigated by taking appropriate precautions, which are made easier by sophisticated systems and information technologies. Since GIS can process large amounts of data and respond quickly to spatial queries, it can be used to analyze data about urban fires Nisanici, (2010).

The possibilities of urban fire are heavily linked to the area's level of urbanization Wang et al., (2011). By 2007, for the first time in history , more than half of the world's population 3.3 billion people were lived in cities Khouri et al., (2018), urbanization is a worldwide phenomenon which is at its peak. Currently, 54 percent of the world's population lives in cities , with that number predicted to rise 66 percent by 2050 UN DESA, (2014). The increase of population will facilitate the fire incident occurrence in the city. According to World Health Organization (WHO) statistics, fire-induced burns cause over 300,000 deaths per year among over 95 percent of these deaths occur in low and middle-income countries. Building fires are a major threat to the safety of building residents and are mostly caused by people's activity. Fires, especially in big residential complexes with many occupants, can result in increased injury or death as a result of emergency evacuation difficulties Shokouhi et al., (2019).

2.1.2.2 Africa

The Fire Protection Association of South Africa (FPASA) compiles data on fire from brigades across the country but this is not without its challenges, including incompletely documented or unreported fires Potts, (2012). Consequently, their data typically underestimates incidence data. In 2016, FPASA recorded 41,873 fire callouts nationally, which translates to about 115 fires per day. Between 2003-2016, the number of fires increased between 1.5-1.7% per annum with the number of fatalities rising between 5-10% per annum.

Zimbabwe is among the most fire vulnerable countries in Africa south of the Sahara Chinamatira et al., (2016). Per year more than 1 million hectares of land destroyed by wild land fires during the fire season span from July to November .There are several causes of wild land fires. Chinamatira argued that recent increase in fire incidences has attributed to newly resettle smallholder farmers.

Several key historical documents including some dating back to the independence of Ghana were lost because of the fire incidence. A fire in early 2015 destroyed the Central Medical Store of Ghana Health Service (CMSGHS) in Tema , which housing medical supplies for distribution to medical facilities nationwide. Between January and September 2016 , GHC 86 million worth of property were lost .Every year Ghana cause huge damage due to fire disasters. Critical sectors of nations economy and infrastructures are consumed by fire and the cost of the item damaged has 916,355 GHS in *Ghana Lost GHC86 Million to Fires between Jan-Sept.2016*, (2016). The country was hit by yet another large fire in late 2016, this time at the Ghana International Trade Fair Center which resulted in six human deaths Ibrahim, (2016).

2.1.2.3 Ethiopia

In 2010-2012 , considering that there were only 159 fire disaster events were recorded all over Ethiopia cities during the 2-year period Osuteye et al., (2017) In Ethiopia , Fire accidents occur frequently NDRMC, (2016), Fire accident, caused by either humans or nature, can pose a hazard to people, properties, and the environment, possibly resulting in psychological damage, physical injuries, death and significant economic losses. For example, there were about 9,755 fires during 2000-2016 in Ethiopia, involving 853 deaths and more than 5,421 non-fatal casualties and above 615-million-birr economic costs of property damage caused by about 9,755 fires in 2000-2016.

However, recently in Ethiopia 2020/2021, associated with the expansion of the cities, there has been an increase in fire accidents , road traffic and construction-related accidents. Among them, many fire incidents have been registered throughout Ethiopia cities including Addis Ababa, Gondar, Woliyta Soddo, Bahir Dar, Dire Dawa, and others, resulting in extensive property damage and loss of human lives.

2.1.2.4 Addis Ababa

Addis Ababa city has the largest number of business centers such as Mercato. Moreover, due to the existence of densely residential and commercial centers as well as the increasing population from day to day the vulnerability to fire incidents becomes widespread. The study used a two-year report of fire incident data i.e., 2020/2021 acquired from AACFEFRA which was categorized based on sub cities occurrences reported with estimated property loss of 1,065,785,980 (ETB) as presented in Table 2.1. Beside this there were also the loss of lives and injuries

Table 2.1: Fire Incidents report on each sub city in addis ababa 2020-2021

Sub City Name	Fire Incidents in 2020/21				Property Damage In Both Years
	2020	2021	Total	Percentage	
Addis Ketema	16	26	42	15.33	85,348,400
Akaki-Kality	8	9	17	6.69	103,216,900
Arada	13	19	32	11.68	118,431,910
Bole	21	27	48	17.52	121,426,910
Gulele	11	12	23	8.39	113,930,510
Kolfe Keranyo	12	20	32	11.68	125,457,510
Lideta	6	5	11	4.01	108,888,510
Kirkos	6	9	15	5.47	84,432,510
Nifas Silke Lafto	15	14	29	10.58	109,878,910
Yeka	12	13	25	9.12	94,773,910
Total	120	154	274	100	1,065,785,980

(Source : AACFEFRA, Sept 2020- Aug 2021 fire report)

2.2 Emergency response using GIS

In Bhagat and Sharma, (2013) the authors develop a GIS desktop-based emergency response management system in Delhi, India. In this system, a detailed transportation network and real-time traffic data were maintained and integrated. GIS capabilities, such as network analysis, Origin–Destination (OD) cost matrix, proximity analysis, and buffer analysis were also performed.

In Hoyos et al., (2015) , the authors classify Emergency management activities can be classified into five phases; planning, mitigation, preparedness, response and recovery. Mitigation Phase associated with analytical modeling and reveals the natural spatial variation in hazard, prone and ultimately risk.

In (Nguyen, 2006) , the authors states that creating the fire emergency response database, preparedness in emergency planning is a crucial factor that can impact the lives of people. When emergency preparedness is properly planned and executed, human lives can be saved and some of the economic losses in areas affected by fire can be mitigated. However, if not properly planned or implemented timeously, the consequences can be dire and could cost human lives

In Forkuo and Quaye-ballard, (2013) , the authors introduced a GIS based fire emergency response service in Kumasi Metropolis, Ghana where the Ghana National Fire Service (GNFS) can select the best route from its location of any fire incident. The best route was modeled based on the travel time, travel distance, the slope of the roads and the delays in travel times.

In Bhagat and Sharma, (2013) , the authors based on GIS in Delhi, India to develop a desktop-based emergency response management system. In this system, a detailed transportation network and real-time traffic data were maintained and integrated. GIS capabilities, such as network analysis, Origin–Destination (OD) cost matrix, proximity analysis, and buffer analysis were also performed.

In Hay et al., (2019) , the authors implemented the GIS-Based Fire Emergency Response System for Mandalay Road Network using the Dijkstra routing algorithm. The paper emphasizes the selection of the best route between two locations on the road network data and then finding the nearest emergency service providers and fire stations to an accident site based on traffic conditions.

In Sayed et al., (2017) the authors developed an enhanced GIS-based network analysis that was performed and applied to the Greater Cairo Road network. It focused on finding the best route between two locations on the road network and identifying the closest healthcare service providers to an incident location based on the response travel time and used historical traffic data in the analysis. It shows an improvement in the travel time with 20% to 22%, according to the

travel distances. However, the system did not consider the other factors that cause a delay when traveling through the road network.

2.3 Fire response time

While it is important that fire stations are properly situated to maximize coverage, they must also be carefully placed to minimize response time fire scene Liu et al., (2006). A fire department's response time the length of time it takes a fire truck to arrive at a fire scene starting from the time the call was made to the fire department Flynn, (2009). Response time is important for firefighting. Changes in land use and urbanization request continual evaluation of the spatial spreading of fire stations and fire risk within the framework of costs/benefits. Since these issues have a spatial element, GIS systems are being utilized for solving and supporting them MartinLandré, (2008)

NFPA (National Fire Protection Association) 1710: requires countries to respond to fire incidents within an eight-minute response time (excluding call-processing time intervals) to 90% of incidents similarly provides essential benchmarks. Total response time, which is the time it takes from the instant a call is received at the public safety answering point until the first unit reaches the scene of an emergency occurrences is a baseline for fire department. For all due units and effective response time should be measured and reported. Total response time is consisting of the following terms :-

I) Dispatch time: The point at which the emergency alarm is received at the public safety answering point to the point where sufficient information is known to the dispatcher and applicable are notified of the emergency.

II) Turnout time: The time that begins when units acknowledge notification of the emergency to the beginning point of response time. One minute (80 seconds) for turn out time

III) Response time: The time that begins when units are in route to the emergency incident and ends when units arrive at the scene. The response time should be less than 240 seconds with less than 80 seconds of the turnout time. According to NFPA 1221 requires that 95 percent of alarms shall be answered in 15 seconds, 99 percent of alarms shall be answered in 40 seconds, and the dispatch of the emergency response agency shall be finalized within 60 seconds 95 percent of the time (ESRI, 2007). In accordance with the Standards for the Construction of Urban Fire Stations

(2017) and the development situations of domestic and foreign cities, the standards for the construction of fire stations can be the site selection of fire stations should follow the principle that firefighters should be able to reach the margin of their jurisdictions within five minutes after receiving the set off instructions (the drive time of fire trucks should be within four minutes). Habibi et al. (2008) suggested a response time of 3 minutes to 5 minutes be applied in a region of high population density and residential land uses. The use of a 5-minute response time aids in the fight against fire before it reaches flashover. Flashover occurs when the room temperature rises between 825° F and 1,000° F and this takes place within 5 to 8 minutes from the initial ignition. To successfully combat the fire, an effective fire attack must be carried out before 8 minutes John r. Waters, (1999) . On the other hand, the National Fire Protection Association referred to its pointing to five minutes limit as the suitable response time goal NFPA, (1710).

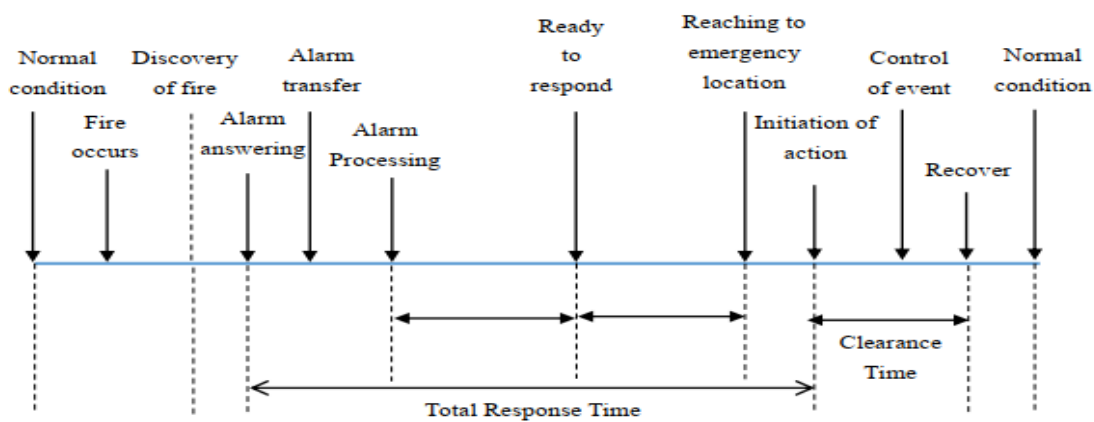


Figure 2.1 Cascading event chart for an emergency situation

Source : Oh et al., (2019)

Table 2.2 : Different fire response time standards for different countries

Country Name	Fire response times standards
United kingdom	5,8, 10 & 20 minutes (based on risk type)
Ghana	5 minutes
South Africa	8 minutes (commercial& industry)
India	5 minutes
Ethiopia, AA	8 minutes

Source : Table was adjusted by Author using different source (Boakye, 2017; Green et al., 2014; Tali et al., 2017) to align with the study needs.

2.4 ArcGIS network analysis

ArcGIS Network Analysis is an ArcGIS extension that allows performing a spatial analysis of the network, including routing between nodes, location and allocation of facilities and definition of service area among others. One of the major advances of the tools is the possibilities of using the actual condition of the road network such as direction , speed limits and blocks of any kind. Users can use ArcGIS network analysis to dynamically model realistic network conditions at different times of the day including turn restriction , speed limits , Hight constraints and traffic conditions Kumar and Kumar, (2016).

In Sui Min, (2012) , authors implied that network analysis is one of the main functions of GIS, that plays an important role in vehicle routing, traffic tourism, urban planning, electric power, communication and closest facility. This network is used, among other things, to build an immediate, rapid and efficient emergency fire response system for the study area. The computation of the optimum path between different locations on a network is the most fundamental and the most crucial problem in network analysis Sui Min, 2012; F. Zhang et al., (2009).

In Reveshti et al., (2015), the authors also describe that network analysis program is one of most useful applications of GIS. It has various applications in different natural and urban fields. One of the urban applications of this program is finding the shortest and best route for timely response in emergencies. International standards recommend 5-km radius for fire stations as well as 3-5 min response time for reacting to fires.

In El & Badri, 2016; Nagib & Ali, 2010; J. Zhang, (2005), the authors have common sense about ArcGIS network analysis, It uses the standard Dijkstra's algorithm to calculate the least accumulated cost between the destination node and every other node and details of this algorithm and its assessment can be found in.

In Tishi, (2015), the authors stated that the service area includes the area in which the firefighting vehicle is supposed to reach at a place of fire incident within the standard response time within 5 minutes. Designated coverage area of a station should not be larger than the standard service area of that station.

2.5 The role of GIS for fire stations

In Meyer., (2011), the author has described that Geographic Information Systems also plays a vital role for locating fire stations. In the area of urban cities, GIS can effectively assist in the design and operation of successful emergency response. Habibi et al., (2008) the authors stated that GIS is an important and efficient tool that can be used by local administrations to reduce the impact of natural disasters. Thus, GIS technologies have been used in fire analysis related to the optimum location of fire stations, the researcher has made spatial analysis of urban fire stations in Tehran, using an analytical hierarchy process and GIS. The authors stated that, using models and software in urban planning has become prevalent in response to the complex dimension of the urban issues and the role of many different indicators in this field.

In Yang et al., (2004) also carried out studies concerning the selection of fire station locations using GIS. In Jasso et al., (2009), the author has carried out the location information of fires from 911 emergency calls that could not be identified accurately. By matching linking address information with coordinate information, GIS aids in determining the location of fires or accidents in the least amount of time. The literature reveals an increasing use of GIS in the fire service in the last decade Corcoran et al., (2007).GIS technology has become a powerful tool for improving all aspects of fire service delivery systems .With all the challenges confronting emergency crews today, effective response requires good planning, risk management, comprehensive training, and intelligent deployment through preparation ESRI, (2006).

In Derekenaris et al., (2000), the authors also carried out Geographical Information System (GIS) which is used for modeling of road networks offering algorithms to analyze and find the shortest or minimum route through a network. GIS can be used to calculate the distance between sets of origin and destination, meanwhile location-allocation can be utilized to establish site locations and assign demand to sites. Street addresses can be converted to map coordinates (address geocoding). A comprehensive GIS-based fire station location analysis can serve as the foundation for a fire station master plan. This plan can demonstrate both the efficiencies and insufficient of present fire stations coverage for a predefined travel time and provide a model for future fire station coverage using the predefined or other travel time standards ESRI, (2007).

2.6 Location-Allocation

Only six different problem types are available in the ArcGIS location allocation analysis layer to address a particular type of question which are minimize impedance , maximize coverage ,

minimize facilities, maximize attendance , maximize market share and target market share ESRI, (2010). Location-allocation is a modeling technique , integrated into ArcGIS Network analysis to solve problems of equating facility supply with demand using sets of criteria's and constraints Church,(1910). According to Drezner,(1995) describes that location-allocation model as the process in which distribution of demands are taken into consideration to select the optimal location for facilities from a set of available locations. Location-allocation is a public sector planning tool used to attain the optimum location services and facilities within a given urban area. including emergency services (police and fire stations or ambulances service), schools, libraries, depots, warehouses, hospitals ,grocery stores and other public utilities are examples of such services. In Bolouri et al., (2020) , the authors describe that location–allocation problem aims to select the appropriate locations from a number of possible supply centers to provide the appropriate services for customers and decision makers in connection to the customer allocation (demand centers), based on given criteria for the facilities.

In Habibi and Lotifi, (2008) , the authors developed a model for fire station locations in district 6 of Tehran using the Geographic Information System (GIS). For the optimal location of fire stations in Kuwait City Algharib, (2018), use the location–allocation analysis in a GIS environment. Meanwhile, In Bolouri et al., (2018), the author employed both genetic and simulated annealing algorithms to overcome a variety of location and allocation problems for fire stations in district 11 of Tehran as multi objective problems; comparison finding for the algorithms showed the superiority of the genetic algorithm.

2.6.1 Maximum coverage in ArcGIS

The issue of maximum spatial coverage was first introduced by Reville and Church. It has been confirmed that this issue, in terms of practical benefit and technical competence, has a significant contribution to location analysis and modeling. A lot of commercial software programs based on spatial information systems such as ArcGIS and Trans CAD, have also been synchronized for general use and the paper gives an overview of the problem of fire station maximum coverage. Reville and Hogan, (1988). To implement emergency rescue center location like fire station , police station in order to cover maximum demand , maximum coverage type problem is used. If the objective is to cover 100% demand for emergency support this solution will help to model it ARIFIN, (2011). Maximum coverage location problem seeks to maximize the total number of

covered demands within a maximum service distance or time by locating the candidate facilities near locations with high population density. Emergency service location models have the objective to maximize the coverage within a standard response time or distance. One of the most popular models that was applied to locating emergency service facilities is the maximal covering location model. This model was often applied to selecting the best location for emergency service facilities such as fire stations, ambulance and police stations Algharib, (2011)

2.7 Multi criteria analysis – analytical hierarchy process

Analytic hierarchy process is an effective, flexible and simple method to be used in certain cases on which contradictory criteria make the decision-making process very difficult. This multi – criteria evaluation method was proposed by Thomas L. Saaty in 1980 and since then had several applications in different sciences.

Multi-criteria decision-making analysis (MCDMA) is an effective approach to support decision making process in which different options are based on a set of explicit objectives measured by weighted criteria. GIS-based MCDMA is powerful for spatial related decision-making process. Which has enhanced multicriteria decision making process since 1980s and is a process that combines geographical data and value judgments Estoque, (2011) Analytic Hierarchy Process is a common method in the field of fire risk assessment. Its major goal is to solve the problem of target selection and achieve the objective of optimization. The weight computation is a crucial stage in determining whether or not the AHP will succeed.

Analytic Hierarchy Process is a method integrated with GIS useful for locating new fire stations to assess all criteria simultaneously which analyzes complex decision problems under multiple criteria, and helps the decision makers to set priorities and make the best decision Abstract, 2014; Chhetri and Kayastha, (2015) and it's one of the most applied approaches of Multi Criteria Decision Analysis (MCDA) for spatial analysis decision makers. For site selection process it starts with the identification of the pertinent site selection factors.

In Chaudhary et al., (2016), the author has proposed a method that combines analytical hierarchy process and geographic information system to provide a decision maker for suitable fire site selection, a case study from Kathmandu metropolitan city, Nepal.

In summary, GIS based network analyst and AHP are very important techniques when planning for locating fire stations. This chapter discusses the notion of GIS based network analysis and emergency response analysis and reviews the international and local context of time response. From the literature, it can be noted that GIS techniques and procedures integrated with analytical hierarchy processes have an important role to play a decision-making problem when locating fire stations. This study seeks to fill a gap within the present literature by analyzing the impact of an application in cities as well as highlight the usage of more advanced network analysis which helps for emergency response analysis within GIS.

2.8 Conceptual framework

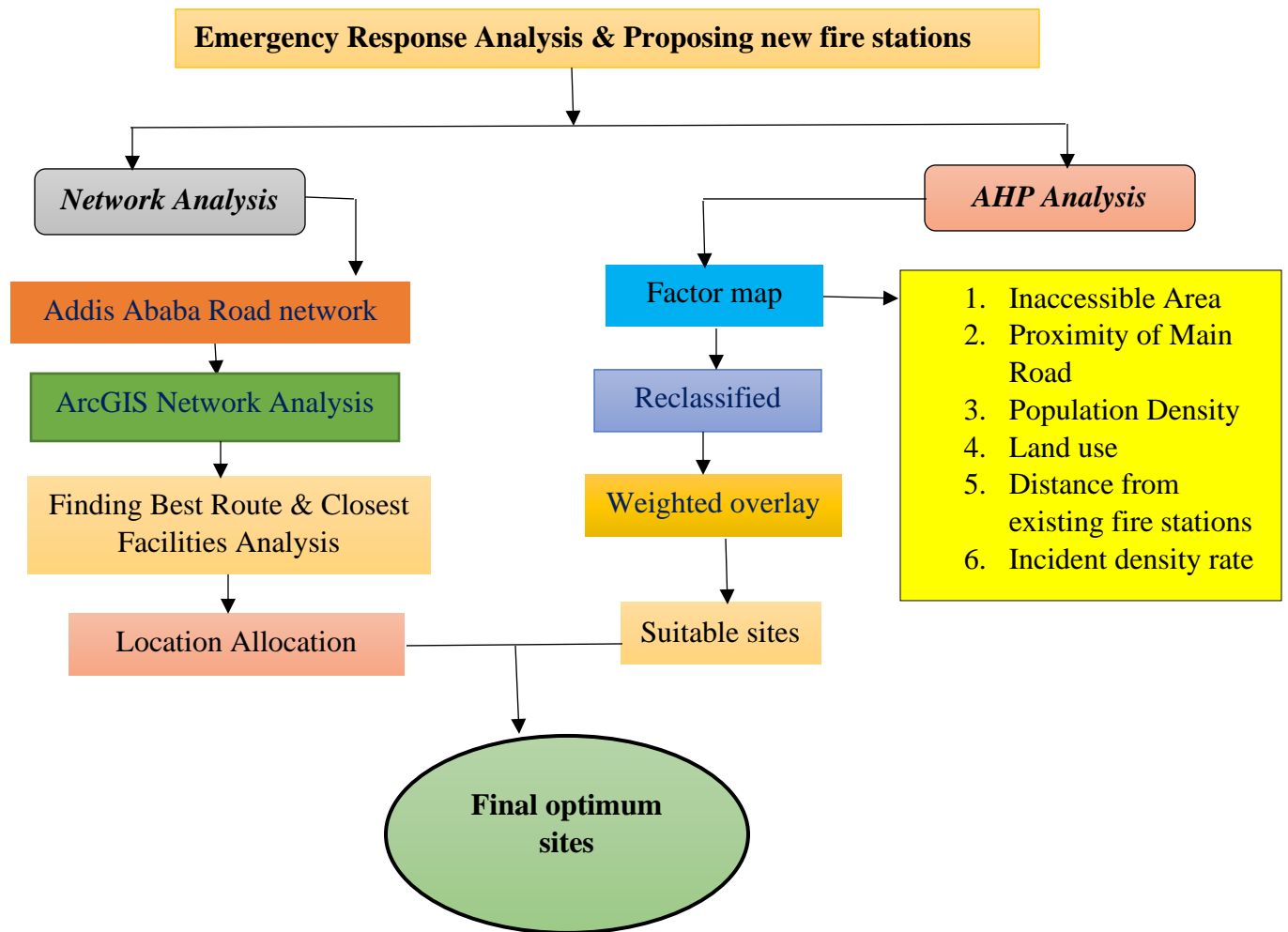


Figure 2.2 Conceptual frameworks of the study

(Source : Prepared by Author ,2021)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Addis Ababa is geographically located at the heart of the nation between $9^{\circ}2'$ N latitude and $38^{\circ}45'$ E longitude with time zone of UTC + 3 (East Africa Time), it occupies a total of 519.458 km² land area surrounded by mountainous landscape and the average population densities of the city is 7102.43 people/km² (Fig 3.1). As the diplomatic Centre of Africa Addis Ababa hosts a number of international organizations including the headquarters of African Union (AU) and the United Nations Economic Commission for Africa (UNECA) (Abnet et al., 2017).

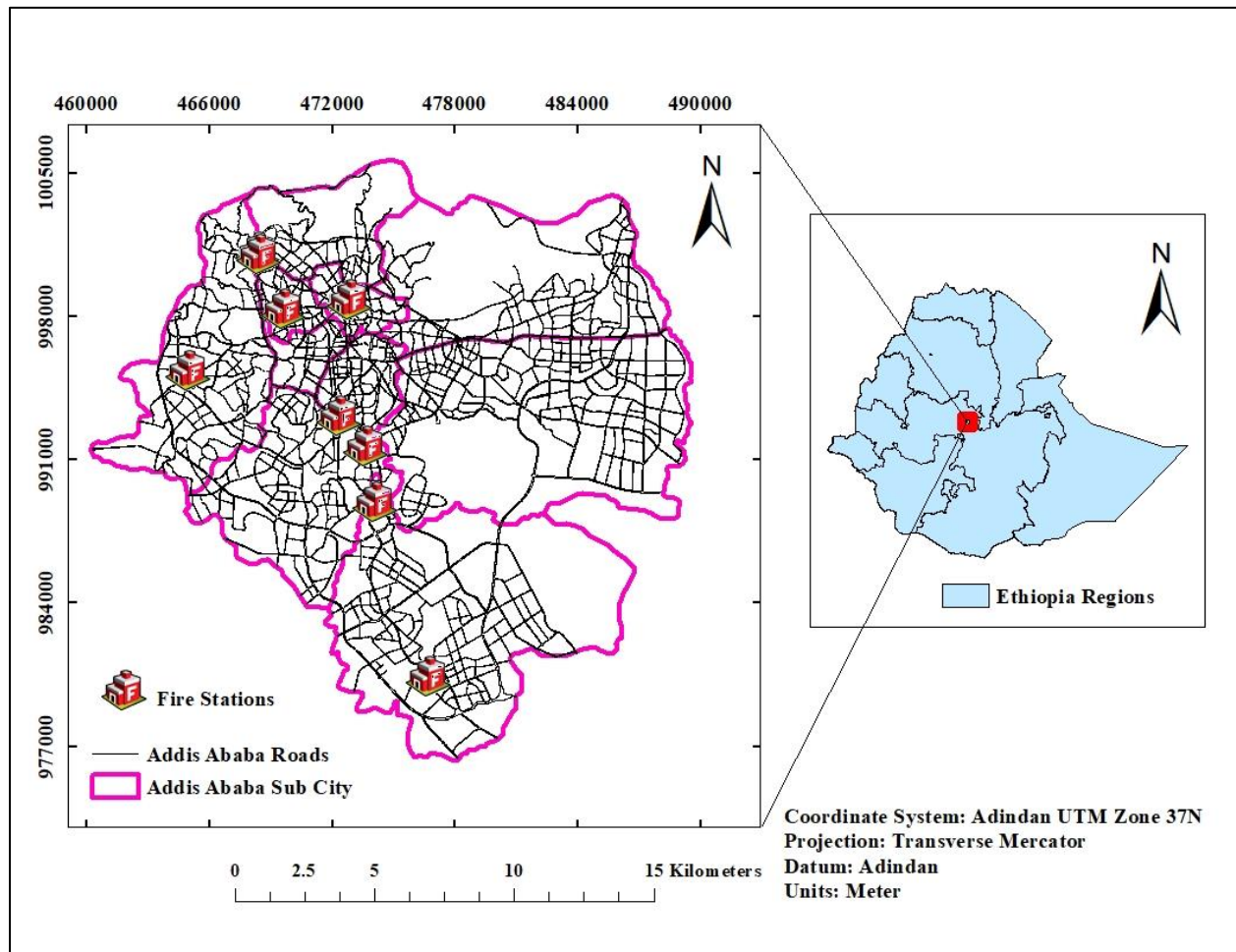


Figure 3.1 Location map of the study area

3.1.2 Population

According to the Central Statistical Agency of Ethiopia 2007 population census conducted by the Ethiopian national statistics authorities, Addis Ababa has a total population of 2,739,551 people, including in the city and in the countryside. 662,728 households were counted in 628,984 housing units in the capital city, resulting in an average of 5.3 people per household. In connection with this the population of Addis Ababa city is increasing from year to year because of the migration of people due to economic and social problems, the population greatly increased in the city. Based on census conducted by (CSA, 2020) the population figure is estimated to be 3,689,001 which comprises 1,743, 000 Male and 1,946,000 Female (Fig 3.2).

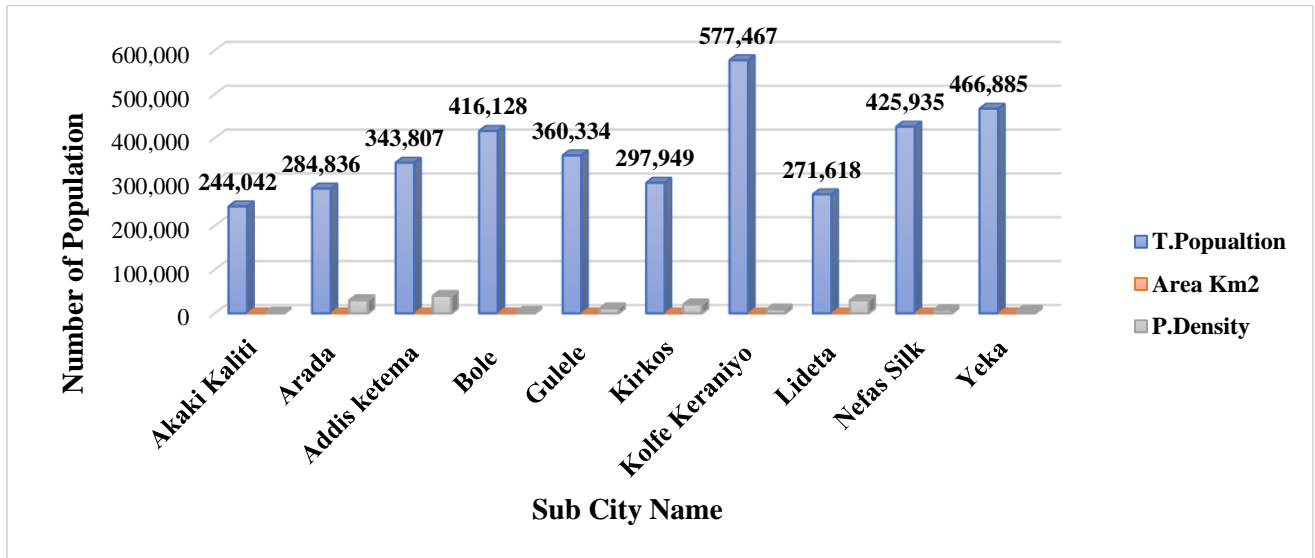


Figure 3.2 Population census of Addis Ababa city in year 2020

3.1.3 Climate

Addis Ababa has subtropical highland climate with a constant moderate temperature of roughly 21.5°C average high and 14°C average low throughout the year. Climatically, the maximum temperature recorded in May around 25°C being its hottest months and the lowest average temperature recorded was around 14°C in Nov & Dec, which is the coldest month (Fig 3.3).

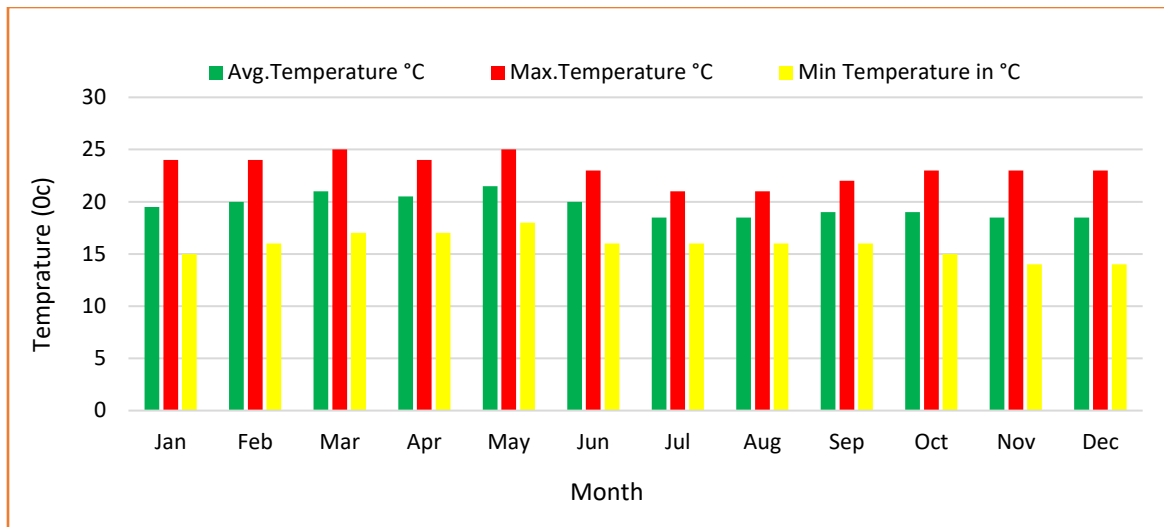


Figure 3.3 Monthly temperature variation

(Source: <https://www.world-climates.com/city-addis-ababa-ethiopia-africa/>)

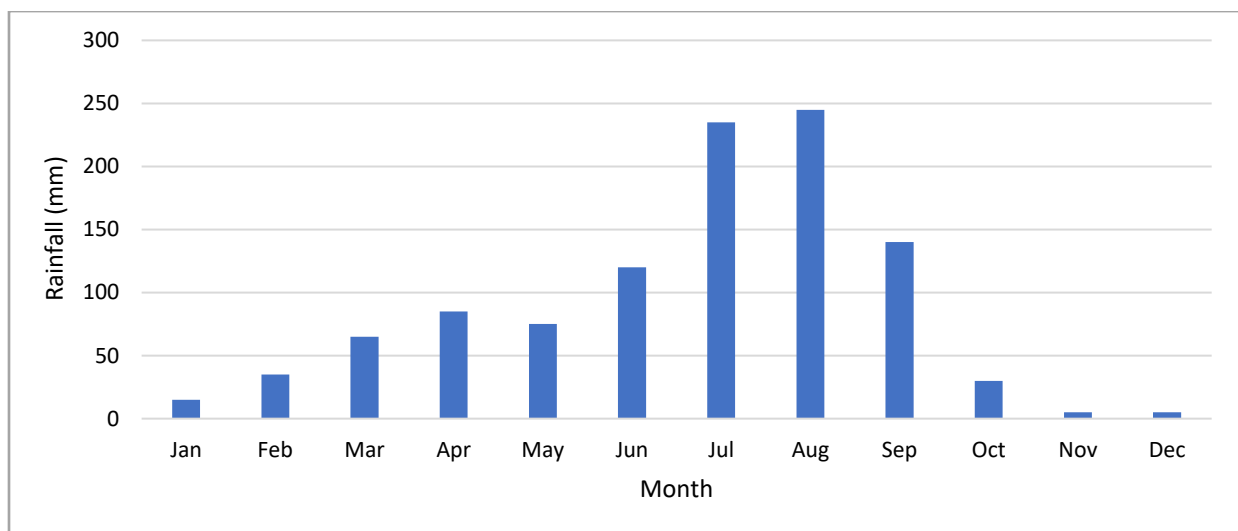


Figure 3.4 Average monthly rainfall in the study area

Addis Ababa city has a rainfall peak between July and August and minimum rainfall (driest month) between November and December. There is 5 mm of rainfall in both months. The greatest amount occurs in August, with an average of 245 mm, out of which close to 83.9% has a chance of rain (Fig 3.4).

3.1.4 Topography

The average altitude of Addis Ababa city is 2,400 m above sea level, with the highest elevations at Entoto Hill to the north rising over 3000 m (Fig 3.5). This makes Addis Ababa one of the high-altitude capital cities of the world and takes the first rank from African cities. The city has experienced spatial spread mostly towards the southern, eastern, and southwestern parts. The northern part of the city, which is the foothills of the Entoto Mountains has a higher elevation whereas the southern part of the city, which is the Akaki Kaliti area has a lower elevation up to 2052 m. The elevation map of the study area is extracted from earth explorer website Landsat image with 30m spatial resolution (<https://earthexplorer.usgs.gov/>).

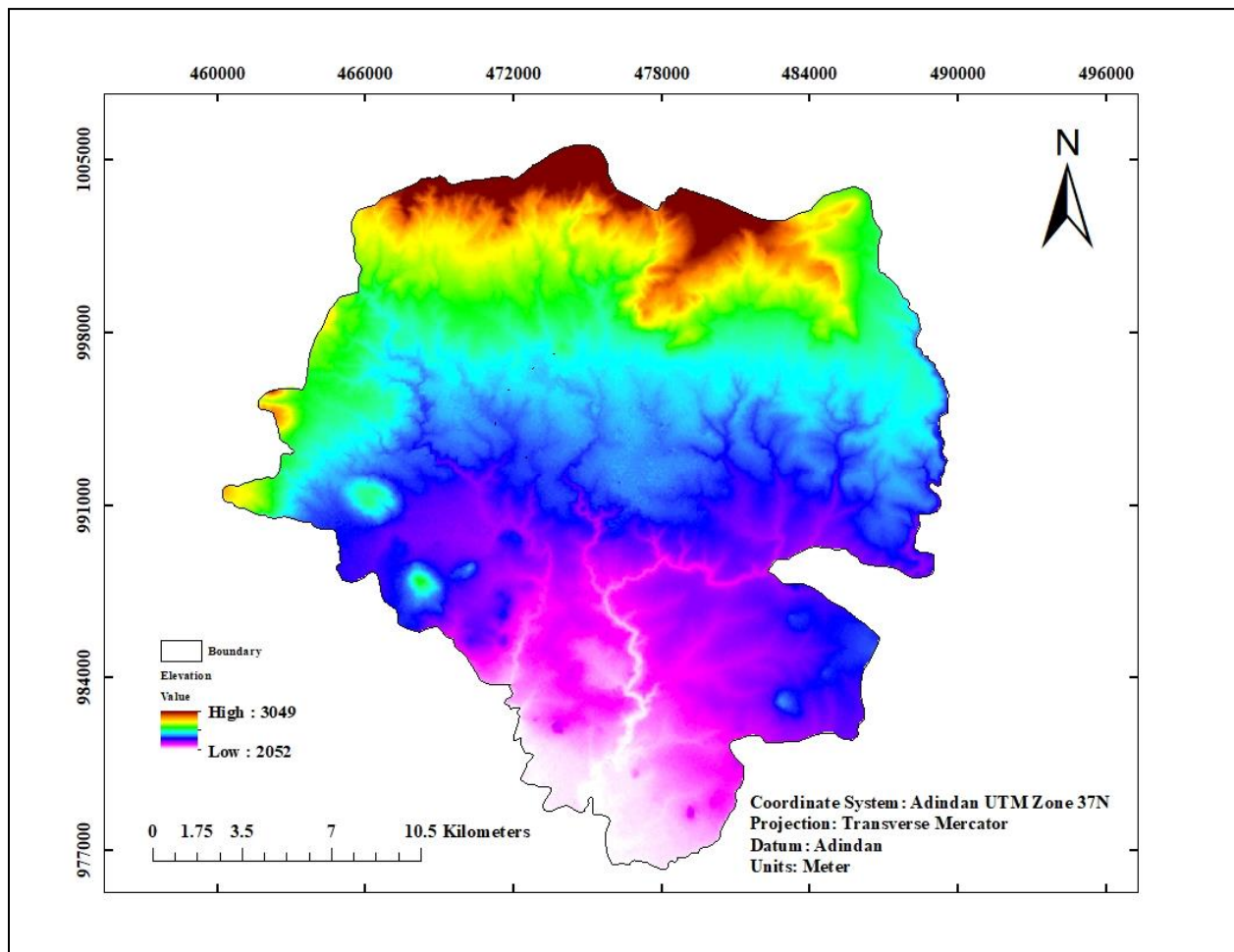


Figure 3.5 Elevation map

3.1.5 Road Transportation in Addis Ababa

Urban transport plays an important role in transferring people and goods from a given origin to some other destination within a city or beyond. The construction of the first roads in Addis Ababa dates back to the foundation of the city in November 1886 by Emperor Menilik II and Etegie Taitu. The first roads served to link villages within bigger settlements by non-motorized modes of transport. The construction of modern roads was intensified during the beginning of the reign of Emperor Haile Selassie.

The construction of roads during that period was carried out by the public work department of the municipality of Addis Ababa. The road construction had further been strengthened during and after the brief Italian occupation. The total length of roads in the before 1983 was 1503 km while the share of asphalted roads was below 20%. Following the establishment of the addis ababa city road authority (AACRA) in 1998 large scale road construction had commenced. The total length of roads in the city almost double to 3731 km between 1992 and 2012 and road density reached 12.9%. Today there are different mode of public transportation are there in addis ababa which provide service for the community including Lionbus/Anbessa buses,Shegerbuses,minibus,midibuses (Higerbuses),and etc. (Addis Ababa City Planning Project Office., 2017)

Taking into account Addis Ababa's fast growth and to enable the transport sector to play its required role, the Government has invested a huge resource to construct roads so as to expand the road network. An effort has been made to improve the transport service provisions. Preparatory actions required have also been taken to introduce a light rail transit (Transport Policy of Addis Ababa., 2011).

3.2 Data and Data Source

3.2.1 Primary Data

The primary source of data is direct collection of fire incident spatial location using handheld GPS with 3m horizontal accuracy level involved in input data for routing analysis. Based on this the primary datasets that are used to compile this study work mostly: fire incidents locations, road network. Additionally, oral interview between stakeholders were also done to get enough information required for the study.

3.2.1.1 Fire incidents locations

This study made the use of primary fire incidents data and its attribute information was acquired from Addis Ababa Fire and Emergency Prevention and Rescue Agency (AACFEPR) report for 2020/21 stored in Excel Sheet format. This contained sub city name, the special name, district, accident type, sex, date and time the fire engine started to move and the time the fire engine arrived at the incident location, and others. The collected field data of fire incident locations were imported into ArcMap. These are projected into Adindan UTM zone of 37 N coordinate system and stored in shapefile as shown in figure 3.6. See Appendix 2 for data the source.

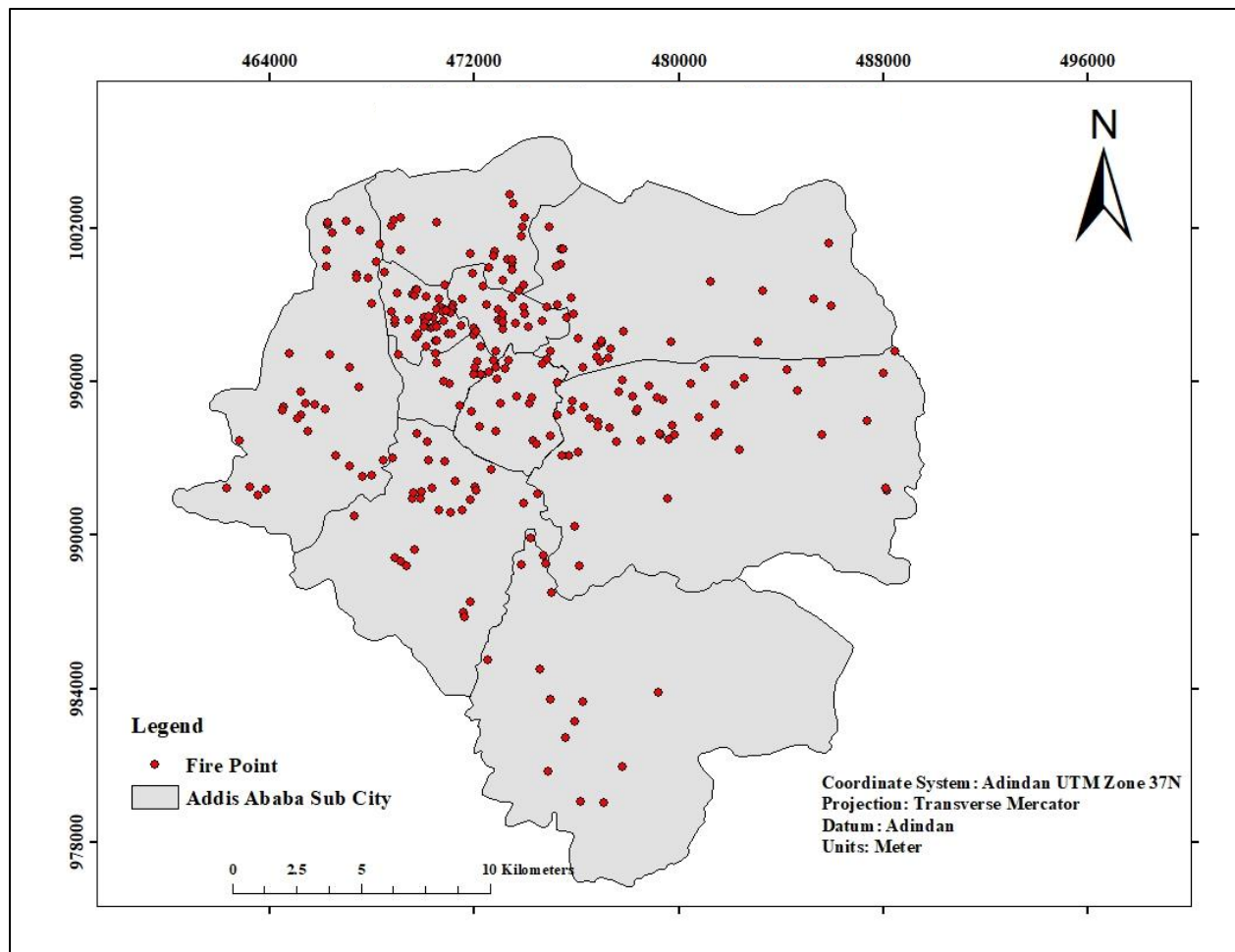


Figure 3.6 Fire Incidents locations map of the year 2020-2021

3.2.1.2 Road network

The road network consists of a system of interconnected paved/unpaved carriageways which are designed to carry buses, cars and goods vehicles; the road network generally forms the most basic level of transport infrastructure within urban areas, the function of a road network is to facilitate movement from one area to another. as such, it has an important role to play in the urban environment to facilitate mobility. For this study the road networks data was obtained from OpenStreetMap(OSM) (<https://extract.bbbike.org/>). After downloading all road segments were classified by using Field Calculator Parser VB script and coded based on ACRA Standard and Esri format into five functional class within GIS.

1. Expressway : The city roadways with full or partial control access and grade separation at intersections that are reserved for motor vehicles. These are often built to provide a direct link between key traffic generation points in an industrial, commercial, or business districts.

2. Arterial: It is a type of urban road that is commonly encountered within the cities. They are designed to carry through traffic on continuous route. Arterial roads are divided highways that have full or partially controlled access. Parking, loading and unloading are carefully regulated.

3. Sub Arterial : the city street which provide a lower level of travel mobility than arterial roadway. Their spacing may vary from central business districts to sub-urban areas. typically loading and unloading are carefully regulated.

4. Collector: this are the city roads that are constructed to collect and distribute traffic from and to local street as well as to provide an access to arterial and sub-arterial streets. These roads can be found in residential, business and industrial areas.

5. Local Street : this are city roads that offer access to residences, businesses, and other structures. The traffic that is carried either originates or end on local streets. A local street might be residential, commercial, or industrial, depending on the importance of the nearby areas. Pedestrians are free to move on local streets.

The design speed limit used for this study is described in Table 3.1 which helped to calculate the travel time of each road segment.

Table 3.1 Functional Road hierarchy Detail

Road type	Speed limit
Expressway	90 km/h
Arterial	80 km/h
Sub Arterial	60 km/h
Collector	50 km/h
Local	50 km/h

Source : (Addis Ababa City Planning Project Office., 2017)

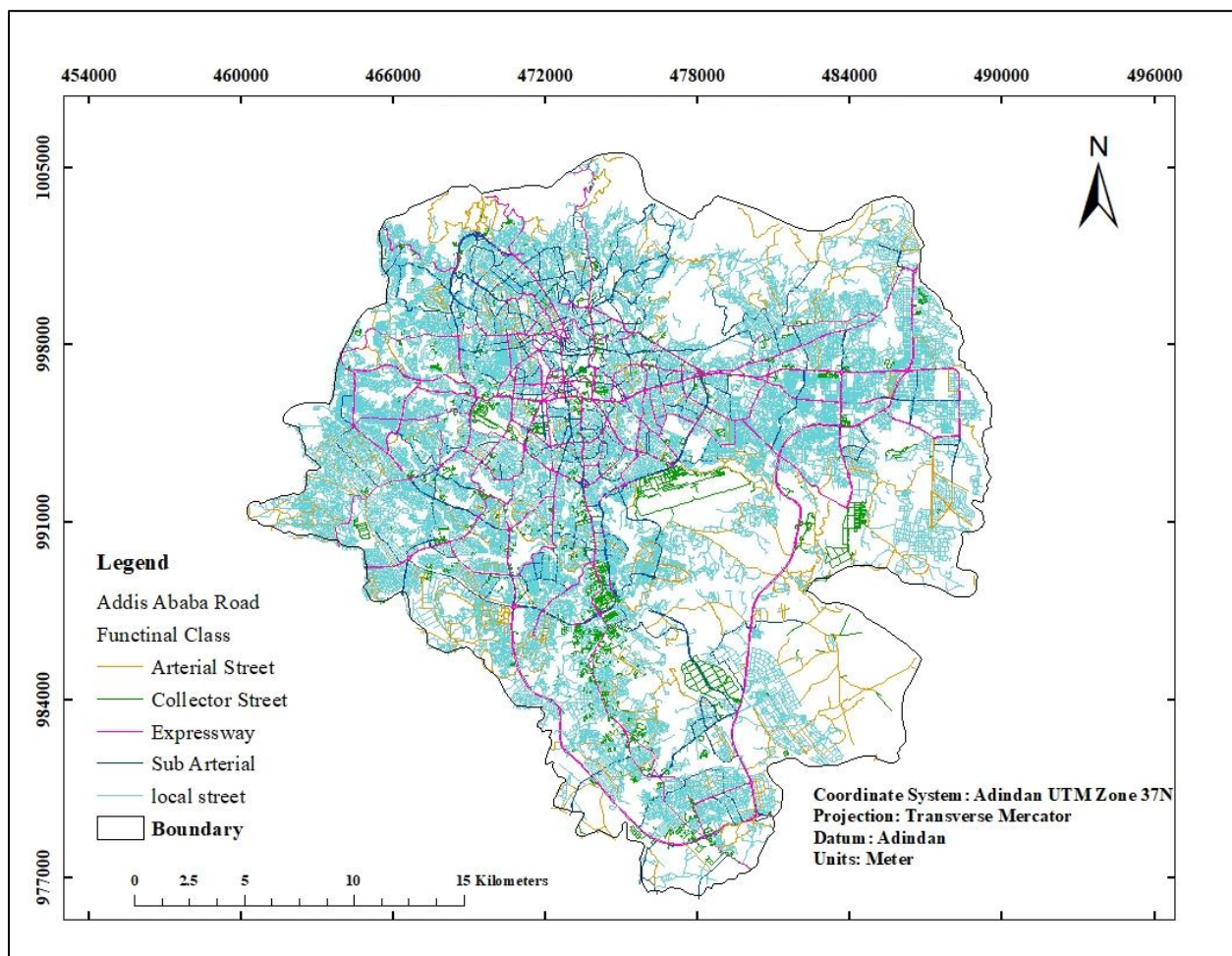


Figure 3.7 Addis Ababa City Road Network Map

3.2.2 Secondary data

The secondary source of data were collected from a various source such as organization record, institution and individual experts were very important to generate the desired result of this study.

The most widely used secondary data for this study work are existing fire station locations, land use, study area boundary and population data. In addition to this official report, books, journal articles, and internet sources were also used in order to have fully understanding and solving the research problem at hand.

3.2.2.1 Existing fire station locations

The exact geographic coordinate of all existing fire stations in decimal degree was taken from Google Map. On this year, 2020/21 Addis Ababa Fire and Emergency Prevention and Rescue Agency (AACFEPRRA) have ten existing fire stations namely(Fig3.8): Addis Ketema Sub City Fire Station, Nefas Silk Lafto Sub City Fire Station , Kirkos Sub City Fire Station , Akaki Kaliti Fire Station, Bethel Fire Station, Tigist Fire Fighting Equipment, Addis Ababa Fire Stations Headquarters, Gulele Sub city Fire Station(Fire Accident), Addis Ababa Fire and Emergency Management Authority and Arada Fire Station (<https://www.addismap.com/fire-stations>). Appendix 1 for the data the source.

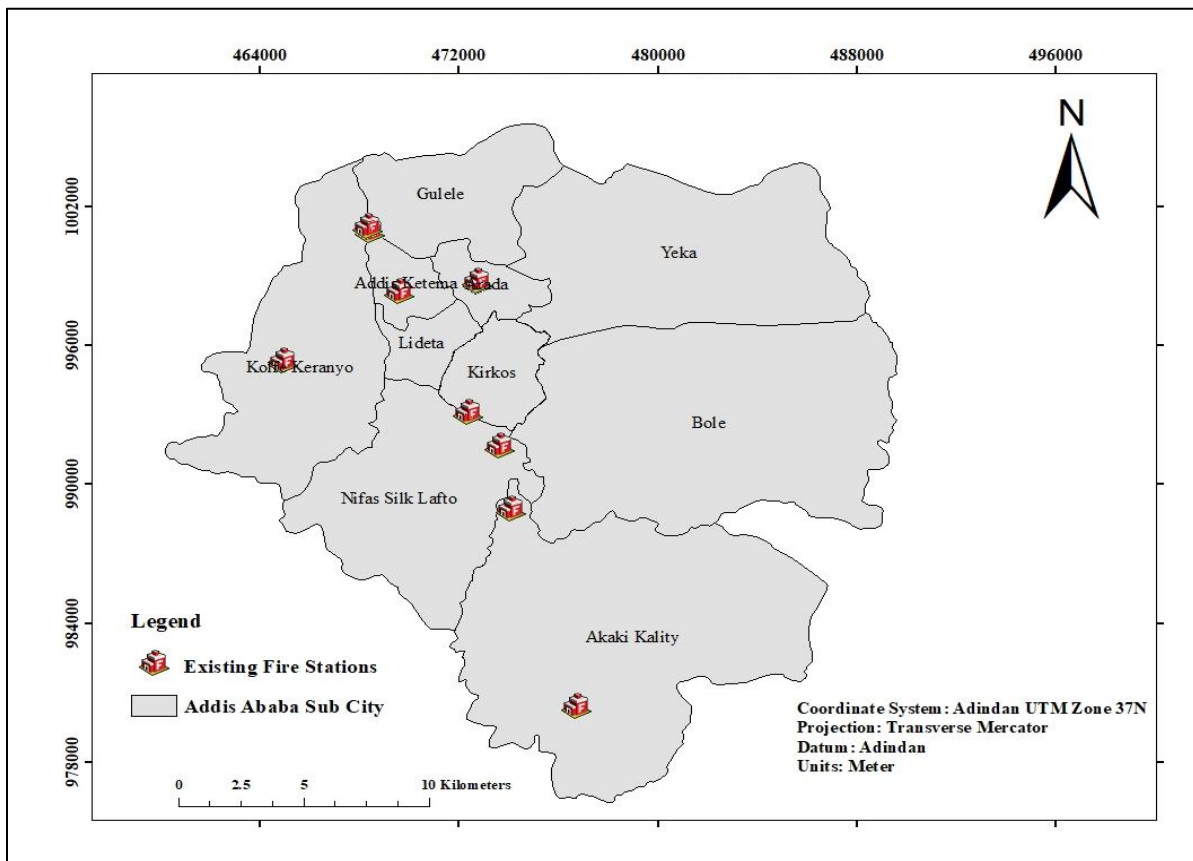


Figure 3.8 Existing fire station location map

3.2.2.2 Elevation

The elevation map of the study area was generated from DEM in the Arc GIS environment using Spatial Analyst tools. Therefore, based on the map shown, the elevation of the study area ranges from the highest point of 3049 m to the lowest point of 2052 m above sea level as it is indicated in the Figure 3.5 (<https://earthexplorer.usgs.gov/>).

3.2.2.2 Land use

Land use map is one of the major criteria used to select potential sites for fire stations in Addis Ababa city. The land use map was collected from addis ababa city government plan and development commission. The area coverage and percentage of each land use type indicated in the following (Table 3.2)

Table 3.2 Existing land use of Addis Ababa city

No	Land use type	Area (sq.km)	Area (%)
1	Administrative Services	8.35	1.60
2	Commerce	7.60	1.46
3	Environmental protection	158.20	30.41
4	Historical Construction and Site	0.18	0.03
5	Infrastructure Service	8.01	1.54
6	Manufacturing & Storage	30.99	5.96
7	Mixed Residence	221.85	42.64
8	Municipal Service	5.90	1.13
9	Social Service	15.03	2.89
10	Special Project	7.20	1.38
11	Street network	36.37	6.99
12	Transport	11.53	2.22
13	Urban Agriculture	9.09	1.75
Sum		520.29	100

The existing land use map of addis ababa is analyzed based on the data collected on July 2013 E.C (Addis ababa city planning project office, 2017). Among the various uses, thirteen significant land use types have been mapped in an ArcGIS Figure (3.9) . The land use analysis of

the study area helps us to know which areas are more preferable or not for locating fire station based on various reviews. Based on the above (Table 3.2), the largest part of the study area is covered by Mixed Residence with the area covered of 221.85 km² (42.64%) while the smallest land use of the city is occupied by Historical Construction and Site with the area covered of 0.18 km² (0.03%).

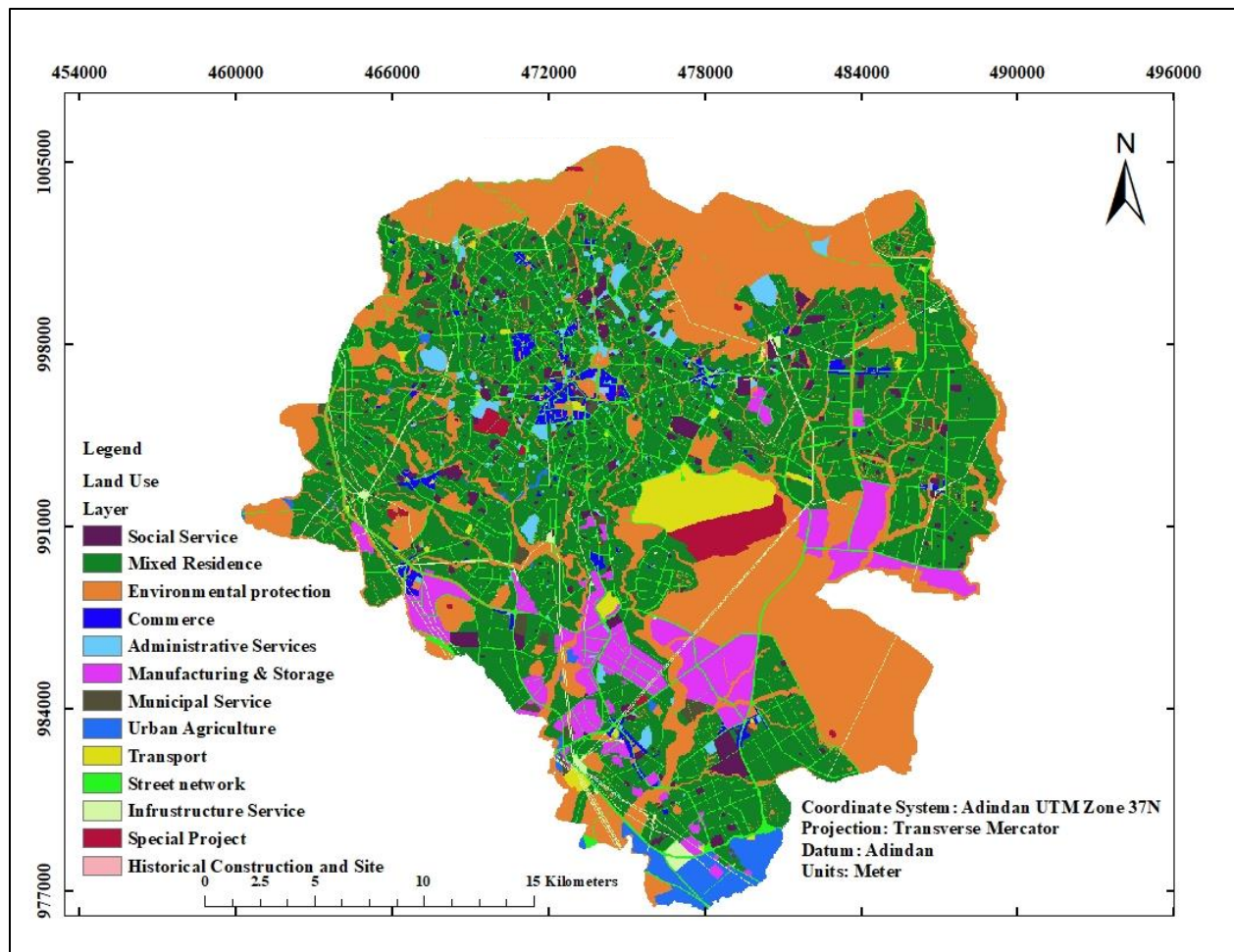


Figure 3.9 Land use pattern of Addis Ababa city

3.2.2.3 Study area boundary

Previously the city administration of Addis Ababa was divided into ten sub cities. Right now, the city administration adds one more sub city namely Lemi Kura sub city so that Addis Ababa has eleven total sub cities. With the help of those in this profession information, the boundary of this sub city is taken from between Yeka and Bole sub city boundary. However due to unable to get the boundary of the new sub city this study performs the entire analysis of this paper by using

previous boundary of the city (i.e.,10). The boundary of the study area was acquired from Geospatial Information Institute (GII) in Esri shape file format as presented in the Figure 3.1

Table 3.3 *Data and data source*

Data Set	Data Source	Format	Data Purpose
Study Area Boundary	Geospatial Information Institute (GII)	.shp	For defining the study location
Parcel Map of Addis Ababa	Addis Ababa City Administration Land Management Office	.shp	To extract residential house
Population data	CSA	.pdf	For giving weight for maximize coverage
Land Use map of Addis Ababa	Addis Ababa city government plan and development commission	.shp	Generate land use classification
Road Network of Addis Ababa	OSM	.shp	Input data for network analysis
Existing Fire Stations	https://www.addismap.com/fire-stations	Lat and Lon	For defining existing service coverage
Fire Incident information	AACFEPPRA	.xlsx	Was used for closest facilities and spatial analysis
Demand points	Generated from residential housing block	.shp	Was used one of the parameters for location allocation
DEM	EarthExplorer (usgs.gov)	Grid	Generate Elevation

3.4 Software and instrument used

Some of material and software used for data collection ,management, and processing which are used further data analysis applied in this study are(Table 3.4).

Table 3. 4 *Software and instrument used for the study*

Type	Source	Purpose
Arc GIS v. 10.4.1	Self	Network Analysis, Propose Optimum sites& others
Google Earth	Self	To show the ground truth of the selected optimum sites
IDRIS SELVA 17.0	Self	For pair wise comparison
MS-Office	Self	To prepare the study text and to preform statistical analysis.
Handheld GPS	AAiT	Collect the X and Y coordinate of Fire Incidents
Computer 8 GB Ram (Toshiba)	Self	Processing of raw data
External Hard Disc	Self	Data backup

3.5 Methodology

The methodology of the study was integrated with roads network analysis and locating optimal fire stations for the study area using GIS software as shown in Figure 3.10. Six stages of the process have been applied for network analysis process, beginning with collecting and preparing the data that was used in the analysis (primary and secondary data), Then processed the data which were used for further analysis. Following this, the creation of a Geo-database that were store the prepared data. Then building both the network topology and the network dataset. And then , the network analysis process has been applied and then it search optimal route between fire incident location and fire station by applying Dijkstra's algorithm to the road network of the addis ababa city in connection with service area analysis of existing fire stations also applied. Consequently , multi criteria analysis model has been developed to choose suitable sites for the inaccessible place together with factor identifications. Based on this, the final optimum sites for new fire stations was chosen by applying location allocation analysis particularly maximize coverage. This were performed after all candidates site and residential housing polygon are converted into point feature. 35 Candidate sites as Facilities, and population census 2020 as Demand Points here population data was assigned as weights were used. Finally, using solver tools 10 optimum sites was generated. The methodology adopted for this study is shown by a flow chart in figure 3.10. Following this, the steps of methodology that have been described in the subsequent sub-sections.

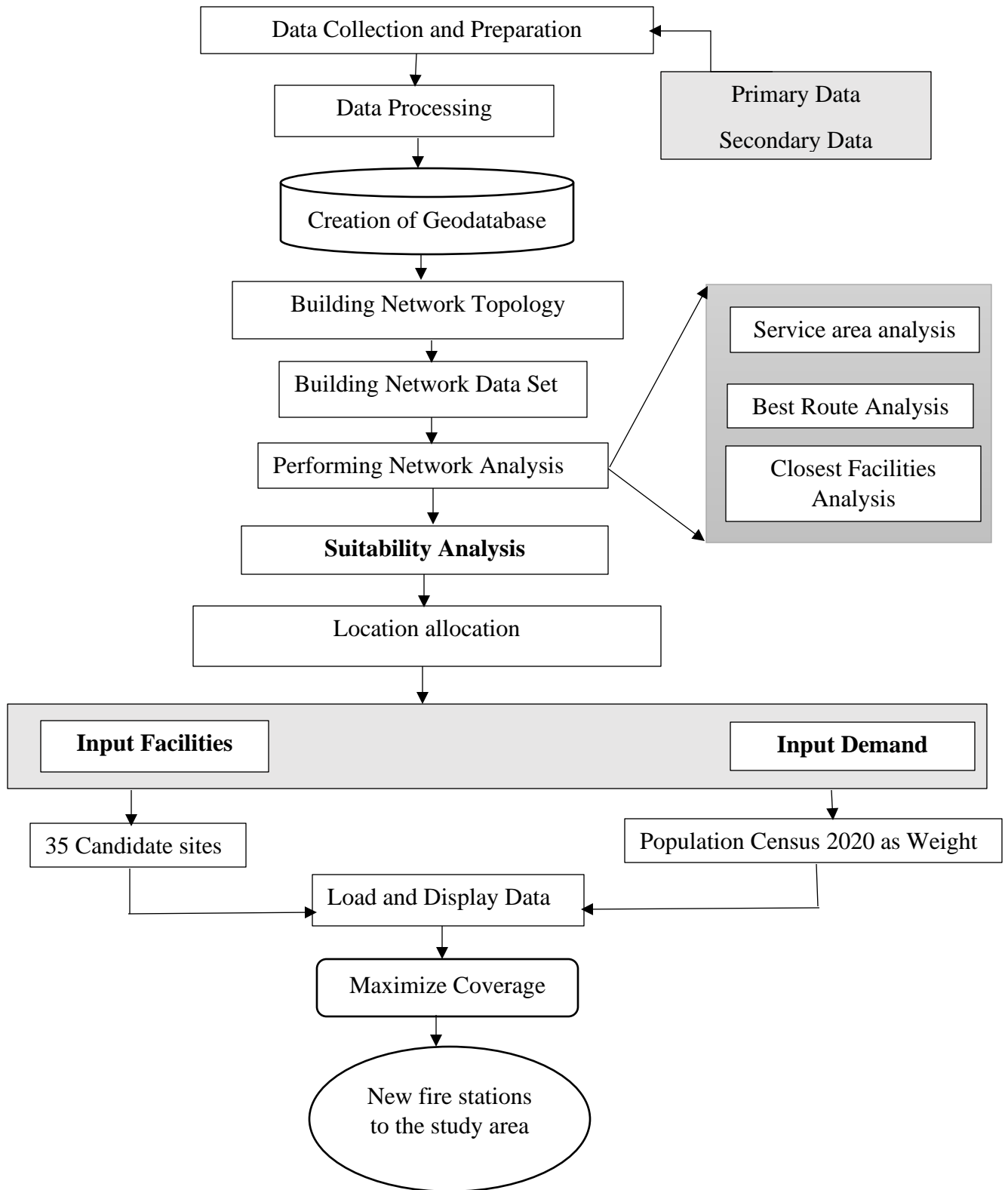


Figure 3.10 Flow chart of the methodology

3.5.1 Data Collection and preparation

This phase includes collecting the study area map, preparing the road network data used for further analysis. First of all, the road network data of Addis Ababa City was downloaded from Open Street Map (OSM). The road network data are created with attributes such as functional class to store the name of each road segment, their length, travel time, and speed of each road segment was stored in ArcGIS.

3.5.2 Data processing

After data collection and preparations, the data processing stage is essential, since it is one of the procedures of transforming raw data into a compatible format that is more suitable for further analysis and interpretable for users. For this study, the collected primary and secondary data were stored in Excel format (.xlsx) and have been imported into Esri shapefile format (.shp).

3.5.3 Creation of geodatabase

The Geo-database is the native data structure used in ArcGIS and is the fundamental data format used for both editing and management of the data. It provides the fundamental data structure for managing and editing the data. A Geodatabase can be personal, file, or enterprise. In this proposed method, a personal Geo-database has been created using ArcGIS. A personal Geo-database is a database that can store, query, and manage both spatial and non-spatial data. It is used to handle road network, existing fire stations, and parcel data.

3.5.4 Building network topology

To get good analysis and results, it is necessary to build a topology of the road network to discover whatever errors in the data. These errors were verified and appropriate correction was conducted using topology editing tool, and ultimately error-free digital road shapefile was generated that could be used to create road network dataset. This was performed by applying some topology rules including: Must Not Be Overlap, Must Not Have Dangle, Must Not Intersect, and Must Be Single Part and they have also their own error correction method.

3.5.5 Building network dataset

To make a network analysis within ArcGIS, a network dataset is needed to be created. After correcting the road network errors, it is ready for being used in building the network dataset that is ready for use in the network analysis. The created geo-database network dataset with attributes

such as hierarchy, meters, minutes, one way, road class, travel time, and so on. For this study Addis Ababa road was used to create a network dataset and it is well suited to model transportation network. It consists a set of *edges* that represent the links over which agents will travel, a set of *junctions* that connect edges and facilitate navigation from one edge to another, a set of *turns*: that represents to store information that can affect movement between two or more edges. As a result, shows in figure 3.11 the network dataset of the study area with 67152 junctions and 186772 edge for 42998 road segments.

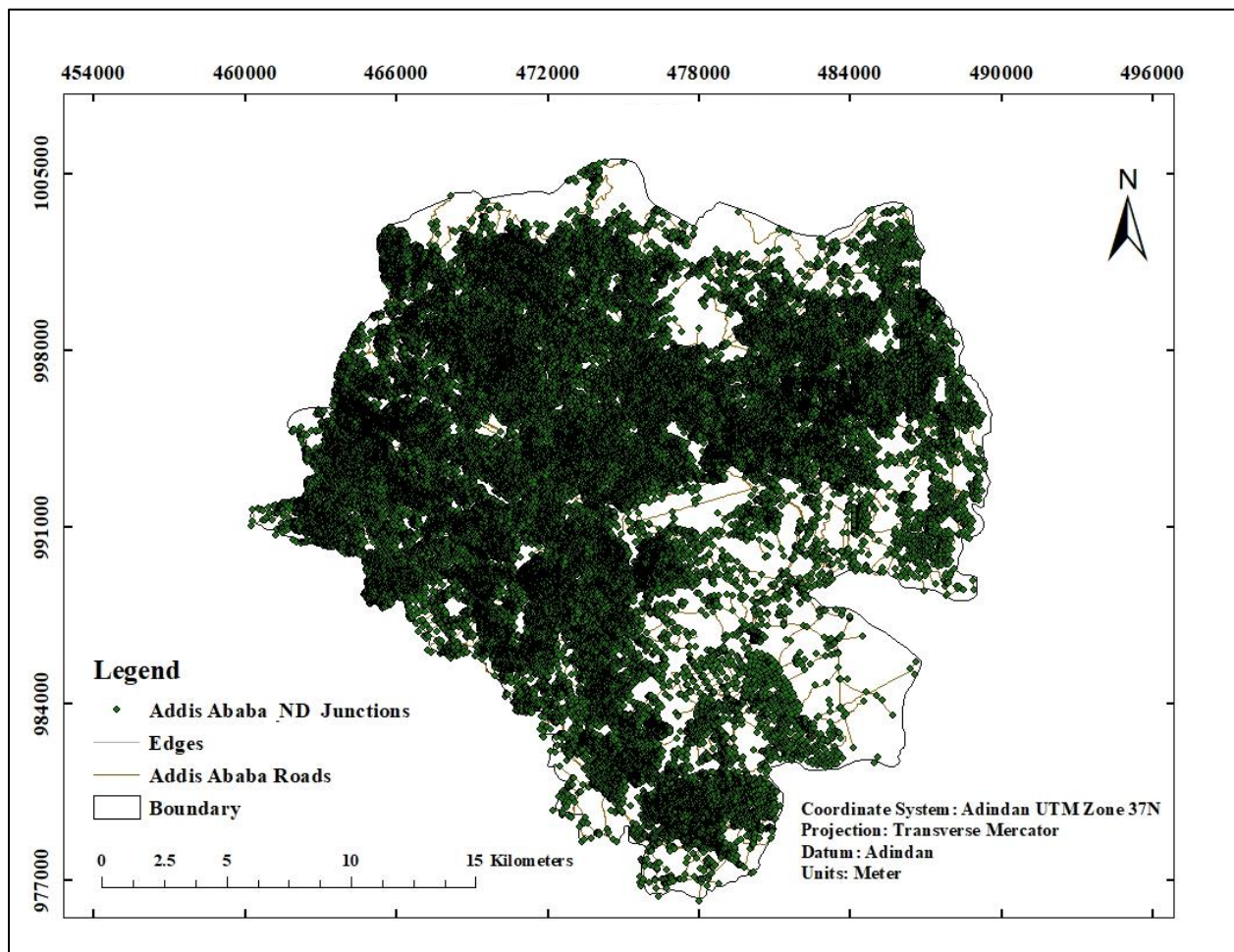


Figure 3.11 Road network dataset of the study area

3.5.5.1 Network attributes

Network attributes are properties of the network elements that control travers ability over the network. Examples of attributes include the time to travel a given length of the road, which streets

are restricted for which vehicles, the speeds along a given road, and which streets are one-way. These network attributes have basic properties including name, usage type and use by default . This study also considers on usage type which specifies how the attributes will be used during analysis. Here are some of network attribute applied in this study such as Connectivity and Cost.

- ***Connectivity***

To create network dataset choices that determine which edge and junction elements are created from the source of the features. Ensuring that edges and junctions are formed correctly is important for accurate network analysis results. Connectivity in a network dataset is based on geometric coincidences of line endpoints, line vertices, and points as well as applying connectivity rules set as properties of the network dataset. In this study Any vertex connectivity policy method was implemented.

- ***Cost***

Certain attributes are used to measure and model impedance such as travel time .These attributes are distributed along an edge. During the calculation of a path (also known as finding the best route) network analysis usually involves the minimization of cost (also known as impedance). Finding the fastest route (minimizing travel time) or the shortest routes (minimizing distance) are two common examples. Travel time and distance are also cost attributes of the network dataset. The Cost attribute which was presented in this study is based on data attached to the shapefile consists of travel time and distance by car hence the data in the shapefile was measured in minutes and meters respectively and One way restriction was ignored.

3.5.6 Performing network analysis

The road network analysis has been implemented using ArcGIS Network Analyst Extension. It is a powerful extension of ArcGIS that provides network based spatial analysis, including route analysis, travel directions, closest facility analysis, and service area analysis (Dabhade et al., 2015) It allows users to dynamically model realistic roads network factors, such as turn restrictions, speed limits, and traffic conditions at different times of the day. The ArcGIS Network Analyst Extension uses the standard Dijkstra's algorithm to calculate the least accumulated cost between the destination node and every other node in the network. Based on

this well-known Dijkstra's algorithm, there are two types of network analysis: best route analysis and closet facilities analysis.

3.6 Data analysis

This study did both GIS and descriptive analysis. Meanwhile the following sections discuss and illustrates that how the objective this study was achieved one by one.

3.6.1 Road network accessibility

This study began with the development of the road network data via model transportation (i.e., Network Analyst extension). For creation of new network dataset, addis ababa city OpenStreetMap road dataset was used as the base. In addition, the attributes consist of time (in minutes), distance (in meters), and speed (kmph) set to support the source dataset attribute fields. This dataset was calculated on the basis of the Addis Ababa city road authority agency(AACRA) report for vehicles operating at speeds of up to 90 km/h as indicated in table 3.1. Time or distance is commonly used and effectively utilized to carry out accessibility analysis. In the network dataset three important attribute were required and employed in this study in order to perform accessibility analysis of the study including distance, travel time and speed(Table 3.5).

Table 3.5 Important attribute in addis ababa city road network dataset

Attribute	Description
Distance	Length of the road in meter
Travel Time	Time to travel from the beginning to the end of the road
Speed	Speed of the road in kilometer per hour

I) Distance calculation: it was one of the fundamental cost attributes used as impedance factors for road network analysis setting. It measures the distance of each road segment so the study calculates the distance of all road segment conducted by Calculate Geometry Tool and it's measured in meters.

II) Calculation of Travel Time (Minutes)

Travel time is the time from when the first piece of equipment leaves the fire station till the time when it arrives at the incident location. Travel time is the basic variable taken into account in calculating the impedance of each road segment. In this study the travel time of all road network

segments was calculated by using the formula of : length of all road segments divided by speed limit that segment and inserting its values depend on the type of roads (Table 3.2). It was calculated by using a Field Calculator Tool and it's measured in Minutes.

$$\text{Travel Time} = \left(\frac{\text{Length}}{\text{Speed}} \right) * 0.06 \text{ minutes} \quad (3.1)$$

For example, if one vehicle traveled in the arterial road with designed speed of 80kmph and length of the segment is 1000m it will be calculated as:

$$\text{Travel Time} = \left(\frac{1000}{80} \right) * 0.06 = \mathbf{0.75} \text{ minute}$$

Based on this formula the study received a value that has minutes as a measured unit. Therefore, knowing the estimated time helps to examine the service coverage of existing fire stations as per city standard and helps to determine the coverage of the population on the entire services .

III) Speed calculation: Required for calculating emergency travel times was added according to the type of roads. This attribute was required for accurately designing and building the street network to compute travel time and it is measured in meters per minutes.

$$\text{Speed} = \text{Distance} / \text{Travel Time} \quad (3.2)$$

3.6.2 Network analyst in ArcGIS

Network analysis is employed in this study for the spatial distribution pattern of the present fire stations for finding the areas out of the coverage service and optimal site selections. The road network analysis has been implemented using ArcGIS Network Analyst Extension. This study was made the following Network Analyst Tools including: service area coverage , Best route , closest facilities, and location allocations.

3.6.2.1 Service area coverage analysis

Service area is a function of accessibility. It is a region that encloses all accessible streets within a given time and restriction. Service Area is used to evaluate the service coverage extent of a facility within specified impedance and it is established by Network Analyst to examine accessibility by exposing any gap in facility service coverage within a given time. In ArcGIS Network Analysis, accessibility is measured in terms of travel time, distance, or any other impedance on the network.

Drive time polygons are ring-like polygons that display all accessible streets within a particular travel- time from that point of origin. It can also be described as the defining measure of travel time in the study area. The new service area network analysis tool can be used to create driving time-based analysis showing regions that encompasses accessible areas within a specific time window using the road network.

This study uses Network Analysts Service Area tool and road network emergency data with predefined impedance cut off time of eight minutes response time. As the analysis sets were put to obtain time served as the value of impedance, break value placed as eight minutes, path fixed as away from U-turns, and facility enabled, the existing fire station location was used as a reference to set a graphic select. For the return of detailed polygons, aggregation attributes and line generations, impedance (distance and time) , additional settings were placed.

The service area analysis of this study was evaluated by use of the 10-fire station's location and road layers. Network analysis was performed to estimate the coverage of service areas by utilizing the attribute information of each of the road line segments consists of length (meters), travel time(minutes), and speed (kilometers per hour) per road segment were calculated. It was utilized by the five road types and their respective speed limits – local (50km/h), arterial (80 km/h), sub arterial (60 km/h) , collector (50km/h) and expressway (90km/h).

3.6.3.2 Best route analysis

Depending on the impedance this analysis finds the quickest and shortest path of the street so that if the optimal route is the quickest route and shortest route the impedance factors are time and distance respectively. As a result , the best route might be described as the route with lowest impedance or the one with least cost where the impedance is chosen based on the city putted standard. When choosing the optimum route any cost attribute can be employed as an impedance. In this study time impedance factor was used for determine best route analysis as shown in figure 4.3.

3.6.3.3 Closest facilities analysis

The closest facility solver calculates the distance in terms of time and distance of driving between facilities and incidents or vice versa and determines which facility is closest to incidents. The closest facility solver displays the best routes between facilities and incidents,

records their travel distance, response time and driving directions. This helps in emergency situations to know the closest facilities that can be reached from the incident location, which in turns reduces time, effort, resources and saving people life (Gubara et al., 2014). This network analyst extension tools makes it simple to set the analysis parameters for the closet facilities analysis such as the impedance factor, the start time, the period to reach the closet facilities, the number of facilities to find, and the directions of travel (from incident to the facility or from the facility to the incident). This study used travel time as impedance factor from facility to incident for data analysis. Meanwhile as the facility (existing fire station) was added and as incident (fire accidents report) were added as the incident sites and best route was generated within a predefined response time of 8 minute . Then, by using the network analyst extension solver the closest fire stations to the location of the fire incident were solved as shown in Figure 4.5.

3.6.2.4 Location allocation analysis

The ArcGIS location – allocation network analysis tool was used to determine the best location for a new fire station in order to get the most maximum coverage throughout the deficiency region. This analysis has been applied in this study to suggest new fire stations optimum sites and allocating the location to it. After the road network was created the location allocation model was employed. Impedance value (distance or time) and weight attribute, impedance cutoff, number of facilities (facilities to choose), and location-allocation problem type are among the parameters contained in the Network Analyst tools. There are seven problem types of location-allocation to consists of (ESRI, n.d.; Hakimi, 1964) such as : minimize impedance, maximize coverage , maximized capacitated coverage, minimize facilities, maximize attendance , maximize market share and target market share . Among of them the maximize coverage method was applied in this study to overcome the problem of an 8-minute coverage deficiency in the study area. (Rahman & Smith, 2000) with the formula.

$$\text{Maximize } \{F = \sum a_i X_i\} \quad (3.3)$$

where I is the group of demand points or the time duration or the population as a weight, and xi is the location-allocation parameter with a value of either 0 or 1. After setting the parameters of the analysis layer and selecting the “maximize coverage” location-allocation type, the spatial locations of services (facilities) and the demand points were putted as residential housing represented by point layers in the Network Analysis window. 35 candidate sites were inserted as

facilities and the selection of the optimum sites from candidates was conducted by using maximize coverage. After that the location allocation analysis was solved to obtain the result and ten new fire stations were suggested for the study area.

3.6.3 Spatial relationship of fire incidents with population density

The map shown in figure 3.13 illustrate that fire stations coverage and fire incidents occurrence corresponding with population density in a study area. The population density for each sub city of the study area was calculated by dividing the population data of each sub city for the year of 2020 and respective area of the sub city as represented in the following equation and graphically indicated in figure 3.12

$$PD = P/A \tag{3.4}$$

where P is Population of sub-city, A is Area of sub-city, PD is Population density.

The population density map layer was processed and had a range of values from 1979 to 39869 representative of the number of people per sub-city area in sq.km

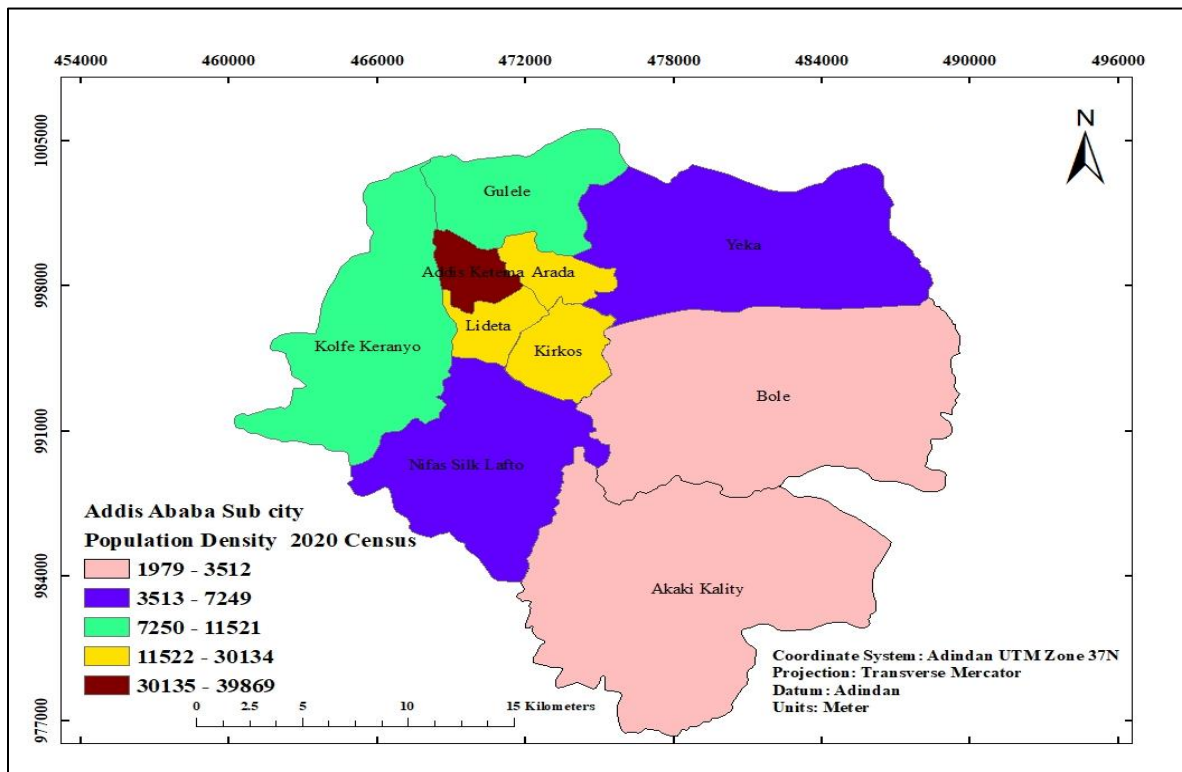


Figure 3.12 Population density map of sub cities in Addis Ababa

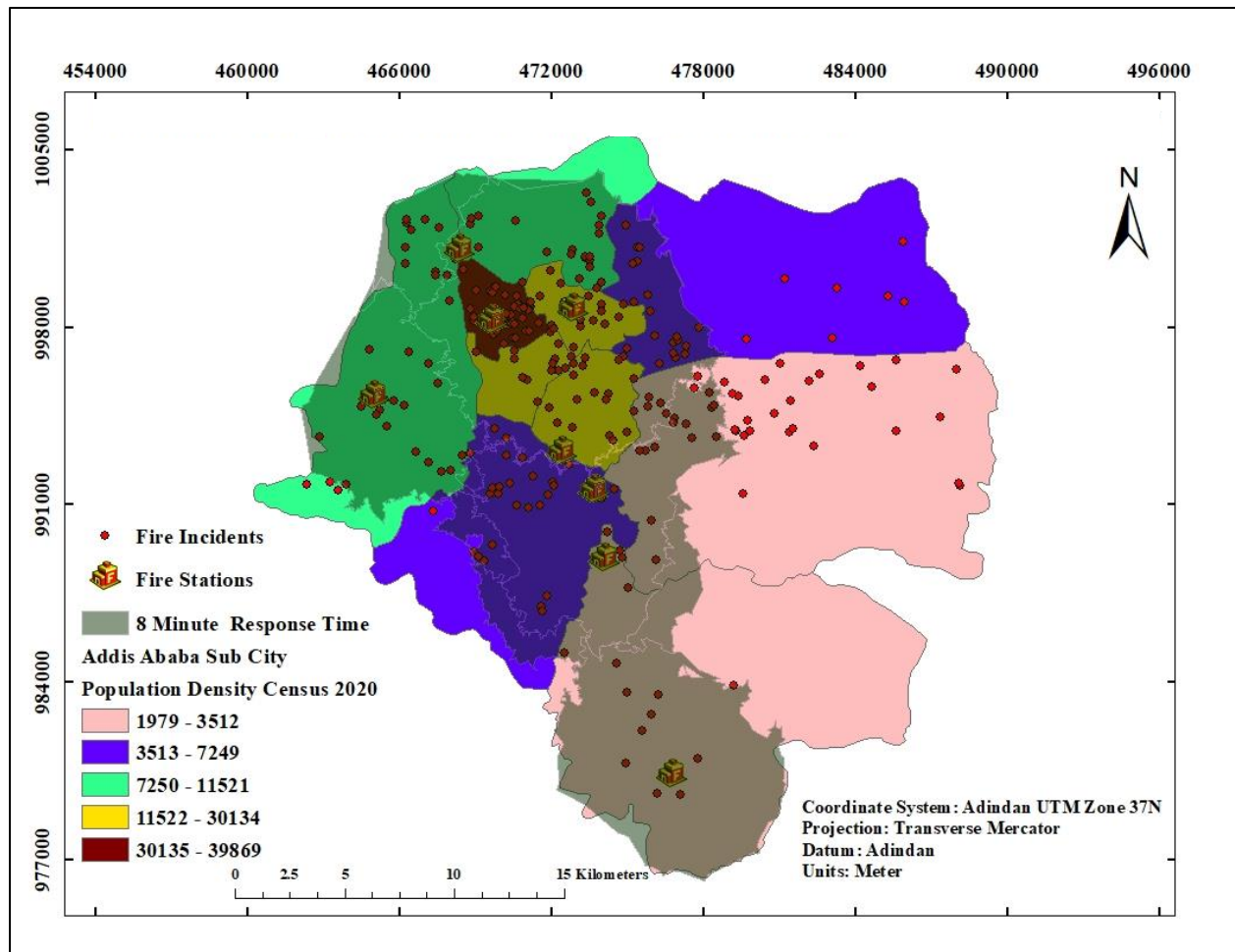


Figure 3.13 8-Minute Service Coverage Overlapped with Population Density

3.6.4 Spatial analyst tools

Spatial analysis is the process of examining the locations, attributes, and relationships of features in spatial data through different analytical techniques in order to address a question or useful knowledge. Spatial analysis extracts or creates new information from spatial data.

3.6.4.1 Kernel density analysis

It is one of the spatial analyst tools in GIS environment for making density analysis of features in a neighborhood around those features. It was used to show the spatial availability and to find the accident probability zone of fire incidents hot spot information in the study area. To calculate magnitude per unit area from point features using kernel density to fit a smooth tapered surface to each point. In this study kernel density analysis has been utilized depending on the point where an incident occurred within two years (2020/2021). This analysis evaluates the number of events

across a given surface by calculating the overall quantity of fire incident located within a given search radius from a target point as presented (Fig3.14) .

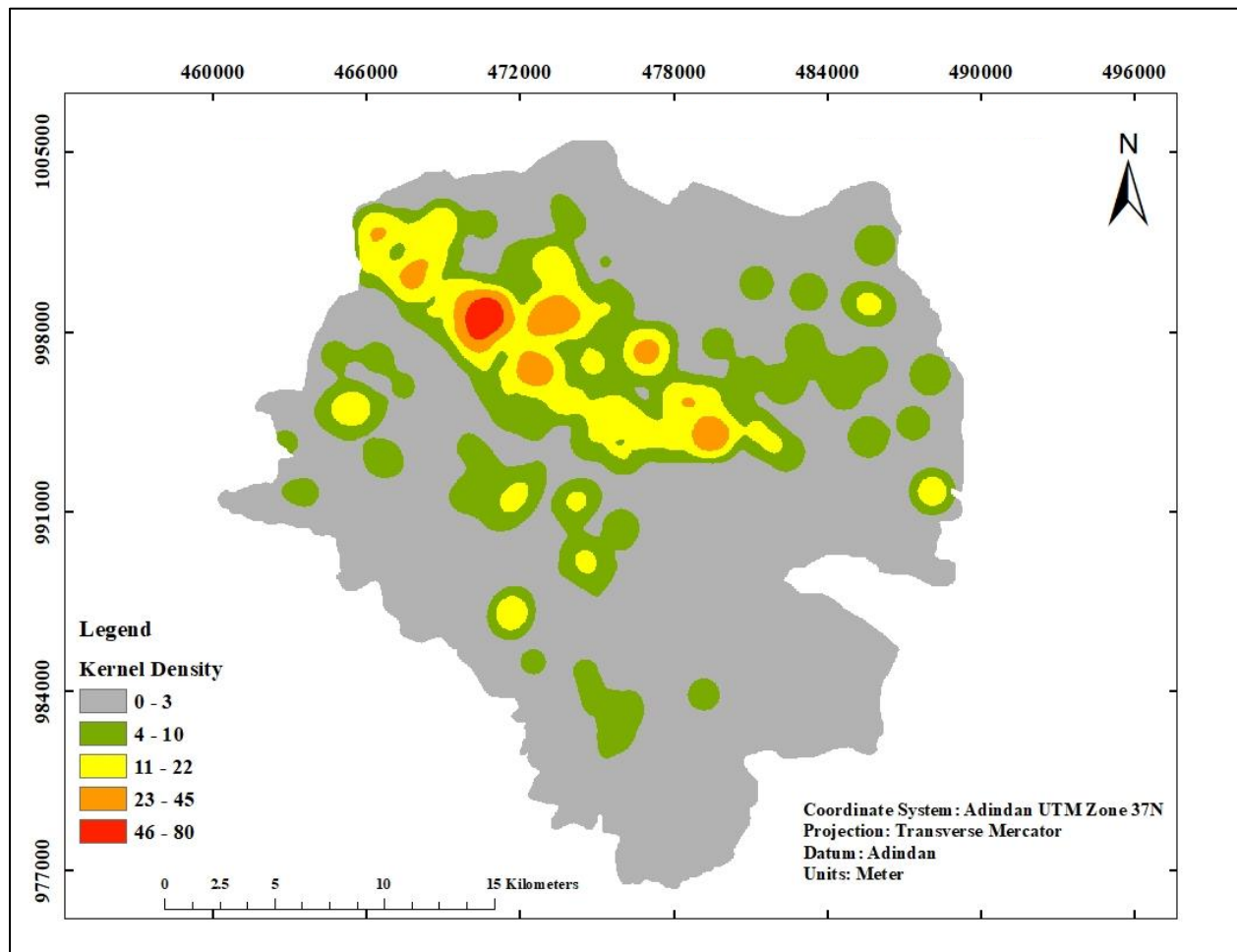


Figure 3.14 Fire Incident Density Rate Value map

3.6.4.2 Candidate site selection for new fire stations

Suitability analysis was conducted to select candidate sites for proposing and allocating additional fire stations. Site suitability is the process of allocating new and candidate sites by examining the existing structure, pattern and condition of existing sites using a set of specific criteria. For this commitment, the present study had prepared a suitable model for determining appropriate location of fire stations by integrating six factors such as : inaccessible area ,population density, land use, proximity of main roads, distance from existing fire stations and incident density rate of the area. All these maps have been converted into raster so that each pixel can detect a score. It is important in suitability analysis to set a score for each category at 1-

5 or 1–9 point scale as per their suitability. For this study 1-5 scale and the reciprocal is $1, 1/2, \dots, 1/5$. has been utilized when the row criterion is less important than the column criterion. This decision approach supported to propose 35 candidate sites for allocating new fire stations facilities for the study areas. Among of this the most optimum for allocating new fire stations was determined by maximize coverage.

An intensive literature review was carried out in collaboration with this study to identify the criteria that have significant influence on the candidate site selection for fire stations, six criteria has been identified that have a significant role in planning for an optimum fire station within the scope of this thesis is shown in the table (3.6).

Table 3.6 Factors used for candidate site selections for new fire stations

Factor	Literature Source
Population Density	(Nyimbili & Erden, 2020)
Land Use	(Chaudhary et al., 2016)
Incident density of the area	(Chiedu, 2011)
Proximity of Main Road	(Habibi et al., 2008)
Distance from Existing Fire Stations	(Nyimbili & Erden, 2020)
Inaccessible Area > 8 Minute	-

3.6.4.3 Factors used for this study

The mentioned factors applied in this study (Table 3.6) are discussed in the following section in a concise and precise manner.

I) Distance from existing fire stations

The existing fire stations were determined by Euclidean distance according to the international standard 5km are the most suitable to propose additional stations. This study applied this standard to find candidate sites for the study area. Moreover, new fire stations must be far from the existing fire stations existing, making sure that newly fire stations are situated in the area where there are no fire stations. Its reclassified map is shown in Figure 3.15 (a)

II) Inaccessible area

This is another major important factor in the areas that don't serve with predefined response time within eight minutes during emergency time. This study employed the service coverage greater than 8 minutes deriving response minutes determined by road network data which used during emergency response and travel time used as impedance factor solved by network analysis extension of service coverage. This analysis result has played a major role in proposing additional candidate sites for fire stations in the deficiency area. Its reclassified map is shown in figure 3.15 (b)

III) **Population density**

Population density is another important factor for locating fire station location. This study was need to consider the population density of the area of the site to be selected. The densely populated areas are usually housing on a relatively densely house area and close to each other which increases the probability of the occurrence of fires and the speed of its spread. The quick response to these areas and ensure the delivery of fire department services to them has a great importance in order to avoid unwanted huge damages of firehouse incident. This study performed point density map using by dividing the total population collected from CSA to existing residential housing accordingly their sub city. This analysis was applied due to the inability to find enough information about how many people lived in each census block. Therefore, the population density has been classified into five class and its reclassified map is shown in figure 3.15 (c).

IV) **Proximity of main road**

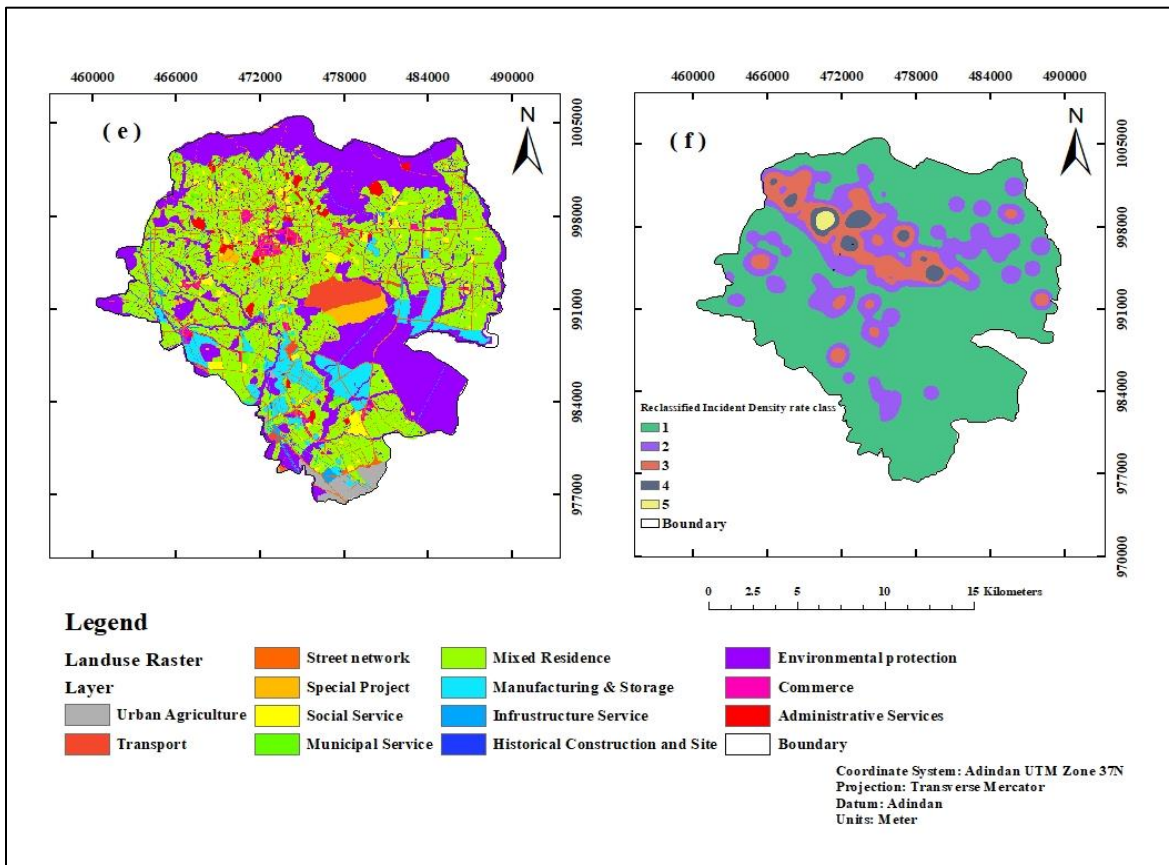
For the need of quick access by car and emergency service, proximity to main roads is being considered as one of the most important criteria in fire stations site selection ;however, a new fire station should be located close to the main road city as far as possible . Close accessibility is taken as the best preference for fire station selection. it will offer higher accessibility in term of travel time during emergency occurrence response. The proximity of main road criterion had a value range from 0 to 300 m indicating the distance from the main road segment layer determined by Multiple Ring Buffer analysis with incremental distance values in meters of 0–60 m, 60–120 m, 120–180 m, 180–240 m and 240–300 m (Habibi et al., 2008). Its reclassified map is shown in figure 3.15 (d).

V) Land-use

Land use maps are another important factor for locating fire stations. Based on the land use map prepared by Addis Ababa city government plan and development commission (Figure 3.9. For this study four land use classes were considered more suitable to locate fire stations namely mixed residence, commerce and urban agricultures has been utilized. Its reclassified map is shown in figure 3.15 (e)

VI) Incident density rate

Incident density rate area is another important factor to locate optimum location for fire stations hence this factor helps to identify the more frequent occurrence of the incident area in the study area with the help of spatial analysis tools of kernel density. Therefore, the more incident density rate location was well suited to propose new fire stations. Its reclassified map is shown in Figure 3.15 (f). All the reclassified map of this study are shown in the following figures.



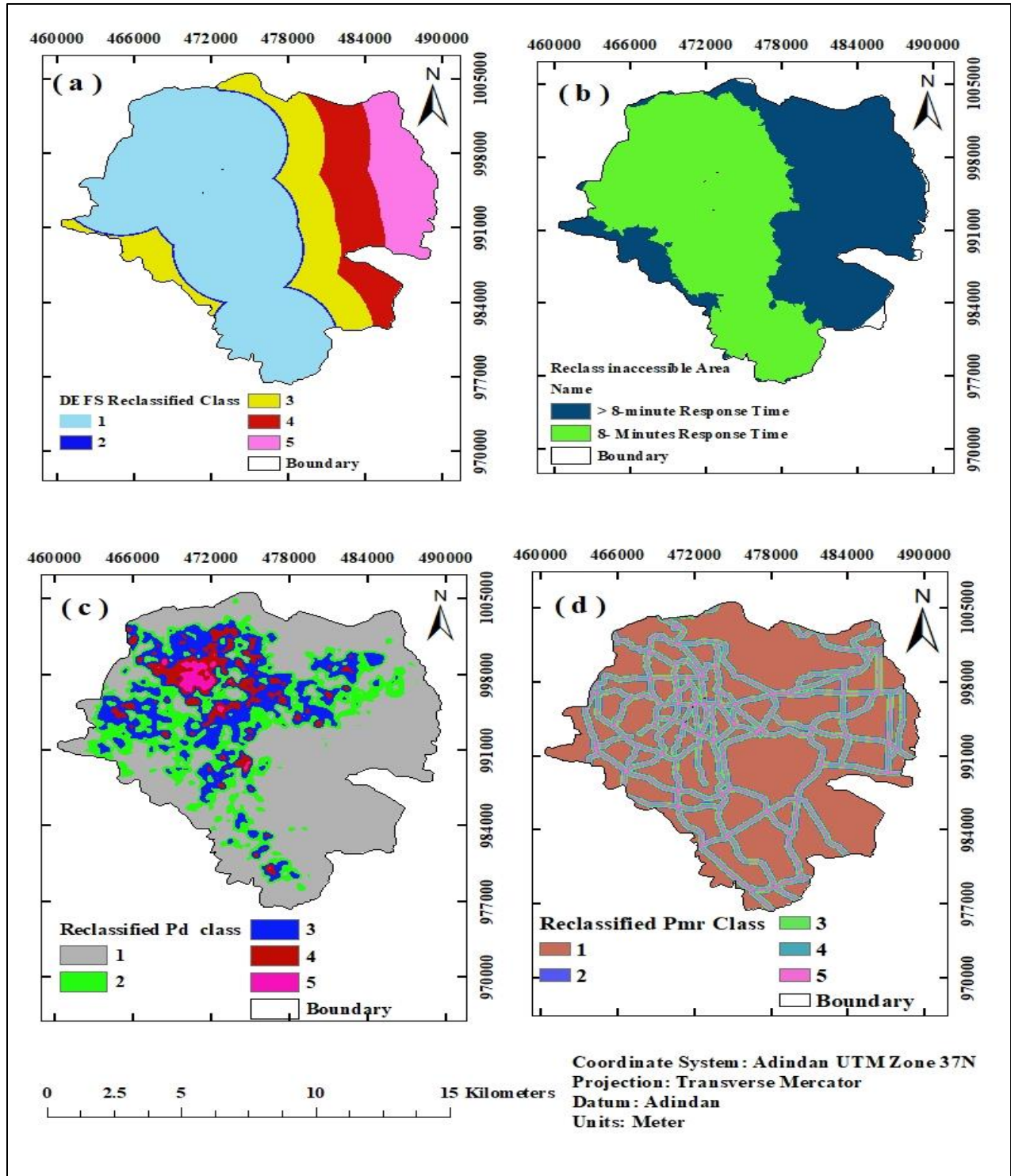


Figure 3.15: Reclassified thematic maps: Distance from existing fire stations (a), inaccessible area (b), Population density (c), Proximity of main road(d), Land-use map (e), and incident density rate (f)

3.6.5 GIS Based Multicriteria decision analysis

This study adopted Multicriteria decision making analysis that is called the Analytic Hierarchy Process (AHP), and the ArcGIS Model Builder was utilized to decide the reasonable locations of fire stations in Addis Ababa City. This analysis helps to find out the candidate sites to the study area. Analytical Hierarchy Process solution approach is well suited to the decision problem of candidate site selection. The solution process of the AHP decision model is begin with the definition of the criteria for site selection which are organized in a hierarchy from a general goal to multiple attributes in progressive levels. The weights of the site selection criteria are computed using qualitative factors and analytical pairwise comparisons to determine their relative importance in respect to the various opinions of the decision-makers. These final criteria weights are then used in the final analysis results to recommend the optimal sites for constructing fire station facilities (Yang & Lee, 1997).

Criteria definitions

The first stage of multicriteria decision analysis(MCDA) is concerned with combining information and data from several criteria for decision-making purposes (Abudeif et al., 2015). The weight preference was applied by six criteria using AHP method including: Inaccessible Area (Ia), Population Density(Pd) ,land use(Lu), distance from existing fire stations(Defs) , proximity of main road (Pmr) and incident density rate (Idr).

Criteria weighing

The process of assigning weights to the criteria is one of the most sensitive points in this type of analysis. The analytic hierarchy process (AHP) was used for criteria weights, as this method proved its high efficiency in solving complex problems(Akinci et al., 2013). It was introduced by (Saaty, 1977) and is very helpful in decision-making. The AHP language scale has 9 importance, as shown in Table 3.7

Table 3.7 Scale of relative importance of analytic hierarchy process (ahp) based on saaty.

Intensity of Importance	Definition	Explanation
1	Equally Important	Two activity contribute equally to the objective
3	Moderately More Important	Experience and judgment slightly favor one activity over another
5	Strongly More Important	Experience and judgment strongly favor one activity over another
7	Demonstrate More Important	An activity is strongly favored and its importance demonstrated in practice
9	Extremely More Important	The evidence favoring one activity over another is of the possible order of affirmation.
1/2, 1/3, 1/4., 1/5, 1/6, 1/7, 1/8 and 1/9	The reciprocal of the above-mentioned importance	

The AHP underwent successive stages of generating a pairwise comparison matrix with criteria values from 1 to 9 as shown in Table 3.7. The diagonal must equal 1(See formula 2) as it represents the comparison of one criterion against itself, and values above the diagonal are the inverse of those below it. After the numerical comparison the sum of the columns is obtained and then divided by the total sum to get the relative weight. To obtain the final relative weight of each factor this study follows five consecutive stages as discussed below.

First Stage: Assigning criteria preference values

The preferences are determined in the AHP based on pairwise comparisons which are based on evaluating each element against all other criteria in a specific hierarchical level. The criteria are a specific character such as a variable or evaluation parameter and the reference comparison point is an element at the top of the hierarchical chain.

$$a_{ij} : \text{where } i, j = 1, 2, 3, \dots, n \quad (3.5)$$

$$a_{ij} = 1 \text{ for } i=j \quad (3.6)$$

$$a_{ij} = 1/a_{ji} \text{ for } i \neq j \quad (3.7)$$

The preference matrix is a result of pairwise comparisons of all criteria at a specific hierarchy level. Formula (3.5) shows a matrix of $n \times n$ dimensions where n denotes the number of criteria being compared. Formula (3.6) represents the principle of preference in which two identical criteria are not differentiated by preference when compared to each other and All values of the elements on the diagonal of the matrix are equal to 1 because the difference in preferences is conveyed by the number 1 (Table 3.8). Formula (3.7) represents the principle of preference value that has inverse importance.

Table 3.8 Preference values of criteria pair wise comparison matrix using AHP

Criteria	Ia	Pd	Lu	Defs	Pmr	Idr
Ia	1	3	2	4	3	5
Pd	0.33	1	2	3	4	5
Lu	0.5	0.5	1	2	3	5
Defs	0.25	0.33	0.50	1	4	4
Pmr	0.33	0.25	0.33	0.25	1	3
Idr	0.20	0.20	0.20	0.25	0.33	1
Sum	2.61	5.28	6.03	10.5	15.33	23

Second Stage : Computing normalize pairwise comparison matrix

In this stage the normalized pairwise comparison can be calculated as all the elements of the column are divided by the sum of the column (Table 3.9).

Table 3.9 Normalized pairwise comparison matrix result

Criteria	Ia	Pd	Lu	Defs	Pmr	Idr
Ia	0.383	0.568	0.332	0.381	0.196	0.217
Pd	0.126	0.189	0.332	0.286	0.261	0.217
Lu	0.192	0.095	0.165	0.190	0.196	0.217
Defs	0.096	0.063	0.083	0.095	0.261	0.174
Pmr	0.126	0.047	0.055	0.024	0.064	0.132
Idr	0.077	0.038	0.033	0.024	0.022	0.043
Sum	1	1	1	1	1	1

Third Stage: The relative weight of preference value percentage for each criteria

The percentage of preference values between two parameters where one is in a column and the other is in a row can be determined by using the formula(3.8)

$$\%pv = \frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \tag{3.8}$$

where %pv is the percentage of preference value and a_{ij} is the value of preference between two parameters in column and row respectively and $\sum_{j=1}^n a_{ij}$ represents the total sum of the column criteria. The relative weight percentage for all criteria were computed and presented in Table 3.10. Finally , the relative weight values were determined by using the formula(3.9)

$$W_i = \frac{\sum_{c=1}^n a_{ic} * 100}{m} \tag{3.9}$$

where W_i is the value of the relative weight for the row parameter, $\sum_{c=1}^n a_{ic}$ is the sum of preference values for a row parameter, and m is the total number of criteria.

Table 3.10 The final relative weight of each criterion

Factors	Relative Weight	≈ Percentage (%)
Inaccessible area	0.357	36
Population density	0.238	24
Land use	0.172	17
Distance from existing fire stations	0.125	13
Proximity of Main Road	0.069	7
Incident density rate	0.038	4
Total	1.00	100

Fourth Stage: Verification index for calculating consistency index

In this stage, for the determination of consistency ratio the eigenvalue of comparison matrix has been done first. This was computed by multiplying the preference value of each column (Table 3.8) with respect to their relative weight. After that summing the values in the row then dividing it with its relative weight which is called weighted sum. Finally, eigenvalue was calculated by taking the average of the criteria weight as shown in the Table 3.11

Table 3.11 Determination of eigenvalue for the comparison matrix

Criteria	Weighted sum	Relative wight	Weighted sum/ Relative wight
Ia	2.312	0.357	6.476
Pd	1.502	0.238	6.310
Lu	1.117	0.172	6.494
Defs	0.807	0.125	6.456
Pmr	0.42	0.069	6.086
Idr	0.292	0.038	7.684
Average			6.584

Therefore $\lambda_{max} = 6.584$ and $m = 6$ then Consistency index (CI) is computed using the formula:

$$CI = \frac{\lambda_{max} - m}{m - 1} = \frac{6.584 - 6}{6 - 1} \approx \mathbf{0.116} \quad (3.10)$$

where λ_{max} is the eigenvalue of the comparison matrix and m = the total number of criteria

Five Stage : Calculating the consistency ratio(CR) percentage

In final , the consistency ratio percentage was calculated by using the formula (3.11)

$$CR = \frac{CI}{RI} = \frac{0.116}{1.25} \quad (3.11)$$

$$= 0.09 < 0.10 , \text{ Pass the consistency test}$$

where CR Consistency ratio determined from consistency index by random value

RI is the random consistency index based on the number of criteria taken from Table 4.1.8

The consistency ratio is 0.09: the result of consistency value for this study is less 0.1 which is acceptable value. The consistency values must be in a range not exceeding 0.1 (10%), as values higher than 0.1 mean more conflict in consistency at this time we have to reconstruct the pairwise matrix as presented in figure 3.17.

Table 3.12 Random stability index (Saaty, 2000)

N	1	2	3	4	5	6	7	8	9	10
R	0	0	0.52	0.89	1.11	1.25	1.3	1.4	1.45	1.49

The value of the random consistency index based on the above table is equal to 1.25 because the number of criteria used is 6. The percentage of the consistency ratio was $0.09 * 100 = 9\%$. After assigning weights to each criterion AHP layer was formed in the ArcGIS and by analyzing the weighted layer the final site selection layer was confirmed .

3.6.7 Weighted linear combination (WLC) in ArcGIS

Weighted Linear Combination (WLC) is a type of multi-criteria evaluation method in GIS environment used to evaluate the suitability of fire stations sites. This allows the decision maker to assign weights according to the relative importance of each suitability map and combines the reclassified maps to obtain an overall suitability score. WLC implemented with the following four steps. The first step is determination of data, second step is development of attributes of criteria and their standardization, the third step is determination of the relative importance weights, and at final step is overlay analysis/combining of all criteria (Malczewski, 2004). Finally, to find out the candidate sites for fire stations to this study the study has been conducted the following procedures (Fig 3.16).

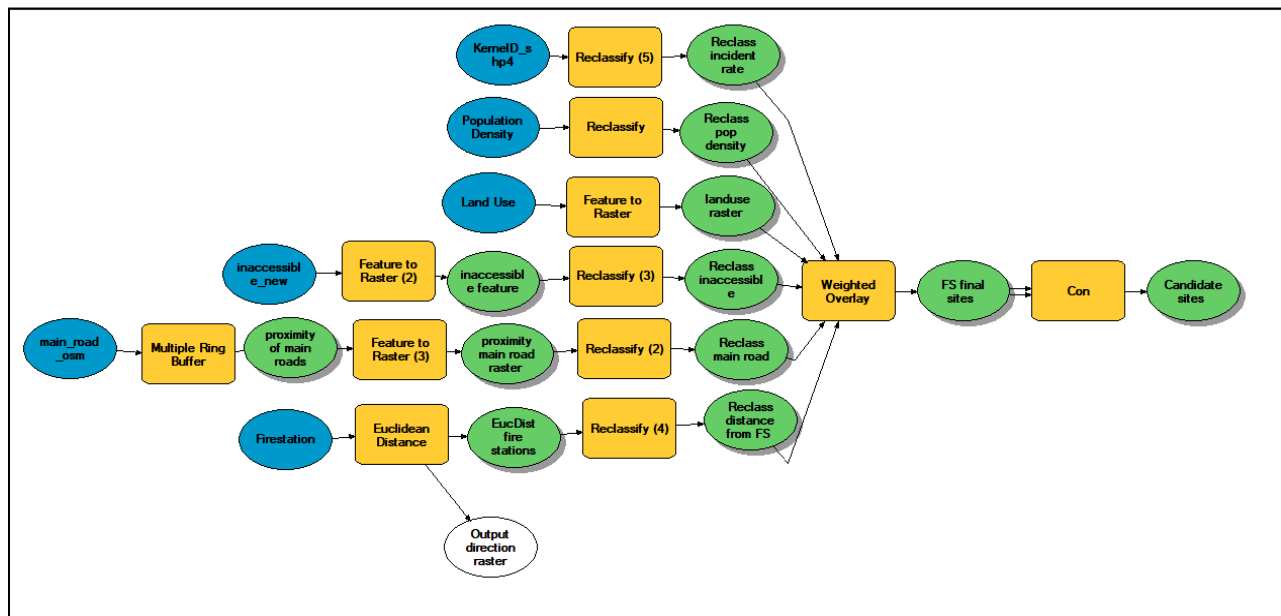


Figure 3.16 Candidate sites selection procedure using model builder for new fire stations

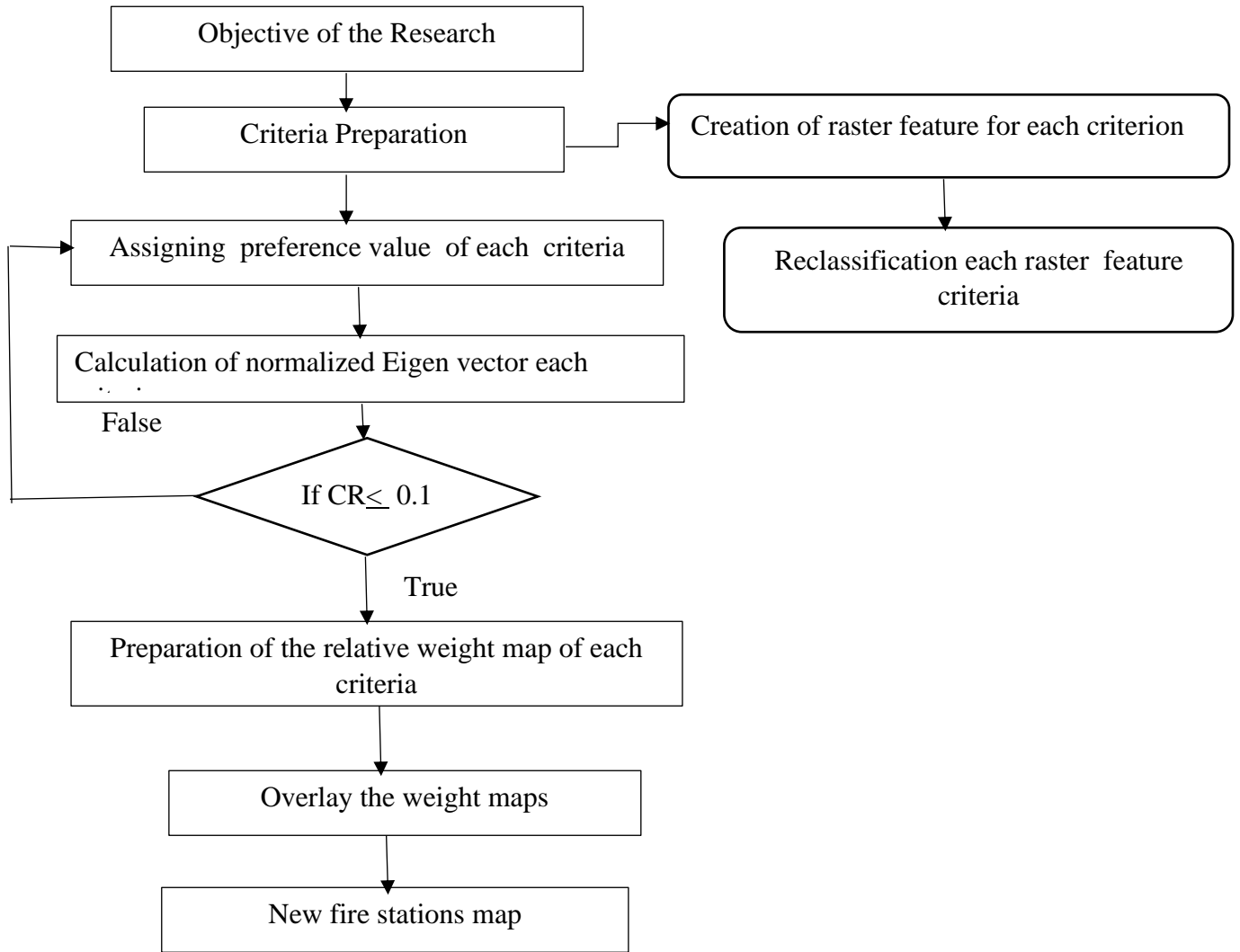


Figure 3.17 Methodological flow chart of fire stations Site Selection of Addis Ababa city

3.6.8 Descriptive analysis

Descriptive analysis has been conducted by Microsoft Excel used to make simple statistical arithmetic calculations as well as for computing Sum , Percentage and Total and then the result was presented in descriptive tools such as tables and charts.

3.6.8.1 Statistical analysis of fire incidents data

According to the AACFEPR report data shows commercial and residential areas are the highest common areas in which fire accidents occurred on average for two years. Which was the highest crowded condition in these areas has contributed more than the other infrastructure. Because of that exchange of goods could take place in a commercial area and a lot of people are there around the residential place. From the report indicated that the highest fire incident was occurred in bole sub city numerically 50 but the lowest is occurred lideta sub city numerically 11 from the total of both years as shown in table 2.1 and graphically represented as shown in Fig 3.18.

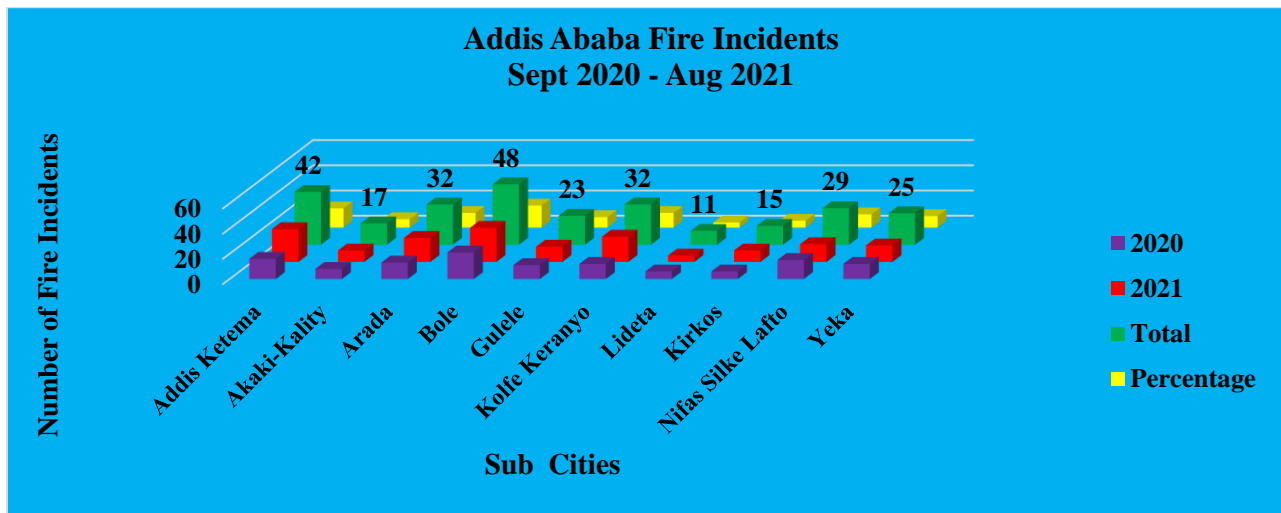


Figure 3.18 Plot Chart Between Sub Cities Versus Number of Fire Incidents

(Source : AACFEPR, Sept 2020- Aug 2021 fire report)

CHAPTER FOUR

RESULTS

4.1 Service area coverage

The analysis process was undertaken using a travel time analysis based on the city standard. The travel time analysis determines the level of accessibility of existing fire stations in Addis Ababa city. To find the service area of the existing fire stations service area tool of network extension has been used. Therefore, service coverage area of existing fire stations in Addis Ababa city was examined using eight minute of travel time as indicated in Figure 4.1.

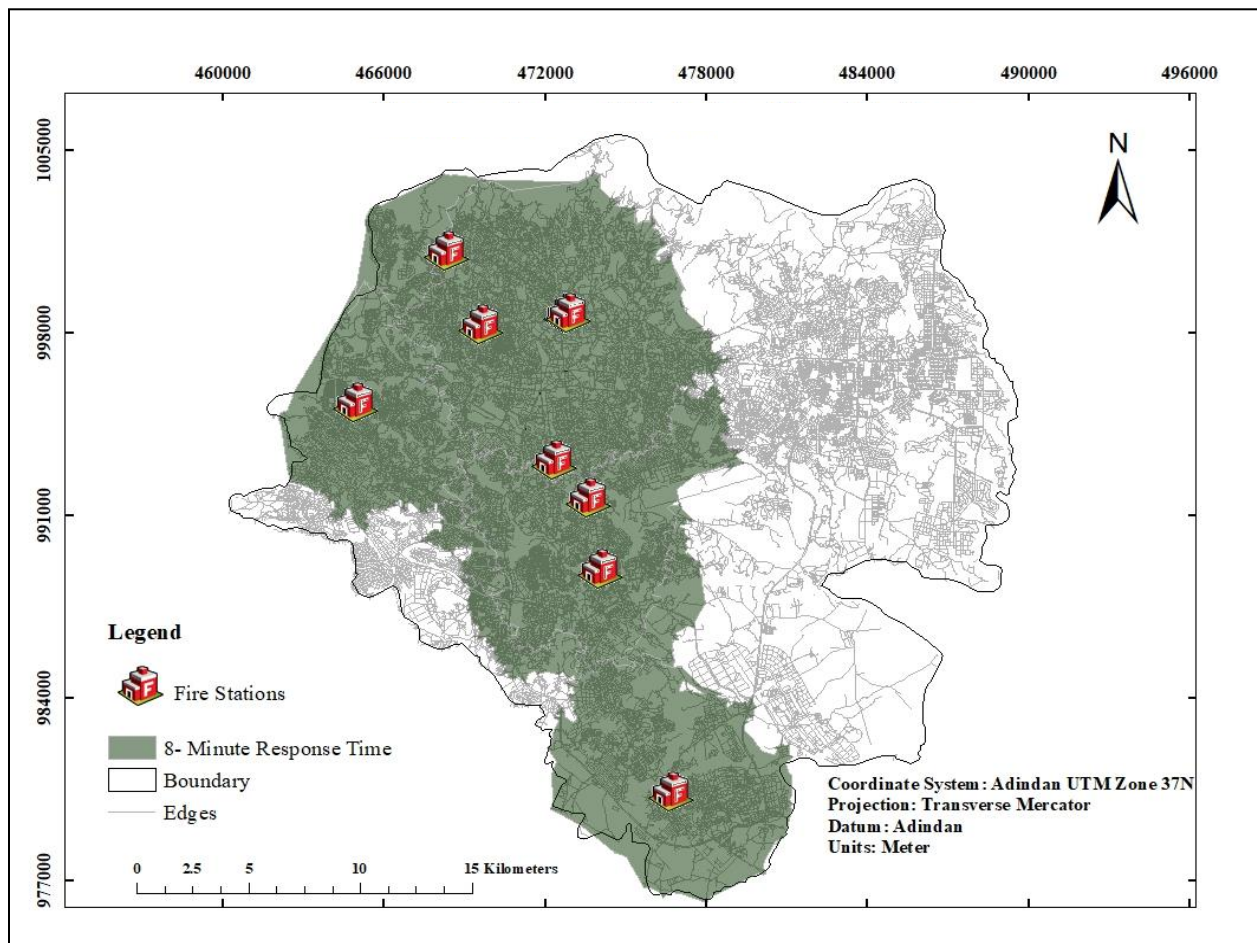


Figure 4.1 Service Area Coverage of Existing Fire Stations

Table 4.1 Fire stations coverage within 8 minutes in Addis Ababa city

Name of Fire Stations	Coverage within 8 minutes			
	Population	%	Area (km ²)	%
Addis Ketema Sub City Fire Station	496353	20.20	18.22	6.60
Nefas Silk Lafto Sub City Fire Station	254949	10.37	41.69	15.10
Kirkos Sub City Fire Station	375186	15.27	32.20	11.66
Akaki Kaliti Fire Station	148678	6.05	56.26	20.38
Bethel Fire Station	319773	13.01	36.25	13.13
Tigist Fire Fighting Equipment	104678	4.26	24.08	8.72
Addis Ababa Fire Stations Head Quarters	453853	18.47	28.61	10.36
Gulele Sub city Fire Station(Fire Accident)	1880	0.08	0.87	0.32
Addis Ababa Fire and Emergency Management Authority	228349	9.29	21.87	7.92
Arada Fire Station	73744	3.00	16.04	5.81
Total	2,457,443	100	276.10	100

From the Table 4.1 indicate that service area time response shows that the served population from existing fire stations is 2,817,315 (66.62%) out of 3,689,001 estimated population which is distributed over the area 276.10km² which corresponds to 53.15 percent of the city are served out of a total of 519.458 km². Along with this the remaining 243.358 km² which corresponds to 46.85 percent of the city are unserved. Each fire stations service area is a much more comprehensive way to determine the most vulnerable location during any kind of fire incidents .The finding shows that the area of existing fire stations coverage to which the firefighter vehicles responded within eight minutes and the available of roads network during emergency response time.

Therefore, it shows that existing fire stations do not cover the whole city area so that it is necessary to make proper plans to protect the un-service area by establishing new fire stations. It is obvious that the fire fighter vehicle has to travel more than prescribed time to reach fire incidence in un-served areas as shown in the map which may be disastrous both in terms of life and property.

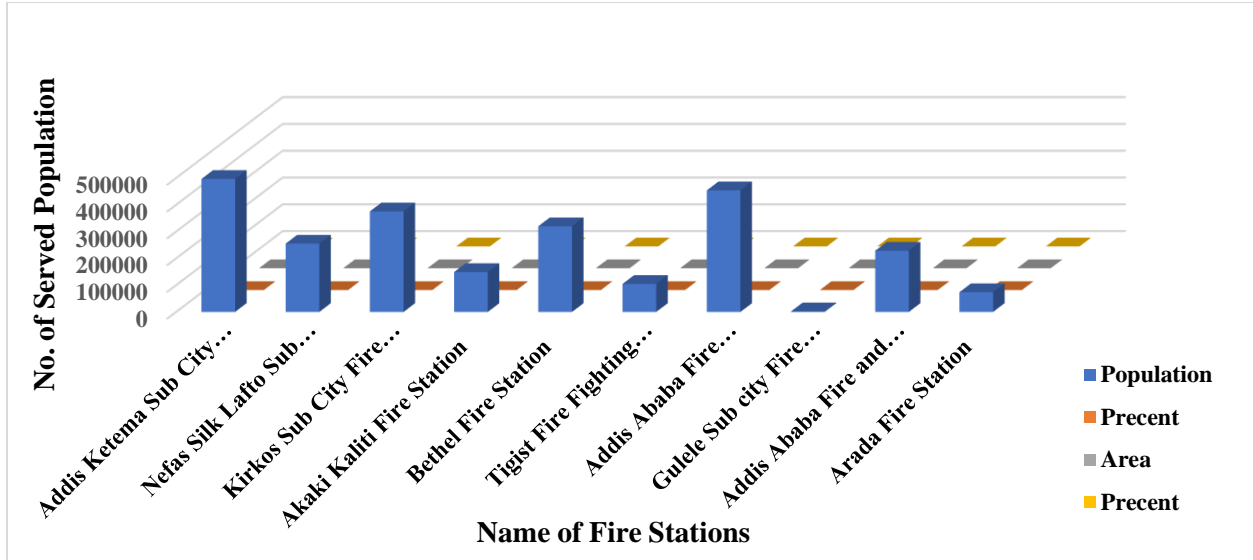


Figure 4.2 Served population and area covered with their percentage

4.2 Best route result

The best route analysis result generates the best route between two locations based on travel time which depends on the traffic conditions with parameter such as travel time and road direction available on the network. The network analyst extension makes it easy to set the best route analysis parameters such as the travel time as an impedance factor for emergency response. Finding the optimal path means that selecting either the shortest path or the path having minimum travel time Eleiche, (2011). GIS intends to find the optimal route between the given origin and destination involving shortest distances as well as shortest travel time. After adjusting the best route analysis settings, the start location is **Arada_FS** location which is main fire stations and **FI_253** location as the destinations, and then by applying solver tool it generate the best route between these two locations. The integrating of all the impedances(time and distance), the best route to reach the incident location is displayed in (Figure 4.3). Its total distance is 8593.8m and the whole time takes is 6 minutes.

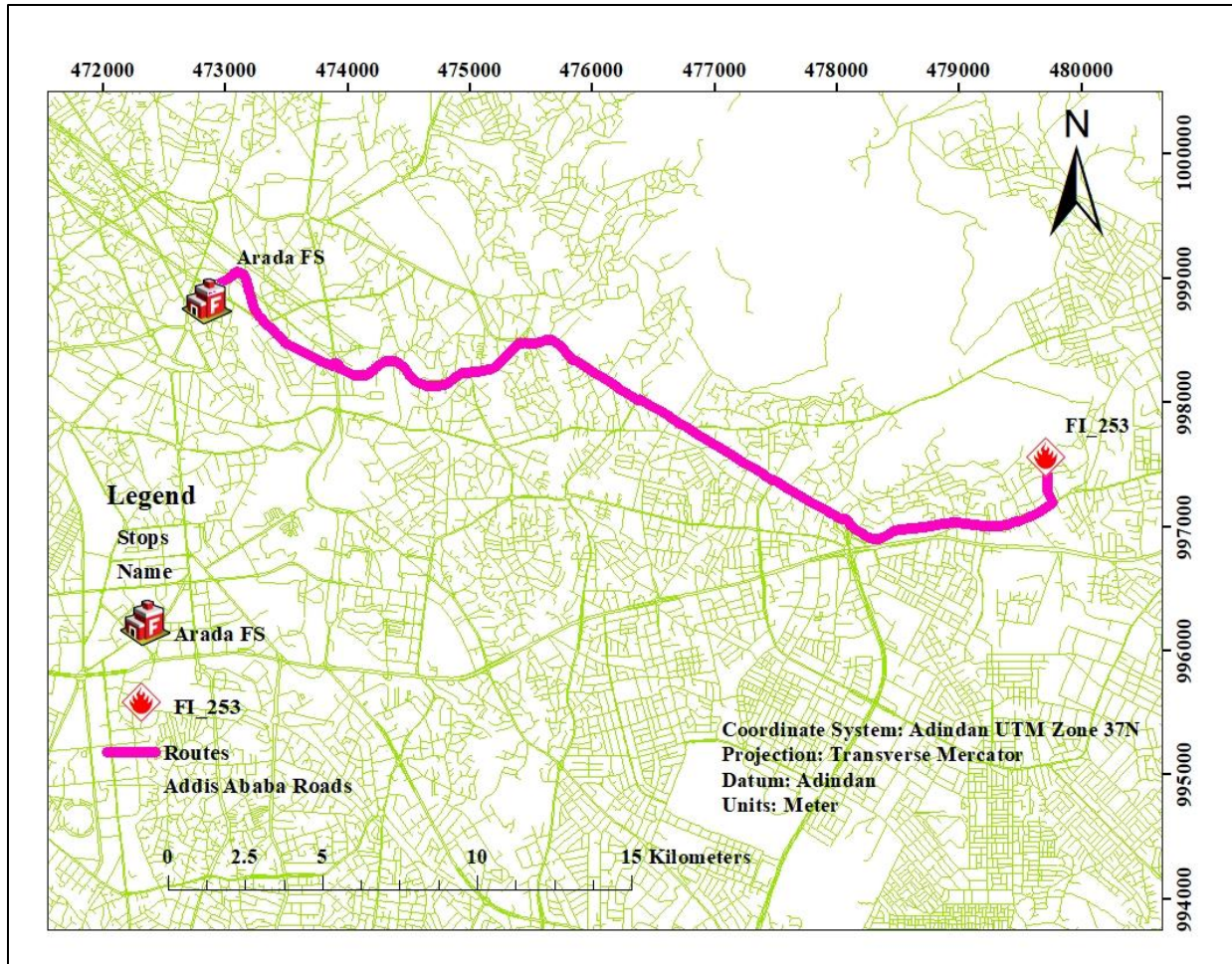


Figure 4.3 Best route map from arada sub city.

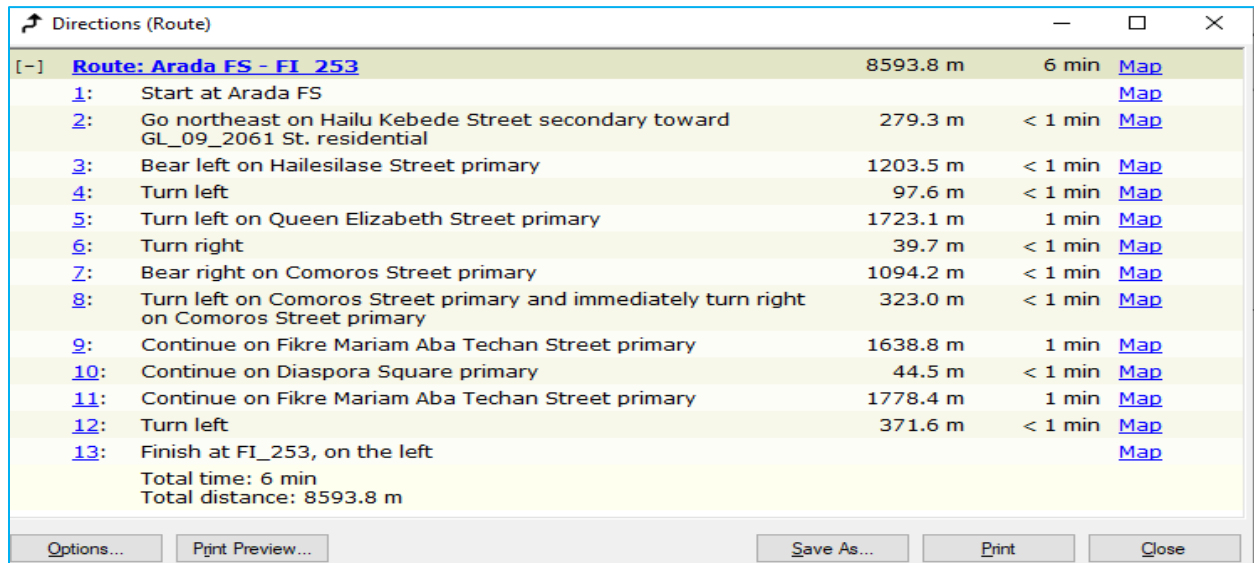


Figure 4.4 Best route directional windows

4.3 Closet facility area

The closet facilities analysis finds the nearest facilities that can be reached in a specific period from an incident location based on travel time and traffic condition available. To apply this analysis, it is required to make a closet facility analysis layer and its analysis properties. Analyzing closet facilities needs to perform with parameters such as impedance factor, start time, period to reach closet facilities, number of facilities to find, the direction of travel and accumulation consists of travel time (Minutes) and Distance (Meters). This layer is useful in determining the closet facility or facilities to an incident based on a specified network. This study finds the closet facilities that can reach in a specific period from an incident location based on 8-minute travel time. Figure 4.5 illustrates the analysis started with existing fire station location as a facility and ends with all the recorded fire incidents locations as an incident and then by applying solver tool it generates the shortest path between all locations.

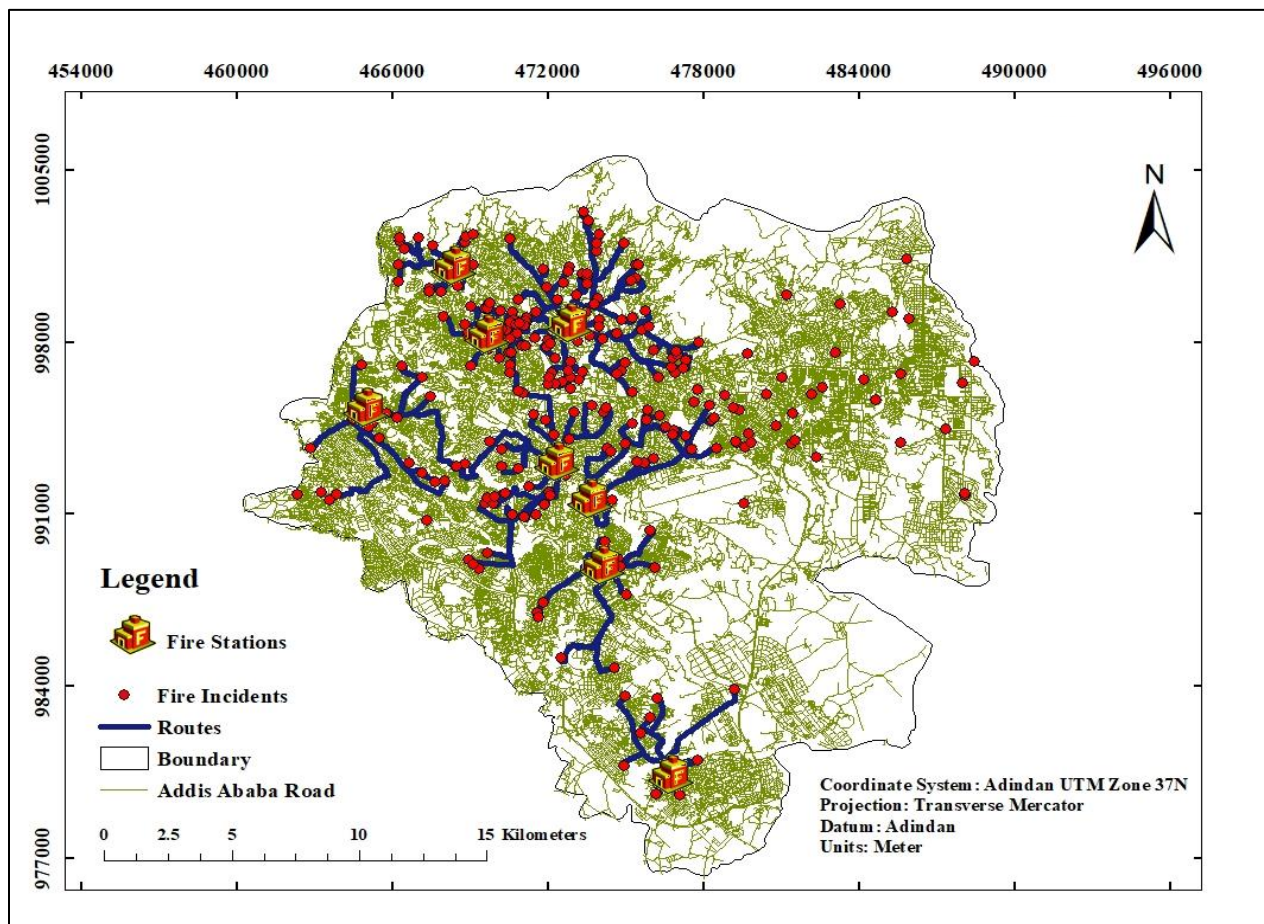


Figure 4.5 Closest fire stations within 8 minutes to fire incidents

Solving for this analysis the finding within eight-minute closest facilities. It generate a total of 230 routes and maximum travel time of 7.99 min, minimum travel time of 0.16 min and maximum length of 11890.42 m , and minimum length of 151.68 m.

In similarly way, the following map explain that the closet facility analysis result and directional window between Arada fire station and FI_272. This was obtained by, firstly all the existing fire stations are inserted as a facility as illustrated in Fig 4.6 black outlined by a rectangular shape as well as FI_272 as incident. And then by hitting the solver tools in network analyst. The system gets Arada fire station as the nearest facilities among of ten fire stations. Then, generate the optimum route from Arada fire station to FI_272. Its total distance is 3865.6m and the whole time taken to reach the incident place is 3min in Fig 4.7.

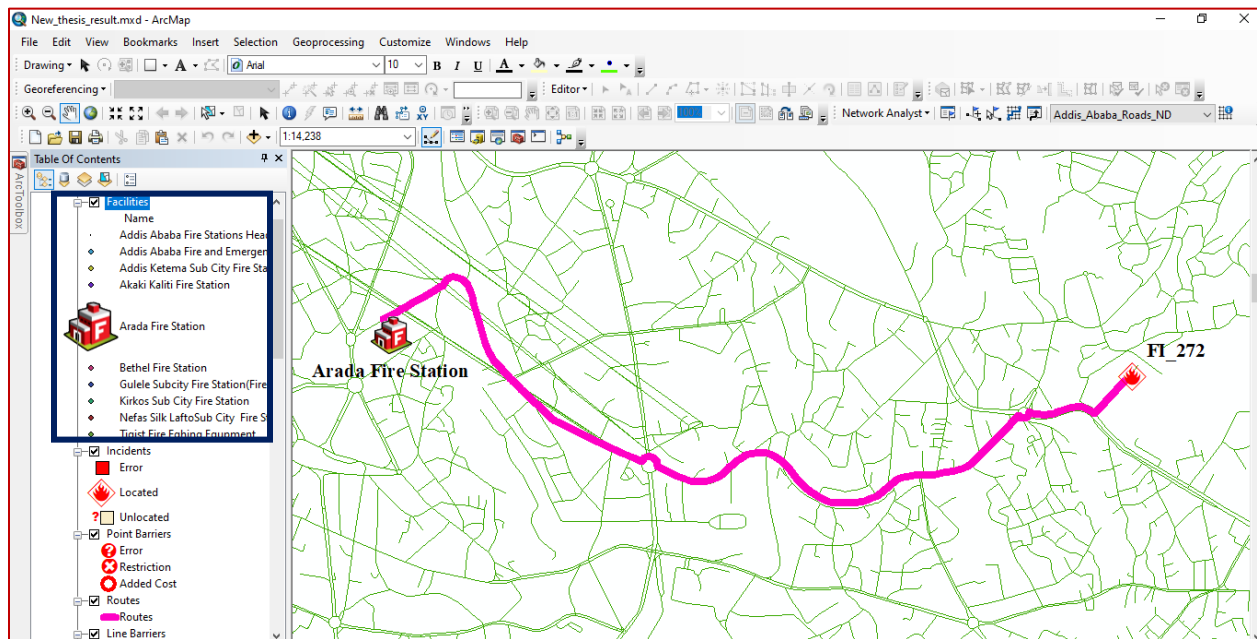


Figure 4.6 Closest Facilities Analysis Result from Arada Fire Station to FI_272

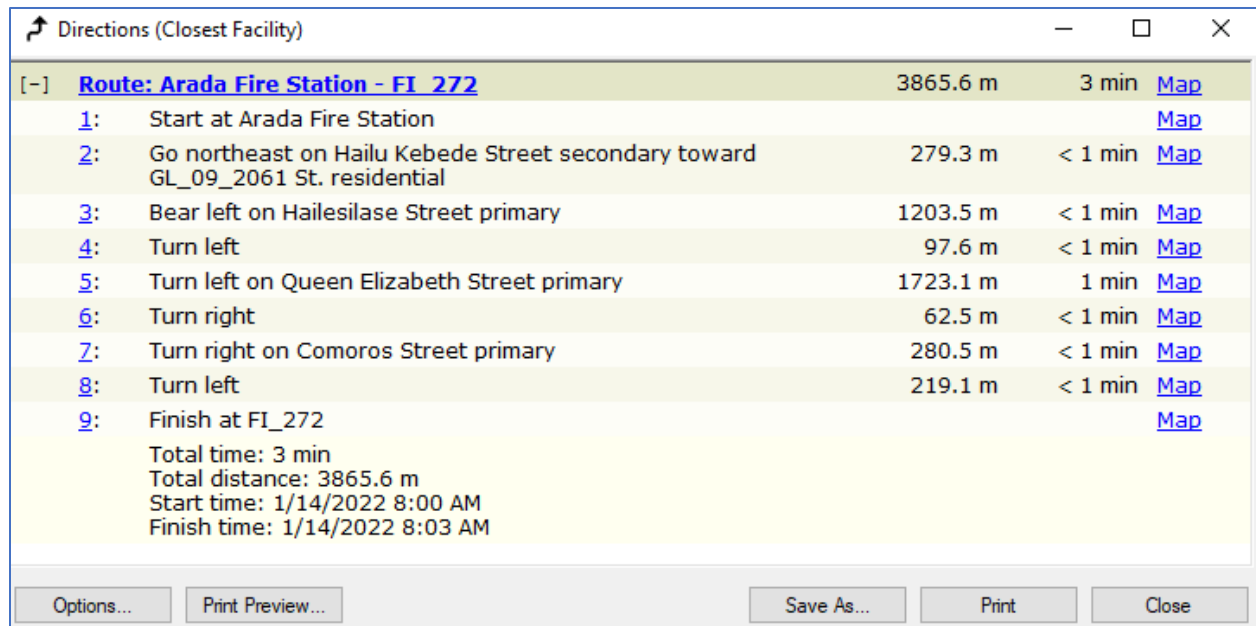


Figure 4.7 Closest facilities direction result from Arada Fire Station to FI_272

4.4 Finding optimum sites based on location allocation

In this study running location allocation using maximize coverage problem types has been conducted to identify optimum sites for additional fire stations. 35 potential candidate sites were identified in the previous sections using AHP method which can offer fire stations service in poor deficiency area within this region to be covered and will have service coverage for emergency situation . Since it was chosen by using analytical hierarchy processes and GIS as stated in previous data analysis sections. Among 35 sites , ten optimum sites have been chosen by location allocation analysis particularly maximize coverage by giving population as weight. Then, the final optimum sites are shown in figure 4.2.8(b)

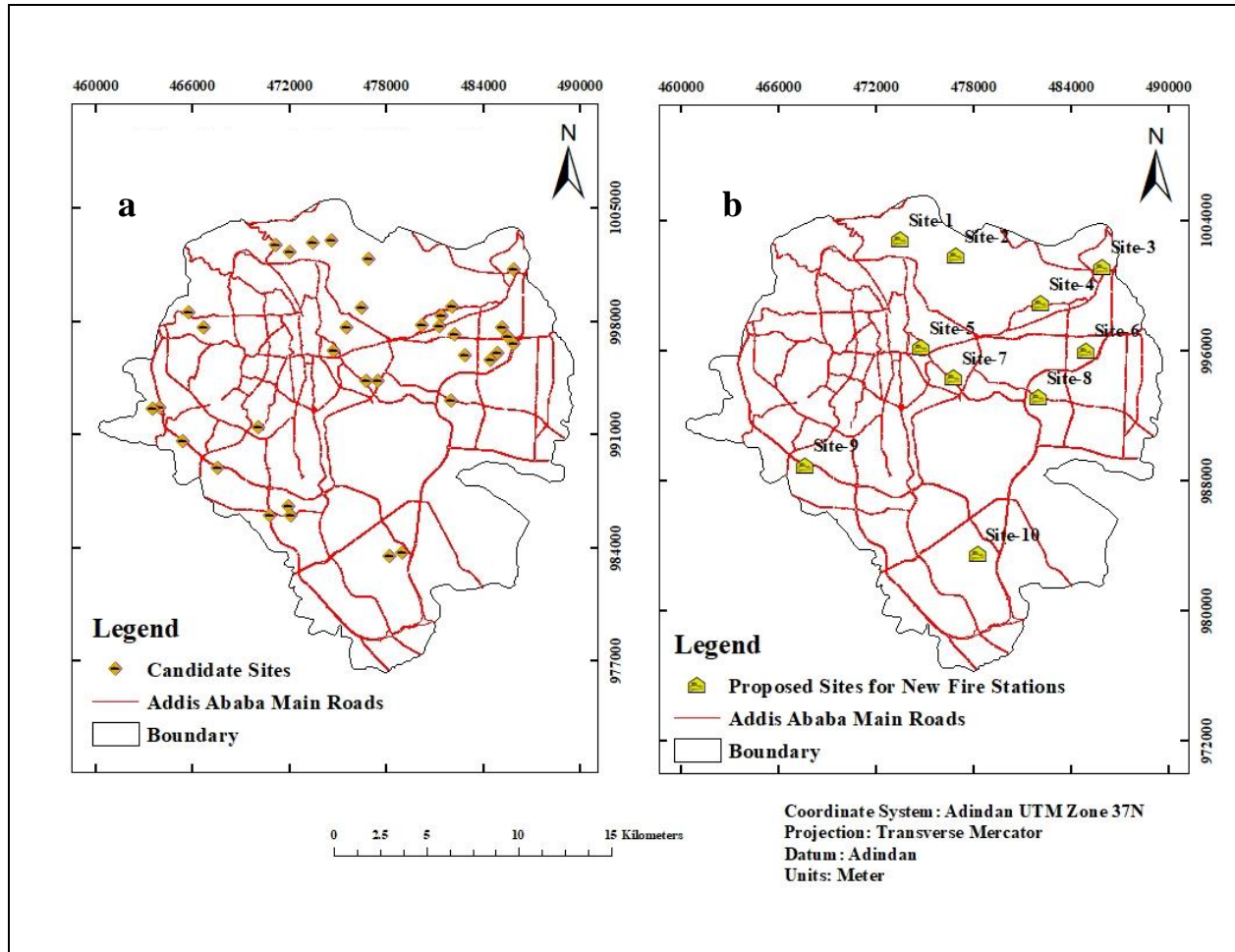


Figure 4.8 The selected candidate sites(a) & Proposed sites to locate additional fire stations (b)

As shown in the figure 4.8 (b) above. The following screenshot image was taken from Google Earth search engine which indicates that what their location looks like the selected optimum site on the ground.





Figure 4.9 The Ground Truth of Chosen Sites for Fire Stations to The Study Area Taken from Google Earth.

Table 4.2 Location allocation analysis using travel time (in minutes) as impedance from 10 optimum fire stations locations.

Name	Facilities Type	Demand Count (Number of residential)	Demand Weight (Population)	Total travel time (In Minute)	Total Weight Time (In Minute)
Site -1	Chosen	40456	160733	6.70	271176.68
Site -2	Chosen	23726	69520	6.61	156764.17
Site -3	Chosen	10538	30876	5.77	60833.55
Site -4	Chosen	70172	203909	5.66	397354.39
Site -5	Chosen	86351	283726	6.01	518916.00
Site -6	Chosen	33075	91728	6.14	203394.88
Site -7	Chosen	44389	121760	5.08	222572.95
Site -8	Chosen	43552	118461	6.25	271999.55
Site -9	Chosen	29815	86151	4.89	145795.35
Site -10	Chosen	5316	13348	6.92	36791.73

The result Table 4.2 shows that the new optimum site for fire station in site-10 had the lowest allocated demand with 5316 residential polygon and a total of approximately with just 13348 people allocated to it and they will be accessible within 6.92-minute total response time. However, site-5 had the highest allocated demand with 86351 residential polygon and a total approximately with 283726 people allocated to it and they will be accessible within 6.01 total minutes response .

From Table 4.2 the output depicts that in term of total travel time , the least amount of travel time were obtained in site-9 with will provide fire emergency response time within 4.89 minutes whereas the maximum amount of travel time were generated in site-10 will also provide fire emergency response within 6.92 minutes.

4.2.5 After Adding additional fire stations

After adding 10 more additional fire stations to the study area. It made the service area of fire stations coverage can be extended from 53.15% up to 87.44 % within 8- minute impedance travel time based on the emergency response time of Addis Ababa city. Those chosen sites help to determine the area of improvement in response time and coverage extent.

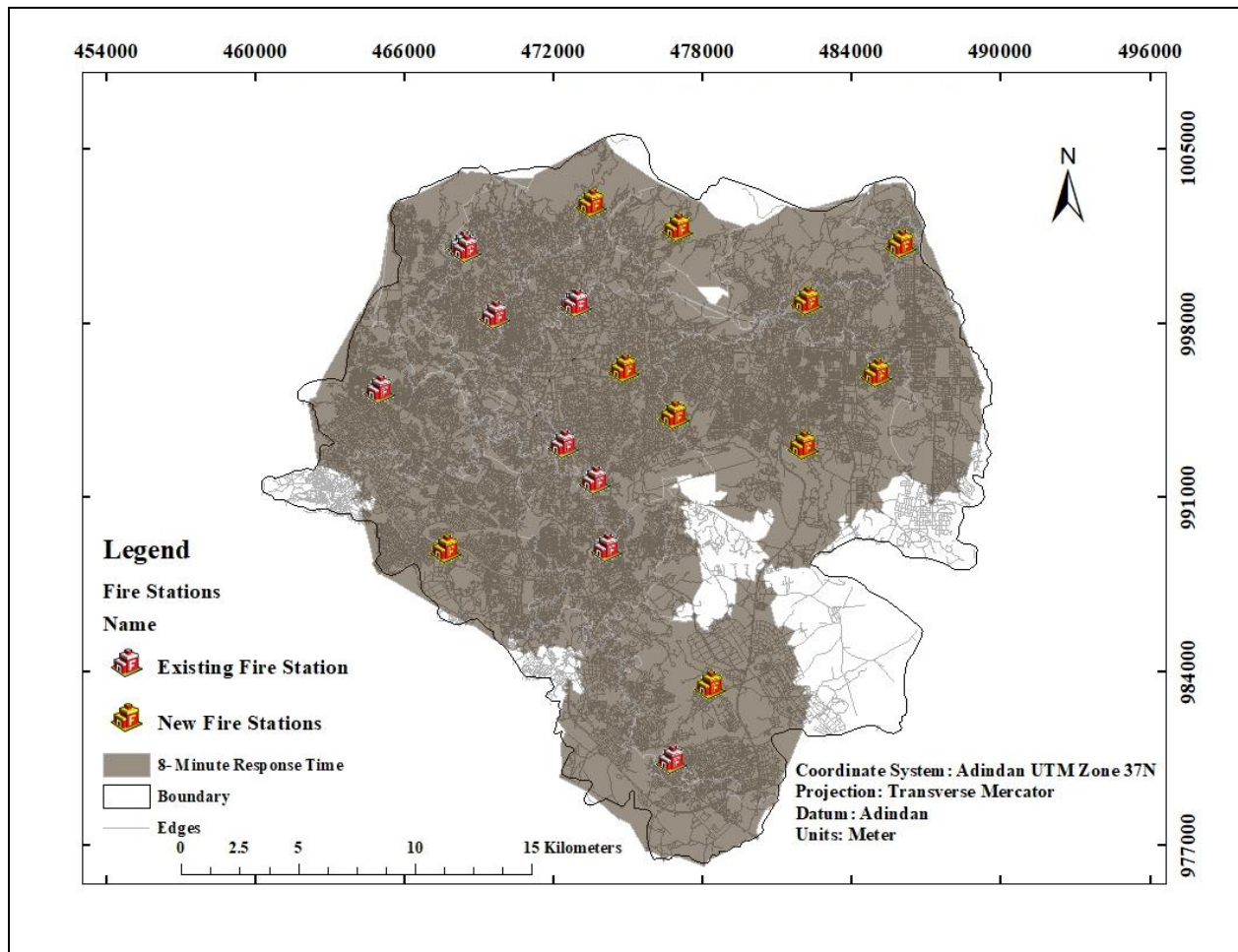


Figure 4.10 New service area created after adding new fire stations

CHAPTER FIVE

DISCUSSION

5.1 Comparative analysis

In the recent years, many researchers have undertaken similar study on locating fire station in different city. However, Tali et al. (2017), estimated the fire station needs in Karnataka, India, based on 5 min of travel distance coverage area. The research used simple GIS network analysis and population data for assessing optimal sites for new fire stations. Habibi et al., (2008), the researcher used an integrated AHP and index overlay (IO) logic for locating best location of fire stations had chosen population density, accessibility, proximity to hazardous point and size of plots as selection factors for fire station location the zone 6 of Tehran, Iran. Oh et al., (2019) ,the researcher proposed a nonlinear programming model to determine the locations of fire stations in the city of Kingsville, Texas. The main objectives of the research were to minimize response time with optimal fire stations and cover the maximum number of inhabitants, in terms of the geographical area and population. Bolouri et al., (2018), the researcher proposes multi-objective location–allocation model for Region 11, Tehran aimed to minimize the distance and time as well as maximizing the coverage of the city. Chevalier et al., (2012) developed a decision-aid tool for locating fire station in Belgium. Their decision-making involved occurrence of fire hazards, high potential risk areas, and fire response capacity.

This study taken into account six criteria have been chosen to find the optimum location of fire station in Addis Ababa city i.e., population density, Proximity of main roads, Land use , Distance from existing fire stations, Distance from existing fire stations, and Incident density rate based on local standard of 8-minute response travel time along with this the study propose ten new fire stations using AHP and network analysis was applied . However ,many researchers such as Wei et al., (2011) had chosen population density, building loss after catching fire and road distance to nearest fire station as selection criteria for preparation of the layout of fire stations within Beijing 3rd ring road by combining GIS and AHP together. Erden and Coşkun, (2010) had chosen population density, proximity to main roads, distance from existing fire stations, distance from hazardous material facilities, wooden building density, distance from area

subjected to earthquake risks as selection factors to ensure optimal site location(s) for fire stations in Istanbul, Turkey.

Chaudhary et al. (2016) had chosen distance from roads, land-cover, distance from rivers population density as selection factor has been used to find out high suitable site for fire station locations. Uddin and Warnitchai, (2020) , the researcher develops a model for locating optimal sites for new fire stations with three integrated method such as geographical information system, multi-criteria analysis, and set cover algorithm to solve the location allocation problem of fire station in complex urban. Idhoko et al. (2015) evaluates the digital road network of Oyo-Town, Oyo State, Nigeria for management of emergency service as long as perform query to select the best route in case of emergence occurrence and access the closest facilities. The main objectives of the research were designing a database, spatial data acquisition, database creation and spatial analysis for the town. Sarker and Ghosh (2021) determines the potential site of fire stations based on the criteria such as distances between fire stations, number of industries and the level of risk in the city coverage area, road accessibility and Arc-GIS network analysis as well as evaluate the existing fire station in 5-minute response time this helps the researcher to identify the deficiency coverage in Gazipur industrial area. Nyimbili and Erden (2020) used the integration of fuzzy analytical hierarchy process and GIS to obtain optimal site for new fire station in Istanbul region, Turkey and the author had chosen six the criteria to select the best sites i.e. wooden building density, density of hazardous material, distance from existing fire stations, distance from the areas subjected to earthquake risk, proximity to main roads , and high population density using this the study propose 34 new fire station. Anna-hajnalKa, (2018), the research paper had focused on developing an optimal route which is used during an emergency situation, the time and distance has been used as an impedance factor , to evaluate between accident and emergency units. Mezaal et al. (2020), focused on the sample of Puchong fire station in Malaysia based on the response time Using Network Analysis Extension some of them utilized are Service Areas and Closest Facility. The service area of the research was evaluated by 10-minute response time along with 325 fire incident data that were used for closest facility evaluation by response time of 10-20min , <20min and > 20min. Hay et al., (2019) , the major objective of the research were finding the best route by considering traffic data for Mandalay, Ghana, develop a system in case of emergency response to identify the best routes from fire

incident to the nearest place such as emergency services, hospitals and police stations and 5-minute response time were used to find the closest facilities.

Forkuo and Quaye-ballard (2013) present to establish a GIS based fire emergency response services where Ghana National Fire Service can identify the optimal route from its location to any fire incident, its the optimal route model were developed and utilized by ArcGIS Network Analysis based on time of travel, the distance of travel, the slope of the roads and the delays in travel times and also used a system which comprises geodatabase of fire hydrate and queries to locate fire incident to the particular service area.

Kc et al. (2018), the study employed the location model i.e. maximum coverage location model to examine the spatial coverage of current and the future proposed new fire stations aligned with population growth, estimated by 14-minute response time based on local context standard in Brisbane, Australia. The researcher had chosen a new fire station location based on the input data of fire incidents, the road network, and areas of significant anticipated population. Davoodi (2019), the researcher develops a hybrid model based on network analysis and set covering location problem for the site selection of new fire stations in Tehran, Iran. The road network data of the city had used to determine the service coverage of existing fire stations by 3-minute standard response time. Even though all the above studies are similar in some points to the present study. Meanwhile the present study is unique in terms of selecting holistic features as well as taking various steps to solve the problem of fire stations deficiency in the study area by combining advanced network analysis and analytical hierarchy processes with ArcGIS.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In this study, GIS-based network analysis was implemented and applied to the Addis ababa road network. It focuses on finding the optimal route between two locations on the road network and finding the nearest fire stations service providers to an incident location based on local context deriving time response. Furthermore, the proposed method integrates the collected fire incidents data of 2020/21 to be used in the analysis, which in turn to produces more accurate results that are suitable for realistic road networks. The Dijkstra algorithm used in this study by using the functions of ArcGIS software's Network Analyst extension is best method for network analysis , especially in the crowded city such as Addis ababa. In connection with this, from the result in the best route analysis it can be concluded that it emphasizes on selecting the best route direction between two given locations on the road network data and their total distance is 8593.8m with time taken of 6minutes. On the other hand, from result closest facilities it can be concluded that some of the fire incident locations that occurred in the study are outside of the predefined response time of 8 minutes which implies that those incidents point in which the fire fighter vehicle not reaching the incident location within cutoff travel time during emergency time. Associated with this, the service coverage of the study area was examined using ArcGIS network analyst tools within in 8-minute response time. From the result it was concluded that 276.10km² which corresponds 53.15 percent of area is served whereas the remaining 243.358 km² which corresponds 46.85 percent of the city are unserved area.

Therefore, in order reduce spatial disparity distribution of fire stations for the city, proposing a new fire station is extremely important. To solve this problem this study applies multi criteria decision analysis such as AHP method which identifies 35 candidate sites using six factors such inaccessible area, land use, population density, distance to existing fire stations, proximity to main roads , and incident density rate. Among of them the more influenced criteria are inaccessible area, population density and land use with associated weights of 36%, 24% and 17% respectively. A number of candidate sites were introduced as the best location for establishment of a new fire station to the study area. Using location allocation particularly maximize coverage has chosen 10 new optimum location of fire stations to the study area. This study concluded that

a total of twenty fire stations (i.e., the existing fire stations together with the suggested new fire stations) are more than enough to cover the entire city within 8-minute.

Finally , the present study suggests 10 new fire stations which helps to maximize the coverage of the city. After the suggested 10 new optimum fire station together with existing fire stations , the current service coverage level of the study area has increased into 87.44%. The ground truth of those locations was taken from Google Earth search engine.

6.2 Recommendations

Based on the finding of the study. This study has made the following recommendations for the study area.

- This study highly recommended that collecting and storing the spatial location of fire incidents at the time of emergency occurrences using handheld GPS is very important for the further interpretation and for researchers to do their study easily.
- Addis Ababa city fire and emergency prevention and rescue agency should increase as much as possible the number of fire stations more than the existing and including the proposed fire stations in this study in order to rescue long term sustainable and viabilities property .
- This study recommended that the future development of the city and the population growth has to be considered during the development of new fire stations. Since its obvious that increasing population will leads fire incident occurrence.
- Addis Ababa city fire and emergency prevention and rescue agency should consider the development of a GIS database for fire stations to capture all the necessary information during emergency situations.

6.2.1 Suggestion for further research

For the possible future research. This study suggests the following recommendation for further study.

- ✓ The development Web GIS based fire emergency response system database to locate fire incident dynamically shall be investigated which provide quick and easy access.
- ✓ Taking into account the fire hydrate location will helps to achieve better results for proposing new fire stations.

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Appendices

Appendix 1 :- Existing Fire stations Geographic Coordinate points

S.no	Fire Stations Name	Easting	Northing
1	Addis Ketema Sub City Fire Station	9.033437	38.724256
2	Nefas Silk Lafto Sub City Fire Station	8.948606	38.7649
3	Kirkos Sub City Fire Station	8.986628	38.749243
4	Akaki Kaliti Fire Station	8.871546	38.788999
5	Bethel Fire Station	9.006456	38.681882
6	Tigist Fire Fighting Equipment	8.973223	38.760958
7	Addis Ababa Fire Stations Head Quarters	9.037573	38.75321
8	Gulele Sub city Fire Station(Fire Accident)	9.058938	38.712672
9	Addis Ababa Fire and Emergency Management Authority	9.05759	38.713312
10	Arada Fire Station	9.037687	38.753776

Appendix 2 : 100 Sample Fire Incidents Coordinate points out of 274 in 2020/2021

No.	Sub City	The Special Place	Easting	Northing
1	A/ketema	Amanuel Church	469706.26	997721.91
2		Bus ordinary	470062.27	998513.24
3		Millennium Health Center	470293.79	998082.71
4		Bus ordinary	470872.63	998809.35
5		Abebe Bakele Stadium	469728.38	999585.27
6		Kolfe Electric Power	469462.68	998432.16
7		Eshet school	469574.12	999400.54
8		South Mercato Hotel	471510.95	998190.38
9		Melata Meda	468522.4	1000276.15
10		Mesalemiya	470397.68	998163.84
11	AK_kality	Chefe Condominum	475951.21	982723.8
12		sertie Mariyam No.1	476234.83	983494.7
13		Saris Health Center	473846.79	988838.17
14		Koye Nefas silek	479180.29	983871.79
15		koye feche medhaniyalem	482367.11	993331.93
16		Abo Matoria Fafa Factory	474704.64	989214.95
17		Cheralia Mosque	984872.34	984872.34
18		Federal Prisons	472517.99	985150.44
19		Gelan Condominium Old	476123.3	988824.37

20		Urban development	477086.35	979565.76
21	Arada	St. Mary's Church Almi Building	474123.48	998156.9
22		Giorgis Church	472485.84	998999.6
23		Piazza Mall	473103.07	998478.22
24		Kurtu Building	471548.16	999227.93
25		degate wube	471176.83	999000.46
26		4Kilo Examinations Agency	473956.54	998920.06
27		Aware Women's Square	473486.33	999259.67
28		4Kilo Bash wolde	473627.19	998262.59
29		Tourist Hotel	998607.1	998607.55
30		Main Post Office	472855.13	997213.42
31	Bole	Bora Children's Entertainment	479611.35	993747.03
32		Gerji Giorgis Church compound	475271.87	994705.09
33		behind Gerge kadisco hospital	479742.57	994311.98
34		No.49 square (medhaniylem shopes)	484213.49	996471.51
35		School of Tommorrow	476083.1	993272.05
36		Summit Condominium Block 2 Second Gate	487360.65	994464.15
37		Figa electric power	480790.91	994610.9
38		Figa Court	482194.47	995889.43
39		Gakrose Guna	480451.28	995914.84
40		Bole ayer abma school	475695.62	993116.16
41	Gulele	Shiro Meda Welega sefer	473874.22	1001699.91
42		Retirement Bridge	470556.62	1002220.11
43		Gulele Police Department	471835.11	1000981.82
44		Shegole kidane mihurte	468772.26	1002076.74
45		Shiro Meda Qusquam Mariam Tabot Madari	473106.39	999945.38
46		kechene 8 No. Rotation	472809.36	1001091.96
47		Medre 7	469127.99	1001156.4
48		Menen Police Station	473329.01	1000757.81
49		Mulugeta Park	468322.06	1001347.54
50		Kechene Medhaniylem	472770.06	1000904.38
51	Kirkos	Addis Ababa stadium Rotation	473213.78	996492.81
52		legahare Common Corporation	472559.43	996390.33
53		Denble back	474149.98	995173.54
54		Meskele Flower Ezra Hotel	474300.6	993716.17
55		Awash Bank National Theater	472852.5	996572.81
56		Sarbet Oromia compound	471899.24	994820.15
57		behind east powedr fabrica	474434.73	993565.1
58		kirkose legahare exit	472881.118	996111.454
59		nearest to arba miche fishe house	472837.962	994061.738
60		around leba fana school	474849.97	996875.32

61	Lideta	African Union Taboo Monopoly	471434.28	995055.74
62		Lideta Balcha	472282.59	996290.72
63		Police Hospital	472004.96	996290.59
64		TekeleHaymnote Hospital	471981.94	998100.2
65		Lideta Balcha	472149.48	996781.24
66		Police Hospital	472033.98	996566.99
67		around welda berka	467409.55	1000052.39
68		around gola Micheal	471971.61	997829.35
69		40 kebelshe office	470535.98	996764.04
70		Gola Micheal	472083.9	997946.38
71	N_silke	Sosofia Mall Zeryakobe School	472048.48	991905.61
72		Sosofia Mall Zeryakobe School	472074.56	991766.08
73		Mekanisa	470837.52	992866.2
74		Bisrat Gabriel Home Depo	469760.96	993992.25
75		Chefe Mekanisa	470354.42	991842.04
76		Haile Garment	479580.68	991454.79
77		Jemo Michael	469580.68	991454.79
78		Bisrat Gabriel	468807.21	993030.82
79		Adey Ababa Zenbaba Hotel	474195.72	989911
80		Meri Ordinary	472668.43	992585.82
81	Yeka	Megenagna Betelehem Building	477327.07	997281.14
82		Kotebe Emmanuel Hospital	483272.27	999569.04
83		Denbroa Hospital	477250.84	996928.76
84		Signal Adwa Bridge	476086.16	997695.05
85		Tiru Eder Temezha Yaze	479715.51	997557.34
86		Embassy of Israel	488838.87	997320.17
87		Were taboot dormitory	485292.76	999222
88		Yeka Michael Bano Sefer	477823.25	997987.18
89		Yeka Adado Woreda 13	483113.39	997574.14
90		Leme Hotel	476247.15	996582.31
91	Kolfe	World Bank Square	464567.36	995003.22
92		Bethel Alpha School	466171.63	994941.51
93		Alpha University School	465223.58	994721.97
94		Kirkos Hotel Air Health	466618.09	993100.65
95		Debre Abay Arsema Church	465780.87	995107.01
96		shewa bread	467484.37	995797.61
97		China Bridge	464781.25	997106.75
98		Asco High School Campus	467427.69	1000192.29
99		Rep Medhaniylem	467156.69	996567.07
100		Kedinae Merhurt church	465506.92	994086.99