

**ROAD NETWORK ANALYSIS FOR FIRE EMERGENCY  
RESPONSE USING GEOGRAPHICAL INFORMATION  
SYSTEM (GIS): A CASE OF ADDIS ABABA, ETHIOPIA**



Dejene Yebasa Baisa

A Thesis Submitted to the department of Geomatics Engineering.

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Master of Science  
Degree in Geoinformatics

Office of Graduate Studies

Adama Science and Technology University

July, 2024

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# APPROVAL SHEET

I, the advisors of the thesis entitled “Road Network Analysis for Fire Emergency Response Using Geographical Information System (GIS): A Case of Addis Ababa, Ethiopia” and developed by Dejene Yebasa Baisa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Getachew Brhanemeskel (PhD) \_\_\_\_\_  
Major Advisor Signature Date

We, the undersigned, members of the board of Examiners of the thesis by Dejene Yebasa Baisa have read and evaluated the thesis entitled “Road Network Analysis for Fire Emergency Response Using Geographical Information System (GIS): A Case of Addis Ababa, Ethiopia” and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geoinformatics Engineering.

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External Examiner (PhD) Signature Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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## DECLARATION

I hereby declare that this Master Thesis entitled “Road Network Analysis for Fire Emergency Response Using Geographical Information System (GIS): A Case of Addis Ababa, Ethiopia” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of material that are used for this thesis have been duly acknowledged through citation.

Name: Dejene Yebasa Baisa

Signature: \_\_\_\_\_ Date \_\_\_\_\_

## RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Road Network Analysis for Fire Emergency Response Using Geographical Information System (GIS): A Case of Addis Ababa, Ethiopia” prepared under my guidance by Dejene Yebasa Baisa submitted in partial fulfillment of the requirements for the degree of Masters of Science in Geoinformatics Engineering. Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Major Advisor

Name: Getachew Brhanemeskel (Ph.D) Signature: \_\_\_\_\_ Date: \_\_\_\_\_

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## LIST OF ACRONYMS AND ABBREVIATIONS

AACRA	Addis Ababa City Roads Authority
AAFDRC	Addis Ababa Fire-and-Disaster-Risk-commission
GIS	Geographical Information System
QGIS	Quantum Geographic Information System
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
SSGI	Space Science and Geospatial Institute
CTIF	International Association of Fire and Rescue Services
LULC	Land use land cover
DEM	Digital elevation model
ER	Emergency response
GCR	Greater Cairo Region
CSS	Central Statistical Service
OSM	Open street map
AM	Anti meridian
PM	Post meridian
GPS	Global positioning System
ESRI	Environmental Systems Research Institute
AHP	Analytic hierarchy process
AA	Addis Ababa

## ABSTRACT

*Fire disasters are a global issue, causing numerous fatalities annually, particularly in low- and middle-income countries. Addis Ababa city is frequently facing fire problems, which result in the loss of lives and valuable properties in the city. The study aims to analyze the road network for fire emergency response using a geographical information system (GIS) in Addis Ababa, Ethiopia. The study combines geospatial and quantitative data types using a geospatial technique. The Network Analyst tool provided by the ArcGIS software was used for selecting the optimal route and closest health facilities, and the Access Mod tool was used to assess the spatial accessibility of fire stations. The findings of the present research indicate that the route from the fire station to the fire incident location, covering 4.538 km, takes 13.9 minutes while considering traffic information and 5.49 minutes when traffic information is ignored. The Kebena Health Center is the closest facility, taking 32.62 minutes. Fire stations are concentrated in central and northwestern areas, serving 45.18% of the city in an 8-minute response time. However, coverage varies across different sub-cities. Sub-cities like Arada, Kirkos, and Addis Ketema have excellent coverage, with over 98% of their populations having access to a fire station within the specified time frame. Yeka, Lemi Kura, and Bole face challenges in coverage, with Lemi Kura having no coverage within the 8-minute travel time. Sub-cities like Akaki Kality, Gulele, Kolfe Keranyo, and NifasSilk Lafto have moderate to good coverage, indicating room for improvement. Enhancing spatial accessibility can lead to more efficient emergency responses, minimize property loss, and reduce injuries and deaths. The current study confirms that GIS is more efficient for road network analysis in fire emergency response, highlighting the growing importance of geospatial technologies in solving global problems and fulfilling human needs, resulting in a safer environment. Lastly, the study recommends that the Addis Ababa Fire and Disaster Risk Management Commission should use GIS for emergence response, assessing accessibility, and improving programs. And future researchers should consider real-time traffic data, junctions, and U-turns in identifying the optimal path for aiding fire emergency services.*

**Keywords:** *Road Network Analysis, Fire Emergency Response, Optimal route, closest facilities accessibility:*

# CHAPTER I: INTRODUCTION

## 1.1. Background of the Study

In today's world, disasters like earthquakes, landslides, floods, and fires are all too common occurrences (Zainal et al., 2022). Among these, fires pose a significant threat to both urban and non-urban areas, with urban fire incidents being particularly challenging (Forkuo & Quaye-Ballard, 2013). In urban areas, fire disasters are a common occurrence, particularly in densely populated or commercially active zones (Ramli et al., 2019).

Urban fires in developing countries, particularly in sub-Saharan Africa, pose a significant threat due to the lack of proper infrastructure, limited resources, and inadequate firefighting capabilities. The magnitude of these fires is often exacerbated by overcrowded informal settlements and poor urban planning. For example, urban fire incidents are a tireless and expensive issue in Ghana. In 2006, there were a total of 1986 fires, and in just the first quarter of 2013, Ghana experienced 2201 fire incidents, causing an estimated US \$8 million in property damage. Marketplaces have been the most common sites of these fire incidents. For instance, a fire in April 2014 at the Accra Kokomba market resulted in the destruction of over 5000 shops, leaving more than 700 people without homes. In Kumasi, known as the largest open-air market in West Africa, around 300 shops were destroyed by a fire in February 2014, resulting in over 500 traders losing their livelihoods (Oppong et al. 2017).

Similarly, Nairobi's markets, particularly Gikomba, have been plagued by fire disasters over the years. These fires have resulted in significant losses, including millions of shillings in goods, fixed investments, and even life. The most recent fire occurred in September 2010, with an afternoon fire raging for three hours. In March 2012, hundreds of traders lost their fortunes following a night fire. Another fire in 2014 ravaged a significant portion of the market, resulting in the destruction of property and goods of unknown value. In 2015, goods worth millions of shillings were destroyed when fire burned down stalls at the market. In 2017, firefighters took hours to put out a massive fire at the open-air market. The worst fire in Nairobi occurred in the Sinai slum fire of March 2012. (Munene, 2019).

Every year, over 180,000 people around the world die because of fires or burns. Over 95% happen in low- and middle-income countries. In poorer countries, there has been a three-fold increase in fires in city areas (World Bank 2021). According to data gathered by the International Association of Fire and Rescue Services (CTIF, 2023), the world experiences a stunning number of fires each year, estimated to be between 2.5 and 4.5 million. These

fires, which can range from minor incidents to major disasters, have a significant impact on human life and property. The casualty count from these fires is also alarming, with recorded fire-related fatalities ranging from 21 to 62 thousand annually.

Urban fire is a significant challenge in Ethiopia, particularly in its capital, Addis Ababa. This city, with a population of 3.5 million, is facing this issue due to its rapid and uncontrolled urban expansion (World Bank, 2016). So, emergency response services are vital, particularly during fire emergencies, to protect the nation from losing important resources (Forkuo and Quaye-Ballard, 2013). In a fire emergency, choosing the most appropriate path to an incident location is crucial for a timely response. (Phyo & Sein, 2015).

At present, Geographic Information System (GIS) technology has recently emerged as one of the most popular research tools globally and is rapidly growing as a leading-edge technology for monitoring. It has been demonstrated to be effective and efficient in addressing real-world issues, such as responding to and managing emergency situations (Ahmed & Hefny, 2017). It has played a crucial role in organizing the locations of fire stations, fire hydrants, and various structures (Forkuo & Quaye-Ballard, 2013). Additionally, this technology assists in assessing the spatial accessibility of fire stations and in examining the area coverage for each fire incident (Kedjanyi et al., 2021). The concept of accessibility generally covers two categories: (a) spatial accessibility (e.g., geographic location and distance) and (b) non-spatial accessibility (e.g., income, social class, gender, and age). One of the crucial factors in determining the optimal location of fire stations is the impedance cut-off point. The impedance cut-off is normally used as a measure of spatial accessibility to public services (Shahparvari, 2020). Access Mod is a tool developed by WHO and Geneva University that uses the power of GIS to analyze accessibility. It considers various factors like distance, transportation, and terrain to provide an accurate accessibility analysis. (Acesmode5 user manual, 2019)

Therefore, this study tries to employ GIS to determine the most efficient routes for fire emergency services, find the health facilities closest to a fire incident, and assess the spatial accessibility of fire stations using the Access Mod tool. Through these efforts, the outputs of the current study boost the efficiency and effectiveness of fire emergency services in Addis Ababa City.

## **1.2. Statement of the Problem**

The strong power of fires causes a lot of harm to buildings, makes the local economy unstable, and is a big danger to people. Currently, Addis Ababa city is facing fire problems frequently, resulting in the loss of lives and valuable properties in the city. Urban fires disproportionately affect low-income neighborhoods. These vulnerable residents often reside in densely populated areas with inadequate infrastructure, limited access to emergency services, and substandard housing (Twigg, 2017). The data accessed from the Addis Ababa Commission of Fire and Disaster Risk Management reveals that the magnitude of damage caused by fire is still high. For instance, in the last six months, 208 accidents were caused. Out of the total accidents, 150 of these accidents were caused by fire, while 89 were attributed to other causes. This resulted in the destruction of property worth over 475 million birr and 31 individual deaths. This data underscores the critical importance of effective fire prevention and response strategies.

When a fire breaks out, it's crucial for fire response vehicles to get to the scene as quickly as possible. To ensure a swift response, it's necessary to accurately pinpoint the location of the incident and identify the most efficient route (Phyo & Sein, 2015). Various methods have been applied to assess the accessibility of existing stations and measure the distance between emergency service providers and demand locations. In this regard, the most frequently used methods are Euclidean and actual road network distance (Shahparvari, 2020). Instead, using Access mod is best because it allows one to analyze the physical accessibility of using terrain information. It considers various factors like distance, transportation, and terrain to provide an accurate accessibility analysis.

Several studies were done concerning this title by different researchers, but in Ethiopia, there are limitations on this topic. For instance, in Alebele (2015) and Temesgen (2022), the authors studied urban fires in Addis Ababa and aimed to reduce losses by optimizing fire station locations and response times. Also, in Forkuo & Quayе-Ballard (2013), the authors provided valuable information about the urban fire problem in Ghana and the potential of GIS technology to enhance fire emergency response services. in Forkuo & Quayе-Ballard (2013), the authors provided valuable information about the urban fire problem in Ghana and the potential of GIS technology to enhance fire emergency response services. However, they didn't consider road traffic conditions, which have a great impact on getting realistic results.

Thus, to fill the existing literature gap, the study aims to resolve these issues by modifying the methodology and considering factors such as road traffic condition, and type to find routes for fire emergency services, find the health facilities closest to a fire incident, and consider various factors like distance, transportation, and terrain to provide accurate accessibility analysis.

### **1.3. Objectives**

#### **1.3.1. General Objectives**

- To analyze the road network for fire emergency response using a geographical information system (GIS) in the case of Addis Ababa, Ethiopia.

#### **1.3.2. Specific Objectives**

- To assess the spatial accessibility of fire stations using the Access Mod tool.
- To identify the optimal path for aiding fire emergency services.
- To locate the nearest health facilities to the site of a fire incident.

### **1.4. Research questions**

1. How can we assess the spatial accessibility of fire stations using the Access Mod tool?
2. What is the optimal path for aiding fire emergency services?
3. Where is the nearest health facilities located in relation to fire incident site?

### **1.5. Significance of the study**

The importance of analyzing the road network for fire emergency response will help to minimize the loss of life and valuable properties caused by fire. The results of this study will be expected to enhance the speed and effectiveness of fire emergency responses in Addis Ababa City. The insights gained will be able to be utilized by the city to refine its strategies; to make evidence-based decision making for allocating resource and strive to improve accessibility. Furthermore, this study will contribute to the existing body of knowledge on fire emergency response and road network analysis. It will also lay the groundwork for future research in this field, potentially inspiring similar analyses in other cities or regions.

## **1.6. Scope of the study**

The study is geographically confined to Addis Ababa City; it covers an area of 432.81 square kilometers. Methodologically, it utilized Network Analyst and AccessMod5 as the main tools for road network analysis, considering elements like the locations of fire stations. Temporally, the study was carried out at a timeframe that reflected the condition of the city's road network in 2023. Data reports from fire incidents in 2022 were also utilized for additional analysis.

## **1.7. Limitation of the Study**

The historical traffic data collected by the Addis Ababa Traffic Management Agency assumes that traffic flow during holidays is similar to traffic on other days. Additionally, the health facilities obtained from the Ministry of Health were exclusively government-owned; no private health facilities were included. These factors might have an impact on the quality of the current findings if route selection is held on holy days and private health facilities are considered.

## **1.8. Organization of the Thesis**

This thesis is structured as follows: Chapter One introduces the study, covering background information, problem statements, objectives, research questions, study significance, limitations, and scope. Chapter Two reviews existing literature, including theoretical and empirical frameworks, along with relevant previous studies. Chapter Three explores materials and methods, providing details about the study area, materials used, data processing, analysis methods, and technical approach. Chapter Four presents findings from data analysis, along with interpretation and discussion. Finally, Chapter Five concludes the study and offers recommendations for future

## **CHAPTER II: LITERATURE REVIEW**

This chapter introduces the relevant literature and studies that have been extensively and thoroughly researched by the investigators. It also outlines the definition of terms and concept, theoretical framework, empirical, and conceptual framework.

### **2.1. Definition of Terms and Concept**

#### **2.1.1. Urban Fire**

One of the most common issues in every country is urban fire. Fire has the potential to seriously harm both people and property. The majority of fire incidents were caused by carelessness, although there were also instances of arson, electric short circuits, and forest fires (Phyo & Sein, 2015). Inappropriate use of power is the main contributor to fire incidents. A lot of people are unaware of safe and proper ways to use energy. Since short circuits can occur at any time, it is crucial to do routine inspections in order to guard against them. Another major factor contributing to fire incidents is gas leaks, which can be directly linked to user negligence or human error. Misuse of combustible substances might potentially result in fire incidents (Global Enterprise Disaster Restoration, 2024).

In densely populated metropolitan areas, fires can quickly spread to nearby buildings. Especially in the event of a big earthquake, where multiple flames occur at the same time, the risk of fire spreading can overwhelm firefighting efforts and cause significant damage. Urban fires can include thousands of buildings at once. Fires have historically caused significant damage in cities, particularly in the United States and Japan.

Every year, fires cause over 180,000 deaths worldwide, mostly in low- and middle-income countries where urbanization is rapid. In these countries, fire incidents in cities have increased by 300%. Poor planning, infrastructure, and construction practices increase fire risks. To reduce these risks, we need better fire suppression, education, and training. We also need good laws, building and fire regulations, and the ability to review building fire safety plans and inspect construction. But formal rules alone can't solve the problem. About 25% of the world's urban populations live in informal settlements, which are often not covered by formal rules and are at high risk due to factors like high population density, overcrowding, flammable building materials, and a lack of water infrastructure. Fires not only cause deaths and injuries but also displace people. For example, fires in Nairobi's informal settlements displaced about 25,000 people in early 2011, and a fire in a refugee camp in Greece left

about 12,000 people homeless in September 2020. Some of the well-known urban fires are listed below: The Chicago Fire of 1871 lasted for three days, during which it destroyed more than 17,000 buildings and resulted in the deaths of 300 people. The San Francisco Earthquake Fire in 1906 consumed an area of 1,200,000 square meters and caused 700 deaths. The Kanto Earthquake Fire in 1926 destroyed nearly 70% of the city's buildings, covering an area of 38,000,000 square meters, and resulted in over 100,000 deaths, mostly due to the fire. The Hakodate Fire in 1934 spread at a rapid rate of 1000 meters per hour due to the spotting of numerous firebrands, destroying 23,000 buildings and causing 2,100 deaths. Despite significant efforts by firefighters, the Sakata Fire in 1976 destroyed 1,700 buildings. The Oakland Hills Fire in 1991, which occurred at the urban interface, destroyed more than 2,300 buildings. Finally, the Hanshin-Awaji Earthquake Fire in 1995 involved fires in multiple locations, resulting in the destruction of 7,000 buildings and 500 deaths (Himoto & Tanaka, 2008). With the swift urbanization of the world, the concentration of buildings and population in urban areas often leads to more frequent fire incidents. This increases the demand for fire rescue services in cities. For example, in 2021, China experienced 748,000 fire incidents, with over 65% of these incidents occurring in urban areas (Chen et al., 2023).

In a similar way, Africa faces urban fire frequently. For instance, urban fire incidents are a tireless and expensive issue in Ghana. In 2006, there were a total of 1986 fires, and in just the first quarter of 2013, Ghana experienced 2201 fire incidents, causing an estimated property damage of US \$8 million. Marketplaces have been the most common sites of these fire incidents. For instance, a fire in April 2014 at the Accra Kokomba market resulted in the destruction of over 5000 shops, leaving more than 700 people without homes. In Kumasi, known as the largest open-air market in West Africa, around 300 shops were destroyed by a fire in February 2014, resulting in over 500 traders losing their livelihoods (Oppong et al. 2017).

Recently, in Ethiopia due to city expansion, there has been an increase in fire, vehicle traffic, and construction-related incidents. Many fire accidents have occurred in Ethiopian cities like as Addis Abeba, Gondar, Woliyta Soddo, Bahir Dar, Dire Dawa, and others, causing considerable property damage and human fatalities. Between 2000 and 2016, there were approximately 9,755 fires in Ethiopia, resulting in 853 deaths and more than 5,421 non-fatal casualties, as well as an economic loss of more than 615 million birrs due to property damage (Temesgen, 2022).

Addis Ababa has the most business centers, including Mercato. In addition, the presence of densely populated residential and commercial areas, as well as the daily growth of the population, makes fire occurrences more common. Fire events are a major issue in Addis Abeba, and they occur regularly as a result of population growth and the presence of dense building, causing the number of occurrences to increase year after year. In 2020 and 2021, there were 120 and 154 firehouse accidents, respectively (Temesgen, 2022).

Addis Ababa, the capital of Ethiopia, home to 3.5 million people, faces several problems as a result of its rapid and unplanned urban growth, urban fire being only one of them. With a population growth rate of 3.8% annually, Addis Ababa is the seventh fastest-growing metropolis in Africa. It is becoming more difficult for the city to provide its citizens with decent housing and urban services as more individuals relocate there in search of employment possibilities. Many have been forced to live in subpar housing as a result, and many have turned to dangerous electrical wiring and cooking methods, which have caused urban fires. Due to their proximity to rivers, many are also impacted by urban flooding, while others are impacted by insufficient road

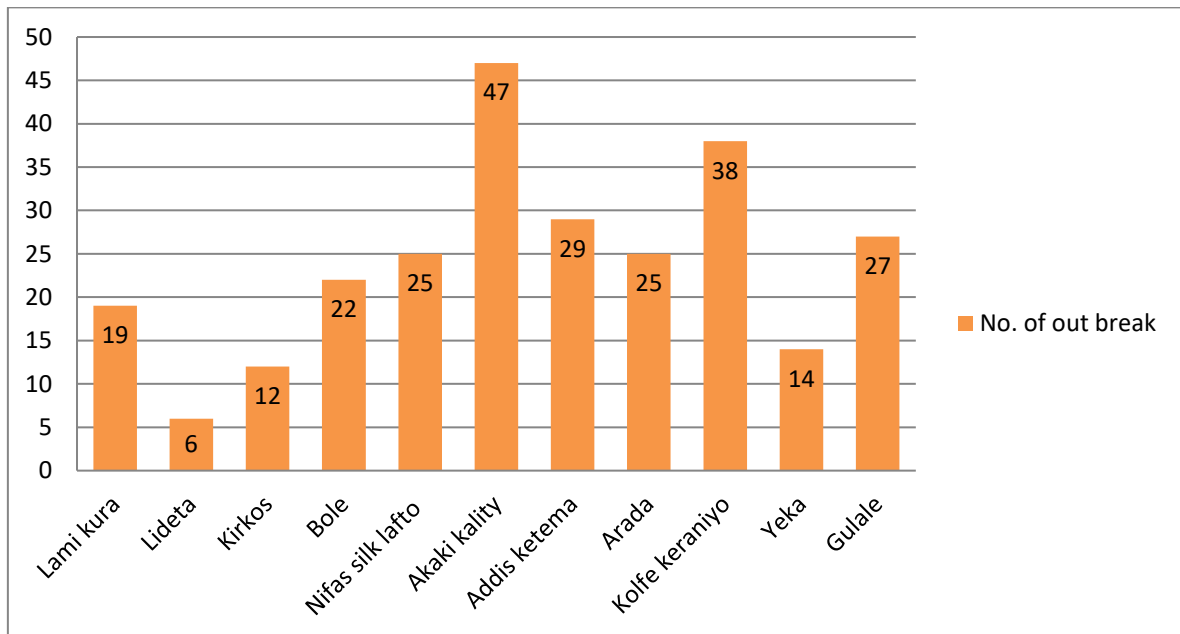


Figure 2.1: Fire out breaks in Addis Ababa in 2022 by sub city.

### 2.1.2. GIS and Emergency Response

Geographic Information System (GIS) technology has recently emerged as a leading research instrument globally and is rapidly expanding as a high-tech monitoring solution. It has demonstrated its effectiveness and efficiency in addressing real-world challenges,

including the management and resolution of emergencies. Geographic Information Systems (GIS) have the capability to rapidly consolidate diverse data, facilitating users to efficiently analyze and visualize information. Its application spans across various domains, including the management of transportation, emergency services, mapping of gas stations, and healthcare planning (Ahmed & Hefny, 2017). The Geographic Information System is a computerized system designed to support decision-making in planning and managing various aspects such as the environment, transportation, land use, natural resources, and urban facilities. It provides a method for capturing, analyzing, and visualizing phenomena that are geographically relevant. GIS is utilized to examine the characteristics present on the earth's surface and the events occurring on it. Moreover, it is highly effective in determining the routing of emergency vehicles and resolving the shortest-path routing problem for these vehicles. In an emergency situation, it is crucial to reach the location as quickly as possible, as even a slight delay can lead to unmanageable circumstances (Mar & Ne, 2019). Also, it can swiftly consolidate various data, allowing users to efficiently analyze and visualize the information. It has found applications in diverse areas such as managing transportation, emergency services, mapping gas stations, and planning healthcare services (Ahmed & Hefny, 2017).

The nature of emergency management is significantly influenced by economic and social situations. Emergency management consists of four phases: mitigation, readiness, response, and recovery. Mitigation is mostly about identifying and eliminating avoidable risks. This involves an assessment of potential dangers to personal or family health and property. One type of mitigation is to avoid purchasing property that is vulnerable to dangers, such as a flood plain, subsidence, or landslides. Unlike mitigation actions, which try to prevent disasters from occurring, personal preparation focuses on preparing equipment and procedures for use in the case of a disaster, i.e., planning. Preparedness measures can take numerous forms, such as the construction of shelters, the installation of warning devices, the creation of backup life-line services (e.g., power, water, sewage), and practiced evacuation strategies. The reaction phase comprises the deployment of emergency services in the disaster region. This involves the relocation of vital emergency services, such as firefighters and ambulance crews. They may be assisted by a variety of secondary emergency services, including professional rescue teams. The recovery phase begins following the immediate treatment of human lives damaged by the terrible incident. During reconstruction, it is recommended to evaluate the property's location or construction materials (Mali et al., 2013).

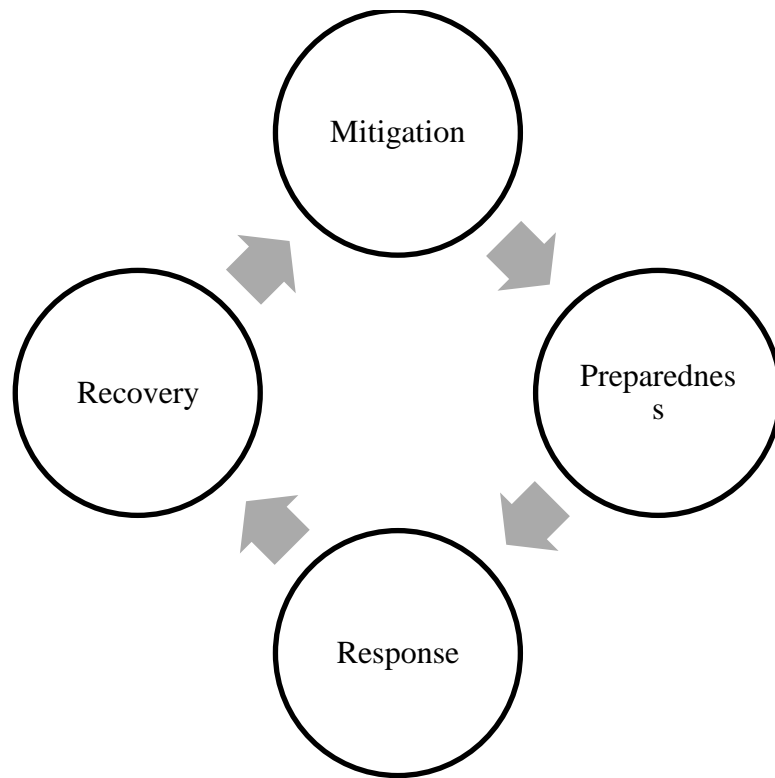


Figure 2.2: Emergency management phases

In each of these stages, Geographic Information Systems (GIS) are utilized. Specifically, in the context of firefighting, GIS plays a crucial role in both the planning stage and the response stage (Mar & Ne, 2019). GIS has been recognized as a crucial tool in optimizing emergency service delivery. It supports planning, preparedness, mitigation, response, and incident management. When a fire occurs, any delay by responding fire companies can make the difference between the rescue of occupants and serious injury or death. GIS technology brings additional power to fire personnel, whereby hazards are evaluated, service demands are analyzed, and resources are deployed. (ESRI, A2007)

Response time is the period of time that starts when the units leave for the emergency occurrence and concludes when they get there. While it is crucial that fire stations are appropriately situated to maximize coverage, they must also be carefully planned to decrease the time it takes to respond to a fire incident. Response time is critical in firefighting. Changes in land use and urbanization require a regular evaluation of the spatial distribution of fire stations and fire danger within the context of costs and benefits. GIS technologies are used to solve and support them. Fire response time standards vary per country (Temesgen, 2022).

Table 2.1: fire response times standard for different country

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 (Temesgen, 2022).

### 2.1.3. Road Network Analysis for fire Emergency Response

Road Network analysis is currently playing an important part in emergency responses to urban fire disasters. A routing system can do network analysis and help users navigate between source and destination points. Network analysis that enables users to move between source and destination points can be provided by a routing system. The device can facilitate the fastest possible arrival of firefighters in this situation. Certain impedance considerations on complex road networks would cause drivers to slow down on a certain road (Widyantoro & Santosa, 2021). Knowing about networks can help you understand how to analyze transportation networks. A network is just a bunch of lines, or edges, that meet at points, or nodes. A Geographic Information System (GIS) keeps track of these edges and nodes and their details. There are some networks, called spatio-temporal networks that change over time. These changing networks are really important for things like planning for traffic during emergencies and figuring out the best route to take.

GIS network analysis comes from math areas like graph theory and topology. Topology, which is about things like connectivity, coincidence, and adjacency, is a big part of graph theory and networks. A GIS network has an advantage over graph theory because it includes geographic features like shape or length. Length is really important when you need to figure out how long it will take to travel somewhere (Winn, 2014). The recent surge in population densities and economic growth has led to an increased accumulation of residential and commercial risks in urban areas. This often results in recurring emergencies and disasters, potentially resulting in the loss of lives and valuable properties. Emergency response (ER) refers to carrying out a series of actions quickly to minimize the damage to people and society after a natural or man-made disaster. (Feng & Cui, 2021)

The road network serves as a vital backbone for a community, facilitating the movement of people, goods, and services. The state of these networks directly influences everyday life and access to essential services (Rivera et al., 2022). The efficiency of a city's road network

plays a significant role in the effectiveness of fire emergency response (Winn, 2014). An enhanced GIS-based network analysis can focus on finding the best route between two locations on the road network and finding the nearest healthcare service providers to an incident location based on the travel time (Ahmed et al., 2018).

#### **2.1.4. Shortest path algorithms**

A shortest path algorithm finds the shortest path that has the least distance between a source node and a destination node. Dijkstra's shortest path algorithm and Euler's algorithm are widely used algorithms for finding the shortest path. Utilizing these algorithms in GIS software for addressing emergency situations may not be appropriate for actual road networks. This is because these algorithms primarily focus on the path length to determine the shortest route, neglecting other real-time traffic data (Ahmed & Hefny, 2017). The "shortest" path could refer to the route with the least distance, quickest time, or optimal conditions, depending on the cost type considered. Various factors can influence the response times of emergency services and vehicles, including the distance to be traveled, the time taken to travel, and traffic congestion due to fluctuating traffic patterns throughout the day. Traffic congestion, a significant issue in urban areas, can hinder emergency response by causing delays (Winn, M. T., 2014). Utilizing graph search, edges, and vertices, Dijkstra's algorithm is capable of identifying the shortest path between two vertices. Given a specific source vertex in the graph, the algorithm determines the path with the least cost, or the shortest path, between that vertex and all other vertices. Additionally, it can be employed to find the cost of the shortest paths from a single vertex to a specific destination vertex, by halting the algorithm once the shortest path to the target vertex has been established (Forkuo & Quaye-Ballard 2013).

#### **2.1.5. Optimal Path Identification:**

An optimal route in a network is the path with the lowest impedance, often referred to as the least-cost path. Impedance is a metric that quantifies the resistance or cost associated with traversing a path in a network or moving from one element to another within the network. This resistance can be quantified in terms of travel distance, time, and the product of travel speed and distance. A higher impedance value signifies greater resistance to movement, while a value of zero implies no resistance. Various impedance factors significantly influence the determination of travel time. These include the volume of traffic, the type of road, the width of the road, the number of junctions, and turns (Forkuo & Quaye-Ballard, 2013). Path-finding solutions are increasingly important in numerous GIS applications. In

critical scenarios, the analysis of the shortest path is beneficial as it computes the most efficient or quickest route. Depending on the type of cost, the shortest path is typically defined as the quickest or most efficient one. 12 (Mar & Ne, 2019).

In a transportation network, a shortest path algorithm can be used to solve routing problems by determining the route from a starting point to a destination that incurs the least travel cost or impedance. The “shortest” path could refer to the quickest, shortest in distance, or most optimal route, depending on the cost type. Various factors can influence the response times of emergency services and vehicles, including the distance to be traveled, the time taken to travel, and traffic congestion, which can vary depending on the time of day (Winn, 2014). In emergency situations, the most desirable route is the one that allows for the quickest arrival at the destination, which can aid in saving lives (Ahmed & Hefny, 2017).

#### **2.1.6. Importance of identifying Health Facilities Location during fire emergency**

The spatial distribution and accessibility of health facilities are crucial in emergency response, and GIS has been extensively applied in this area (McLafferty (2003).

#### **2.1.7. Fire stations Accessibility Assessment**

Assessing the accessibility of fire services is crucial for improving response times, reducing property damage, and saving lives. The two-step floating catchment area method and its variations have been commonly used for this purpose. However, the circular catchment areas these methods employ are not ideal for evaluating fire service accessibility. This is because a fire station typically handles fire incidents within its designated area of responsibility. Improving and optimizing the distribution of firefighting resources in areas with limited spatial accessibility can be beneficial for fire departments. This could potentially reduce the time it takes for emergency responses, thereby enhancing the efficiency of fire rescue operations. Spatial accessibility” is a term that describes how easily available and close public services are. On the other hand, “non-spatial accessibility” refers to the inclination of individuals to opt for these public services. Numerous techniques have been devised to measure spatial accessibility, including the distance to the closest facility, methods for determining regional availability, and the gravity model. Among these, the two-step floating catchment area method is one of the most commonly applied techniques (Mao et al., 2020).

Accessibility is a multifaceted term that can be described as the degree to which land-use and transport systems allow individuals or groups to access activities or destinations using one or more modes of transportation (Shahparvari, 2020). Improving the geographical reach

of the population to fire services is a crucial approach to enhance emergency response, decrease property damage, and lessen injuries and fatalities. This is particularly important considering its impact on the policy and strategic planning of fire services (Kiran, 2020).

Access mod allows one to analyze the physical accessibility of using terrain information. It considers various factors like distance, transportation, and terrain to provide an accurate accessibility analysis. Access Mod is an algorithm that uses least-cost pathways and the accumulative cost surface to define catchments (Ray and Ebener 2008).

#### **2.1.8. Network analyst**

Network Analyst is an ArcGIS extension tool that can be utilized to examine issues like vehicle routing, nearest facility, and service area. In a fire emergency situation, it is important to determine the best route from the service station to the fire incident and also conduct an analysis to find the nearest fire hydrant (Forkuo & Quaye-Ballard 2013). The ArcGIS Network Analyst extension facilitates the smooth transit of goods, efficient management and synchronization of vehicles, and smart analysis of transportation networks. It aids in making informed decisions by formulating strategic routing plans. By designing and executing daily route plans to address vehicle routing issues and conducting post-route spatial network analysis, you can save both time and money. It can be integrated with existing workflows and business systems to enhance organizational efficiency (ESRI, 2021).

#### **2.1.9. Traffic data**

There are many things that can change how fast emergency services and vehicles can respond. One thing is that there are changes in how much traffic there is at different times of the day. This is called traffic congestion. There can be many reasons for traffic congestion. Some, like traffic during busy times of the day, are easy to predict. Others, like bad weather or accidents, are harder to predict. Most of the time, traffic congestion happens because of busy traffic during peak hours (Winn, M. T. (2014)).

Traffic data shows how travel speeds on specific road segments vary over time. It is significant in network analysis because traffic impacts journey times, which influence results. If you plan a route from one site to another without considering traffic, your estimated travel and arrival times may be inaccurate. Furthermore, you may overlook routing options that save time by avoiding slower, busier highways. The ArcGIS Network Analyst extension allows you to store journey speeds in a network dataset using two alternative models: historical and live traffic. This allows you to display traffic on a map and do network

analysis based on current or average traffic speeds. The historical traffic model is based on the assumption that travel speeds follow a weekly trend. Thus, at 8:00 a.m. on Monday of one week, the travel speeds of a given road segment should be identical to those at 8:00 a.m. on Monday of the following week. Because the pattern lasts one week, the speeds are unlikely to be consistent across different days of the week. That is, congestion and travel speeds can vary dramatically for the same road stretch at the same time of day but on various days of the week. For example, travel speeds on Main Street around 8:30 a.m. on Sunday may be significantly higher than those on Monday. The live traffic model allows data providers to measure current speeds from a variety of sources, including GPS receivers in automobiles and speed sensors on roads. A network analyst employs geoprocessing technologies to connect to the data providers via the Internet, download the live trip speeds, and feed them into the network dataset for both visualization and network analysis (ESRI, 2021). A route with the shortest distance can take longer if there's heavy traffic. Traffic data, which provides information on varying travel speeds on specific road sections over time, plays a crucial role in network analysis. It influences travel times, which subsequently alters the outcomes. Without traffic data, the predicted travel and arrival times could be significantly off the mark. Furthermore, this data offers alternative routing options to bypass slower, more congested routes, potentially saving time (Mar & Ne, 2019).

The ArcGIS Network Analyst extension allows you to use historical traffic information to model the time-dependent speeds of traveling on roads. This way, your expected travel and arrival times are more reliable, and the time you actually spend driving is likely to be less than if traffic patterns were ignored. One option for storing historical traffic data is to create a series of costs for each edge. The costs would represent traffic speeds at different times of the day over the course of a week. For instance, a week could be partitioned into 168 discrete, one-hour intervals. This means that each edge would need 168 cost attributes to represent how traffic tends to change over a week's time. If the time span were shortened to 5-minute intervals to provide better temporal resolution, each edge would need 2,016 cost attributes. Storing all these unique values would require a lot of space, especially for large networks. Also, since many streets have the same costs during the day, there would be a lot of unnecessary duplication of data. For these reasons, this modeling option isn't viable for network analysts. In order to construct a network dataset that incorporates historical traffic information, a geodatabase requires a single-line feature class and two tables. The single line is the road network, and the two tables are the Streets-Profiles table and the daily profile.

Every street feature is assigned a unique identifier known as the object ID value. The Streets-Profiles Join Table links streets with their respective traffic profiles using this unique identifier. Every entry in the Daily Traffic Profiles table possesses a unique ID and multiple fields to store the free-flow scale factor at various times throughout the day. The day is divided into equal time segments, also known as time slices. These slices are of the same length, thereby dividing the entire 24-hour period into equal segments (ESRI 2021).

## **2.2 Theoretical Framework**

### **2.2.1 Graph Theory**

Graph theory provides a mathematical framework for analyzing road networks. It deals with nodes (representing intersections or endpoints) and edges (representing road segments connecting nodes). Graph theory has been used for various problems, including finding optimal routes (e.g., Dijkstra's algorithm), circuit board design, and network flows. In geography, it helps model spatial connectivity and landscape patterns (Yan & Yan 2019). A network's topological structure is represented by a graph, which consists of nodes (vertices) and edges (arcs), with each edge connecting two nodes. The number of edges that intersect at a vertex determines its valency. A path is a sequence of edges that share an end vertex. A graph is linked if a path can be found between any two of its vertices. A cycle is a path connecting the same vertices. A tree is a linked graph without any cycles. A spanning tree for a vertex set is a graph with edges that can connect any two vertices. Graphs may accurately depict road network topology, with vertices representing road junctions, intersections, dead-ends, and towns, and edges representing road segments connecting these sites. To improve the representation, consider assigning cost values to each edge to indicate road length or travel time. Graph theory can be used to generalize networks in two ways: quantitatively measuring topological or metric properties of arcs and nodes, or identifying and representing important topological information for effective generalization procedures (Thomson & Richardson 1995). Graph theory is widely utilized in operations research, discrete mathematics, combinatorial optimization, and network analysis. This theory was supportive for understanding route selection process and closest facility because Graph theory provides a powerful framework for analyzing road networks. It abstracts the network as a set of nodes (representing intersections or endpoints) connected by edges (representing roads or links).

### **2.2.2 Traffic-Flow Theory**

Traffic-flow theories attempt to accurately mathematically characterize the interactions between vehicles, drivers, and infrastructure. The infrastructure includes the highway system and all of its operating components, such as control devices, signage, and markings. These theories are essential components of all traffic models and analysis tools used in the planning and operation of roads and highways. The scientific study of traffic flow began in the 1930s with the application of probability theory to the description of road traffic, as well as pioneering studies conducted by Bruce D. Greenshields at the Yale Bureau of Highway Traffic on the study of volume-speed models and the investigation of traffic performance at intersections (Elefteriadou, L. (2014). This theory was supportive for understanding traffic modeling.

## **2.3. Empirical Framework**

Some empirical perspectives on previously worked literature are explored as follows:

### **2.3.1 Global Experience**

In (Forkuo & Quaye-Ballard, 2013), the authors offered insightful details about the urban fire issues in Ghana and how GIS technology could improve fire emergency response services. Their research aimed to create a GIS-based fire emergency response service capable of determining the best route to any fire incident. The optimal route was modeled considering factors like travel distance, time, road slope, and potential delays. This analysis was used for prompt responses to urban fire emergencies. They highlighted the system's ability to check the location and status of a fire water hydrant, including its functionality, pressure level, and connection to the water source. The fire information system they developed could be linked spatially to the building and cadastral parcel database, providing a more robust decision support system.

In Ahmed and Hefny (2017) the authors provided a detailed analysis of how Geographic Information System (GIS) technology can be used for emergency response in the Greater Cairo Region (GCR). They emphasized the significance of GIS in addressing real-world problems, especially in emergencies. They also introduced an innovative approach of using time as a parameter instead of distance to calculate the best route, which could greatly impact emergency response maps. Their result showed that the best route travel time is much better than the shortest route travel time by 22%.

Similarly, Ramli et al. (2019) conducted a study on the optimum route analysis of fire rescue according to fire station location, with a case study focusing on the residence area in Makassar's central business district. Their study aimed to provide information on the optimum route for fire rescue, considering travel time and distance to reach the location of the fire. The authors developed a simulation program for route analysis on QGIS using the road graph function to find the optimum route to the disaster location. The road graph plugin, a C++ plugin for QGIS, was used to calculate the shortest path between two points on any polyline layer and plot this path over the road network. The result of the research shows the optimum route of the fire station rescue to the residence area in the central business district in Makassar. While their study provided information on the optimum route for fire rescue in Makassar's central business district, there is room for further investigation into the scalability and generalizability of the proposed approach. Additionally, the study could explore the impact of varying traffic conditions on response times.

In (Mar & Ne, 2019), the author conducted a study on a GIS-based fire emergency response system specifically for Mandalay. They proposed an effective response system that could identify the best route from any fire incident to the nearest rescue places, such as fire emergency services, hospitals, and police stations. The authors applied GIS-based technology to find the best route, taking into account traffic data. They used both graph theory and network analysis tools in GIS for modeling and analyzing transportation networks. The system used Dijkstra's algorithm to compute the length of the shortest path from the source to each of the remaining points in the graph. However, further investigation is required to address any gaps and improve existing approaches

However, Previous studies by Forkuo and Quaye-Ballard (2013), Ahmed and Hefny (2017), Ramli et al. (2019), and Mar and Ne (2019) all share a common limitation: they assessed accessibility based solely on distance, neglecting crucial traffic conditions. These studies missed an opportunity to account for dynamic travel time variations, which significantly impact real-world accessibility.

### **2.3.3 Local experience**

In Alebele (2015), the author studied urban fires in Addis Ababa and aimed to reduce losses by optimizing fire station locations and response times. He proposed a GIS-based system to locate accidents and select optimal routes. He identified unmet demand for new fire stations

and used the AHP method to analyze various criteria for site selection. His methodology improved service coverage from 46.5% to 87.5% by adding three new fire stations. Finally, he developed a GIS-based response system database for use in emergency situations.

Similarly, in Temesgen (2022), the author conducted a study on urban fires in Addis Ababa, Ethiopia, using GIS-based network analysis. The study aimed to optimize the location of fire stations and emergency responses. The author developed a multi-criteria analysis model to select suitable sites for inaccessible places. The study suggested 10 new fire stations, increasing the service coverage of the study area to 87.44%.

Table 2.2 Summary of the Empirical review

No	Author	Study area	Data used	Methods used
1	(Forkuo & Quaye-Ballard, 2013)	Ghana	Road network Traffic Ancillary data	Network analysis
2	(Ahmed & Hefny, 2017)	Greater Cairo Region (GCR).	Road network Base map Healthcare service Traffic data	Network analysis
3	(Ramli et al, 2019)	Makassar's central business district	Road network Fire stations Base map	Network analysis
4	(Mar & Ne, 2019)	Mandalay	Road Base map Traffic	Network analysis
5	(Alebele, 2015)	Addis Ababa	Road network Land use Population Aerial photo Fire station	Network analysis

6	(Temesgen, 2022)	Addis Ababa	Road network Administration Boundary Population Land Use Existing Fire Stations Fire Incident Demand points DEM	Network analysis multi-criteria analysis model
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### 2.3.1 Lesson learnt from the literature review

Swift response in fire emergency situation minimizes loss of properties and saves life. GIS technology plays vital role in fire emergency response route selection and accessibility analysis. Previously, research both at the global and national levels used geospatial techniques to identify the optimal route from the fire station to the fire incident site. The local researcher didn't consider road traffic conditions, which have a great impact on getting realistic results. And also, to assess the accessibility of existing stations, various methods have been applied for measuring the distance between the emergency service providers and demand locations. In this regard, the most frequently used methods are Euclidean and actual road network distance (Shahparvari, 2020). Instead, using Access mod 5 is preferable because it allows one to analyze the physical accessibility of using terrain information. It considers various factors like distance, transportation, and terrain to provide an accurate accessibility analysis.

Compared to the past literature, this study makes an additional contribution by promoting a new GIS tool called Access Mode, which considers various factors like distance, transportation, and terrain to provide an accurate accessibility analysis. Additionally, this study considers factors such as road traffic condition and type to find routes for fire emergency services and the health facilities closest to a fire incident.

### 2.4. Conceptual Framework

This portion of the present research is built upon both theoretical and empirical frameworks. Literature from both global and local levels that has been previously studied serves as the basis for identifying tools, data sources, and methodologies in this study.

Based on the literature review, appropriate data used to perform road network analysis for fire emergency response are: road network, fire stations, historical fire incidents, administrative boundary, population distribution grid, historical traffic, building footprint, digital elevation model, land use land cover, health facilities, and barrier (river). After identifying appropriate data, the next task was to identify the appropriate data source where the data was acquired with high accuracy and reliability. Space Science and Geospatial Institute, Addis Ababa Fire and Disaster Risk Management, and the Central Statistical Service were appropriate organizations for data sources. Networks Analyst and Aces Mod were appropriate tools to perform analysis. Finally, analysis was performed to get the final output of the study. The overall conceptualized literature review for the current study is summarized below in Figure 2.2.

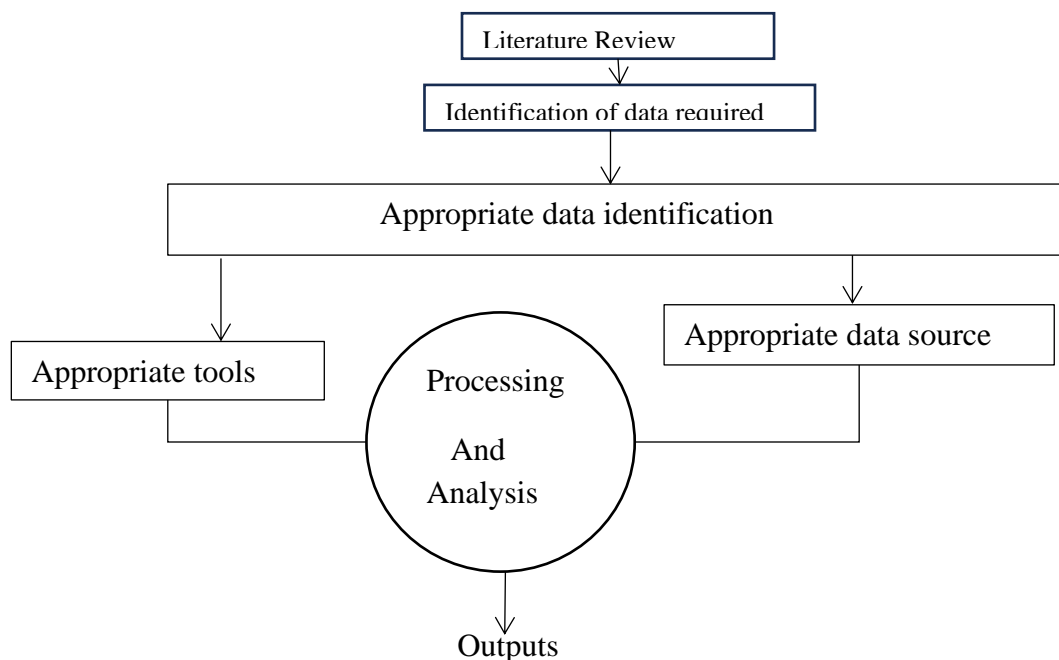


Figure 2.2 conceptual framework

## CHAPTER III: MATERIALS AND METHODS

This part of the study illustrates the data utilized to achieve the research goals and the methods used in the analysis. It also outlines the procedure undertaken to produce the findings presented in the results section.

### 3.1. Description of the Study Area

#### 3.1.1 Location

This research was conducted in Addis Ababa, the capital and largest city of Ethiopia, which is 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) (Temesgen 2022).

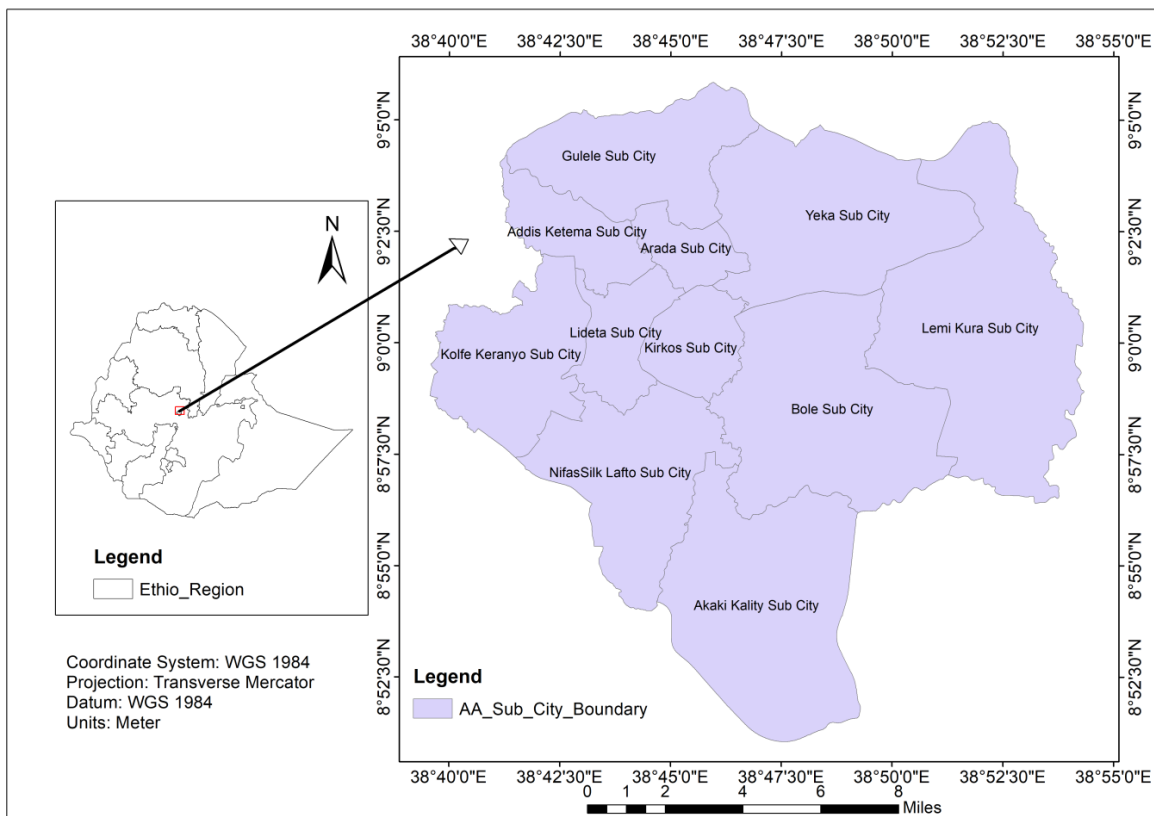


Figure 3.1 Location map of study Area

#### 3.1.2. Population

According to the Central Statistical Service of Ethiopia's 2007 population census conducted by the Ethiopian national statistics authority, Addis Ababa has a total population of 2,739,551. The total projected population of Addis Ababa in 2023 is 3,945,000. The projected population of Addis Ababa is distributed among its sub-cities as follows: The sub-city of Akaki Kaliti has a population of 260,967. Nefas Silk-Lafto, another sub-city,

population of 455,500. Kolfe Keraniyo, the sub-city with the highest population, houses 617,526 residents. Gulele and Lideta sub-cities have populations of 385,332 and 290,466 respectively. Kirkos and Arada sub-cities have populations of 318,634 and 304,610, respectively. Addis Ketema and Yeka sub-cities have populations of 367,651 and 499,301, respectively. Lastly, Bole, another sub-city, has a population of 445,013.

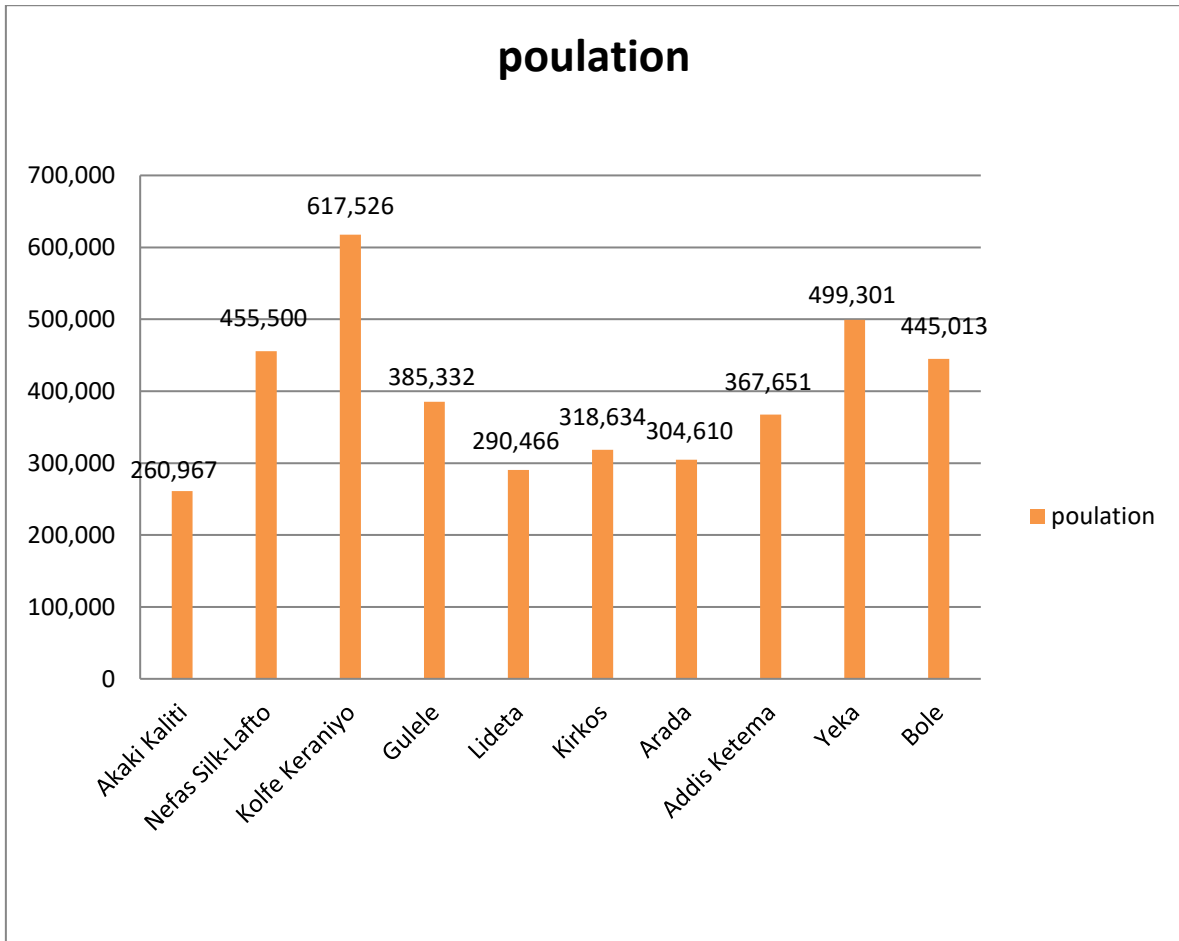


Figure3.2. 2023 projected Population of study area in sub city.

### 3.1.3. Topography

Its geography varies from rolling to hilly, with a rather steep gradient and several rivers and stream valleys. The city is at the foot of Mount Entoto, at an elevation of 2,355 meters above sea level, and encompasses around 540 square kilometers. It is located in the plateau mountain ranges at a height of 2000 to 5000 meters above mean sea level (Alebele ,2015).

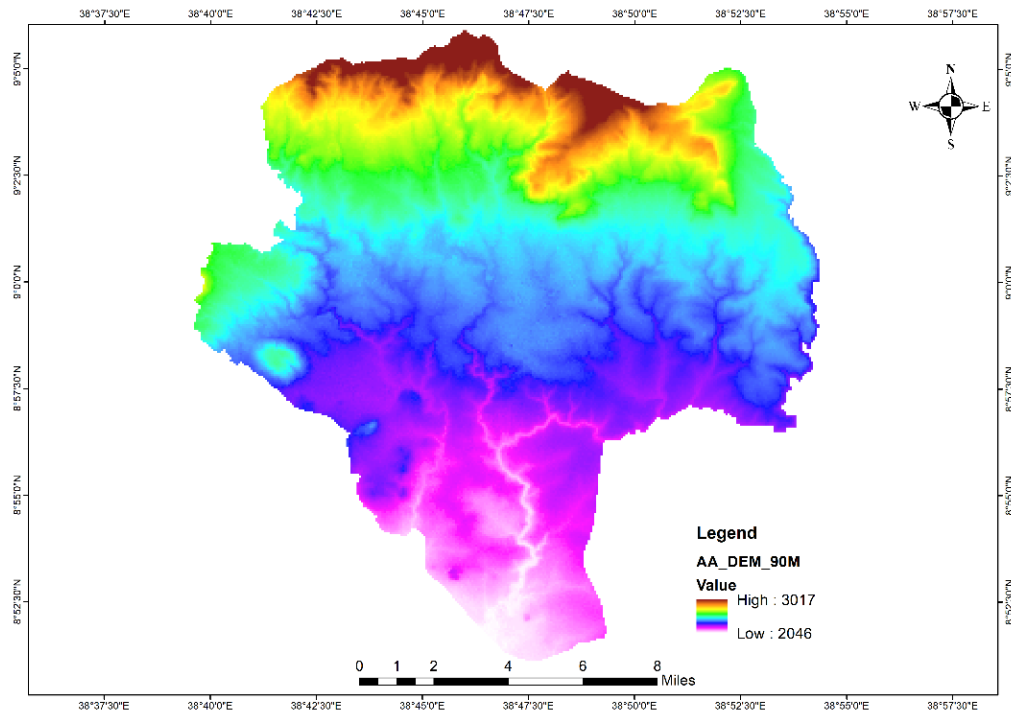


Figure 3.3 Topography map of study area

### 3.2.1. Road Network

A road network is a set of interconnected lines representing the structure of a city road. The road network in Addis Ababa is diverse and extensive. The total length of the roads in the city is approximately 6131.101 kilometers. The local roads form the backbone of the city’s road network, spanning a total length of 4927.326 kilometers. This accounts for a significant 80.36% of the total road length. These roads are crucial for providing access to residences and businesses in the city. The principal arterial roads, which are essential for high-capacity urban traffic flow, extend up to 733.459 kilometers. This constitutes approximately 11.97% of the city’s total roadways. The collector roads, integral for traffic distribution between local and arterial roads, are relatively shorter in length at 238.086 kilometers, making up about 3.88% of the roads.

Table 3.1 Speed and length of Addis Ababa Road network by type

No	Road Type	Speed (Km/hr.)	length (Km)	Percentage
1	Collector	30	238.086	38.83
2	Local	15	4927.33	80.36
3	Principal Arterial	50	733.459	11.96
4	Sub Arterial	40	232.229	37.87

Source Ethiopia urban street design manual 2023

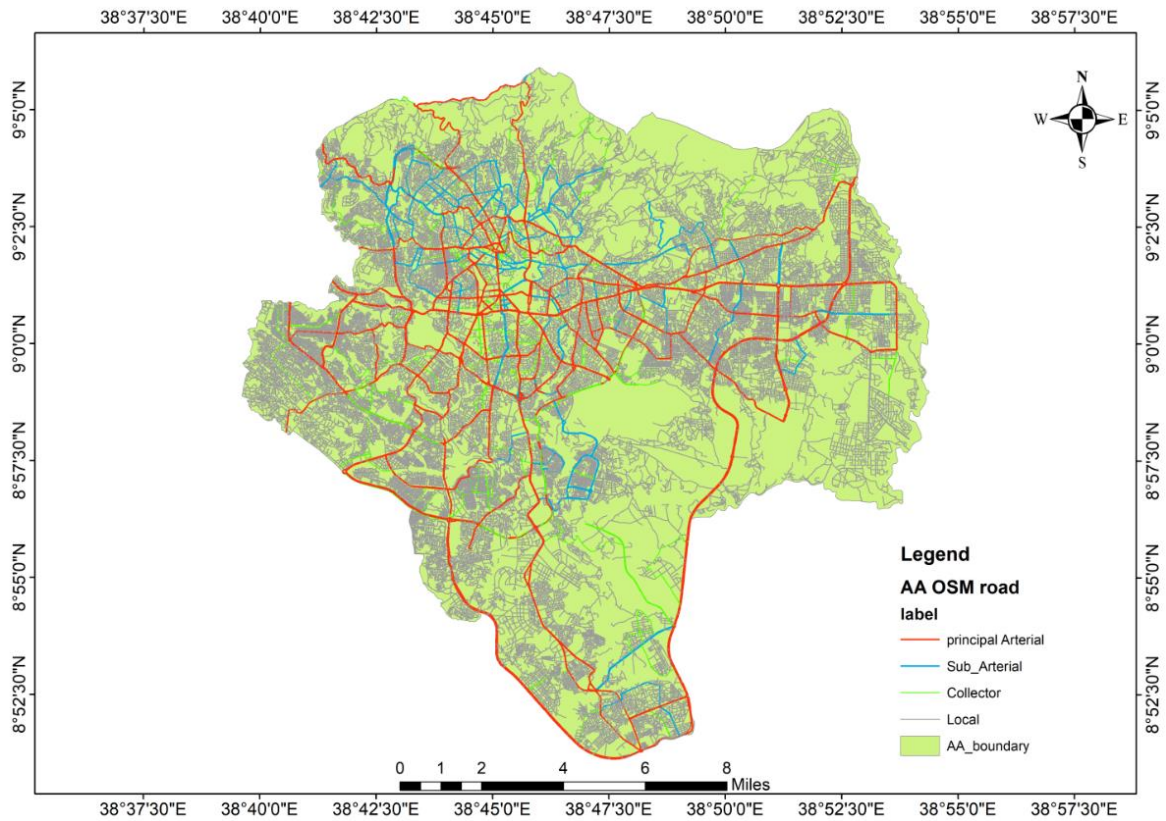


Figure 3.4: Road network map of the study area

### 3.2.6. Land use land cover

Land cover indicates the physical land type such as forest or open water whereas land use documents how people are using the land. Or it refers to the physical and biological cover on the Earth's surface, including natural and human-made features. It categorizes the different types of surfaces based on their physical and ecological characteristics. The city's land cover encompasses sparse forest, settlement, dense forest land, moderate forest land, grass land, and crop land. Land use land cover was used as input for performing accessibility analysis.

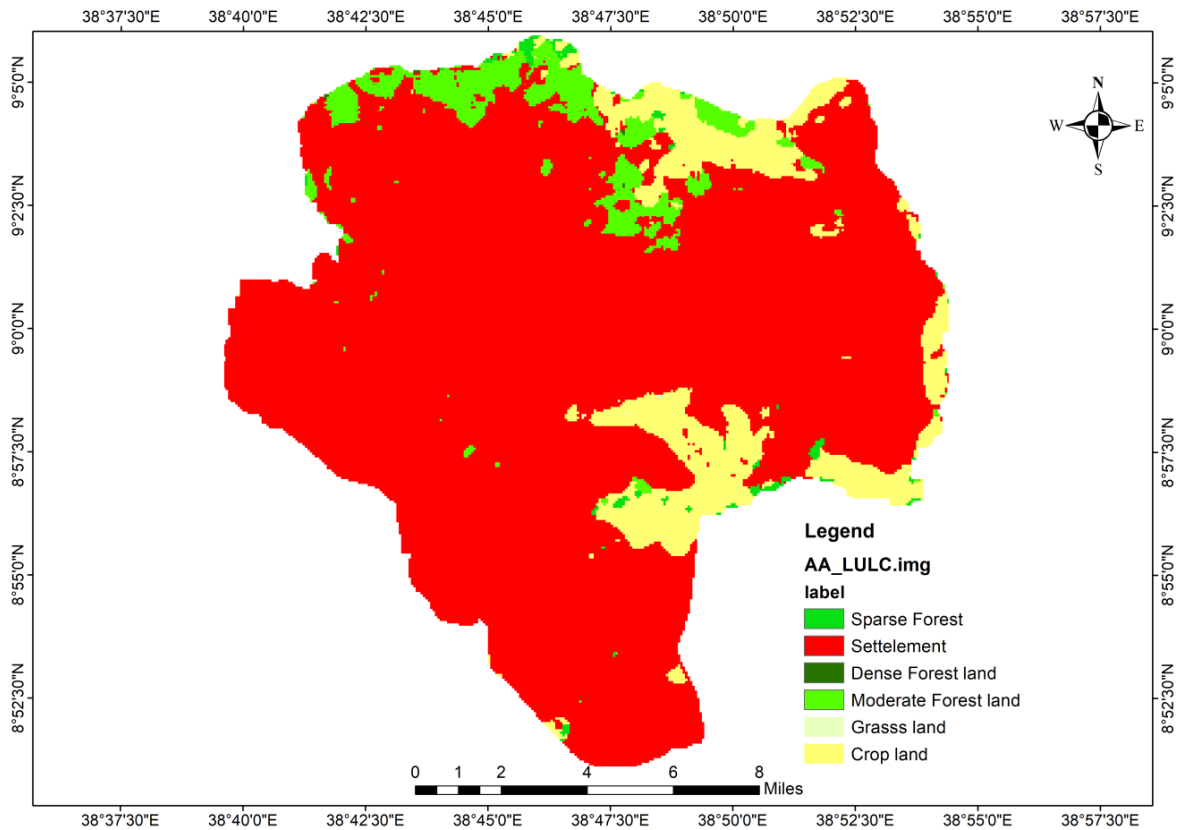


Figure 3.5: Land use land cover map

### 3.2. Data Sources and type

The data used in this study includes road networks, fire stations, health facilities, historical fire incidents, historical traffic, land use land cover, digital elevation models, building footprints and administrative boundaries, and the Population Distribution Grid. Road networks are interconnected lines that represent the structure of a city road. It was a major factor both for routing and accessibility. It was downloaded from OSM and classified as Collector, Local, Principal Arterial, and Sub Arterial based on speed limits displayed in Table 3.1. Fire stations are one of the most important and vital land uses in metropolitan areas, ensuring the lives and safety of citizens. As a result, the location and number of stations are critical to ensuring effective coverage of the area to be covered (Temesgen, 2022). Fire stations were extracted from Google Maps and used as input for route selection and accessibility assessment. When a fire breaks out, the probability of injury is high. Knowing the location of health facilities plays an important role during fire crises. The healthcare facility data was downloaded from the master facility registration interface developed by the Ministry of Health. Used as input for finding closet facilities. Traffic data provides insights into how the speed of travel varies over time on specific road segments. This information is crucial in network analysis as it directly influences travel durations,

thereby affecting outcomes. If traffic conditions are not considered while planning a route from one place to another, the anticipated travel and arrival times could be significantly off the mark (Ahmed & Hefny, 2017). The data was collected by the Addis Ababa traffic management agency and modeled to get realistic route information. Land use land cover data was obtained from the Space Science and Geospatial Institute. Land use land cover was used as inputs for performing accessibility analysis. It is useful to identify locations with distinct land uses (e.g., settlement, forest) and their proximity to transportation networks, services, and facilities.

DEM stands for Digital Elevation Model. It is a representation of the topography or terrain of a surface in digital form. It's downloaded from Global Mapper. And used for accessibility analysis. The building footprint was downloaded from an open street map and used as a base map. The administrative boundary was obtained from CSS and used for clipping and zonal statistics analysis. The Population Distribution Grid is a raster-format layer that contains the distribution of the target population for the study area. Population Distribution Grid was downloaded from World Population Distribution Grid 2020.

Data were gathered from several sources, including online sources and institutions. They are summarized below in Table 3.3.

Table 3.2 summary of data source and type

No.	Data Sets	Data format	Source	Year
1	Road Network data	Vector (.shp)	OSM( <a href="https://extract.bbbike.org/">https://extract.bbbike.org/</a> )	2023
2	Fire stations	Vector (.shp)	Google map <a href="https://www.addismap.com/fire-stations#12/9.0129/38.7550">https://www.addismap.com/fire-stations#12/9.0129/38.7550</a>	
3	Health facilities data	Vector (.shp)	MOH	
4	Historical fire incidents data	Vector (.shp)	Addis Ababa Fire and Disaster Risk Management Commission	2022
5	Historical traffic data	Table(.xls)	Addis Ababa traffic management agency	2018_2020

6	Building footprint	Vector (.shp)	OSM( <a href="https://extract.bbbike.org/">https://extract.bbbike.org/</a> )	
7	Digital Elevation Model	Raster	Global mapper	
8	Population Distribution Grid	Raster	World Population Distribution Grid 2020.	
9	Administrative boundary	Vector (.shp)	Central Statics Service	
10	Land use land cover	Raster	Space science and geospatial institute	
11	Barriers(Rivers)	Vector (.shp)	Space science and geospatial institute	

### 3.3. Software's and Hardware's

A variety of software tools were utilized for different purposes. ArcGIS 10.8 was employed for data processing, analysis, and map preparation. It played a crucial role in interpreting and visualizing geospatial data. Google Earth was used for updating road networks, providing real-time and accurate information about road networks, and geocoding fire incidents. Microsoft Word and Excel were indispensable tools for making graphs and charts, integrating attribute data and writing the report. Lastly, Access Mod 5.8 was used for accessibility analysis. Each of these software tools contributed significantly to the successful completion of the project. They are summarized below in Table 3.4:

Table 3.3 summary of software used

No.	software's	Purpose	version
1	ArcGIS	For data processing, analyzing and map preparation	10.8
2	Google Earth	For updating road networks and geocoding	
3	Microsoft Word and Excel	For making graphs and charts ,integrating attribute data and writing the report	2010
4	Access Mod	For accessibility analysis	5.8

5	Google chrome	For downloading road and building footprint	
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### 3.4. Methods of Data Analysis

The current study's data analysis and organization methodologies are briefly described as follows: This was an applied study that combined geospatial and quantitative data types using a geospatial technique. The initial task was collecting appropriate data from different source .Following data collection, the data went through many processing phases like clipping geo locating, conversion, classification modeling historical traffic data adjusting scenario table .then Creating Database, Checking compatibility of data for Access, Building topology, Building Network Dataset Finally the most optimal path, the closest medical facilities were chosen using the Network Analyst tool provided by the ArcGIS software, and the accessibility of fire stations was assessed also Zonal statistics using Access Mod . Figure 3.9 shows Methodological flow of study.

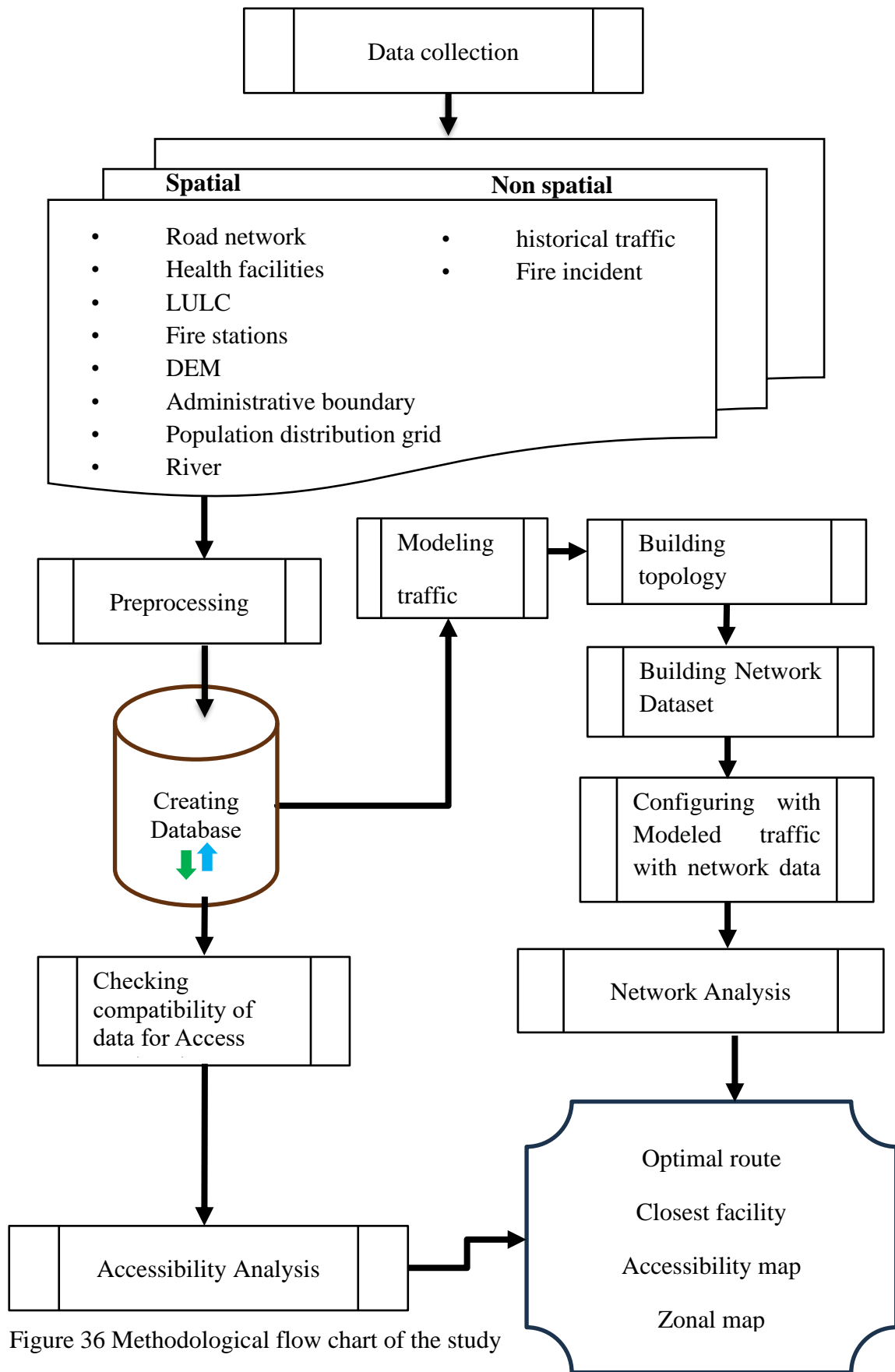


Figure 36 Methodological flow chart of the study

### **3.4.1. Data collection**

The process began with the collection of various datasets. This stage involved acquiring different datasets from different organizations in different formats. These datasets included road networks, health facilities, land use land cover, fire stations, a digital elevation model, administrative boundaries, population distribution grids, building foot prints, fire incidents, and historical traffic data.

### **3.4.2. Processing**

In order to obtain the necessary format for further analysis, data processing was a crucial stage following data collection. This process involved tasks such as clipping, geolocating, classification, and modeling historical traffic data, as well as adjusting the scenario table(see appendix 4). The data processing and analysis were performed using ArcGIS software.

### **3.4.3 Modeling historical traffic data**

The historical traffic data was modeled using the assumption that travel speeds follow a weekly trend. Travel speeds on a road stretch are expected to be similar at different times of the week. To construct a network dataset that incorporates historical traffic information, line feature class representing the city road network, two table representing the street daily profile and daily profile were prepared.

#### **a. Street daily profile**

Every street feature is assigned a unique identifier known as the Object ID value. The Streets-Profiles Join Table links streets with their respective traffic profiles using this unique identifier throughout the day. See appendix 3.

#### **b. Daily profile**

Daily profile stores the speed profiles for each day of the week. Every entry in a Daily traffic profiles table possesses a unique ID and multiple fields to store the free-flow scale factor at various times throughout the day. The day is divided into equal time segments, also known as time slices. These slices are of the same length, thereby dividing the entire 24-hour period into equal segments (ESRI 2021). To prepare daily profile Object ID is a special number assigned to every record in the table. Based on ESRI standard the times of the day were split into time intervals, or time slices (one hour) of equal duration. 24 attribute fields were created starting from 00:00 to 23:00 to represents speed factor. Daily profile was prepared based on

the following Daily Profiles Table Structure. See table3.7. Speed factor was calculated using equation 3.1 (source ESRI, 2021).

$$\text{Speed factor} = \frac{\text{Actual speed}}{\text{free flow speed}} \dots \dots \dots \text{equation 3.1}$$

Table 3.4: Daily Profiles Table Structure

Source ESRI 2021

Field	Data Type	Description
Object ID	Long	A special number assigned to every record in the table.
SpeedFactor_0000 to SpeedFactor_2300	Double	Represent free flow scale factor at different times of the day.

### 3.4.3 Creating Database

The primary data format for managing and altering data in ArcGIS is the geo-database, which is a native data structure. One can have a personal, file, or enterprise geodatabase. In ArcGIS, a file geodatabase is a particular kind of geodatabase that is kept as a folder on disk that has several files. Because it enables the storage of both geographical and non-spatial data types in one place, it is an effective tool for managing and analyzing geospatial data (ESRI 2021). A network dataset operates within a geodatabase, which is why a file geodatabase was created.

### 3.4.4 Checking compatibility of data for Access mod

Algorithm used by Access Mod operates on variables expressed in the metric system. Prior to being imported into Access Mod, all raster and vector data were projected using the same metric coordinate system to prevent any potential consistency issues. All raster format data used in Access Mod should have the same extent in terms of minimum and maximum Easting and Northing. If this is not the case, Access Mod will only consider data within the scope of the input DEM. In addition, all input raster format layers must have the same resolution as the DEM. Before importing the prepared data to Access Mod, issues like units, projection, extent, resolution, and accuracy were checked. The Digital Elevation Model (DEM) had a resolution of 90 by 90 meters, and the resolution of other raster data was identical to that of the DEM.

### 3.4.5 Building topology

Building network topology is an important stage in road network analysis because it describes the linkages and interconnections among the road segments. The topology was fixed based on the following topology rule:

**Must Not Intersect** Lines in one feature class or subtype may not cross any section of another line in another feature class or kind.

**Must not self-overlap** Lines must not intersect within a feature class or subtype. Lines can touch, intersect, and overlap with lines from another feature class or subtype.

**Must not have dangle within** a feature class or subtype, the end of a line must touch any portion of itself or any portion of another line.

**Must Not Have Pseudo Nodes** Within a feature class or subtype; a line's end cannot touch the end of just one other line. Any portion of a line can come into contact with its termination. To clean up data that has lines that aren't properly separated, apply this rule.

### 3.4.6 Building Network Dataset

Once the road network topology was determined, the next crucial task was building a network dataset. This involved importing the road networks and two pre-existing traffic data tables into the geodatabase. After that, a network dataset was created to perform the required analysis.

### 3.4.7 Configuring with Modeled traffic with network data

The modeled historical traffic data was configured with network data set to get realistic route and closest facility analysis. After appropriately configuring and populating the historical traffic tables, they were merged into the network dataset. This was performed during the network creation but before the building process.

### 3.4.8. Network analysis

A network analysis was performed to identify the most effective routes for emergency services in case of a fire. This analysis took into account factors such as road length, speed limits, and traffic conditions. The road network analysis was implemented using the ArcGIS Network Analyst Extension. This powerful extension of ArcGIS provided network-based spatial analysis, including route analysis, travel directions, closest facility analysis, and service area analysis. It enabled users to dynamically model realistic road 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 (Ahmed & Hefny, 2017).

#### **a. Optimal path**

The best route analysis determines the optimal travel time between two sites depending on network traffic situations during a specific time of day. The network analyzer extension allows for easy customization of route analysis parameters, including travel time, start time, day profile, and road direction restrictions (Ahmed & Hefny, 2017). The start location and the end location were chosen after modifying the best route analysis settings. The best route between these two places was then created using the best route solver tool.

#### **b. Nearest health facilities**

The nearest facilities analysis identifies the facilities that are most accessible from a specific incident location within a given time frame, taking into account available travel time and traffic data (Ahmed & Hefny, 2017). Finding the facilities that are closest to the fire incident site allows us to maximize resource allocation, reduce response times, and ultimately save lives (Ahmed & Hefny, 2017).

### **3.4.9 Accessibility analysis**

The spatial accessibility of fire stations was generated by Access Mod. First, DEM (containing terrain information) was imported into the tool, then the travel scenario (surface represents how much time is needed to cross a cell north/southward or east/westward, regardless of the direction) uploaded, and lastly, fire stations were imported to the tool. Finally, an accessibility map was generated.

Raster data containing the spatial distribution of the target population, the travel scenario, and the boundaries of the sub city were considered for obtaining the zonal statistics. Zonal statistics was generated by access mod tool. Zonal statics describe coverage of fire station for each sub city depending on response time standard

## **CHAPTER IV: RESULTS AND DISCUSSIONS**

In this section, the study findings are interpreted and discussed concerning a research Objective, empirical framework and methodology.

### **4.1 Results**

The findings of the current study were, Spatial Accessibility of Fire Stations, Optimal Paths for Emergency Services nearest Healthcare Center Location in Relation to Fire Incidents.

#### **4.1.1 Spatial Accessibility of Fire Stations**

Assessing fire station accessibility at fine scales and strategically locating stations can enhance emergency response efficiency and minimize property losses and casualties. The result of spatial accessibility of fire station in Addis Ababa was generated by tool called Access Mod by considering various factors like distance, road network, land use and terrain to provide accurate accessibility analysis based on Fire response times standard. Fire response times standards for Ethiopia is eight minutes. The fire station accessibility result is depicted in figure 4.1. The map reveals the distribution of fire stations and their accessibility, emphasizing the importance of locating fire stations strategically to minimize response times during emergencies. Locations that can be accessed within a span of 0 to 8 minutes are denoted in green, 8 to 15 minutes, are highlighted in light green. Areas that require 15 to 25 minutes to reach are marked in yellow. Those that take 25 to 35 minutes are indicated in orange. Finally, areas with the longest response times, specifically 35 to 60 minutes, are represented in red. Fire stations are concentrated in the central and northwestern parts of Addis Ababa. However, the northeastern and eastern areas lack fire stations, resulting in lower accessibility levels in those regions. The map underscores the need to strategically position fire stations to minimize response times during emergencies. Focusing on areas with longer travel times can significantly improve overall accessibility.

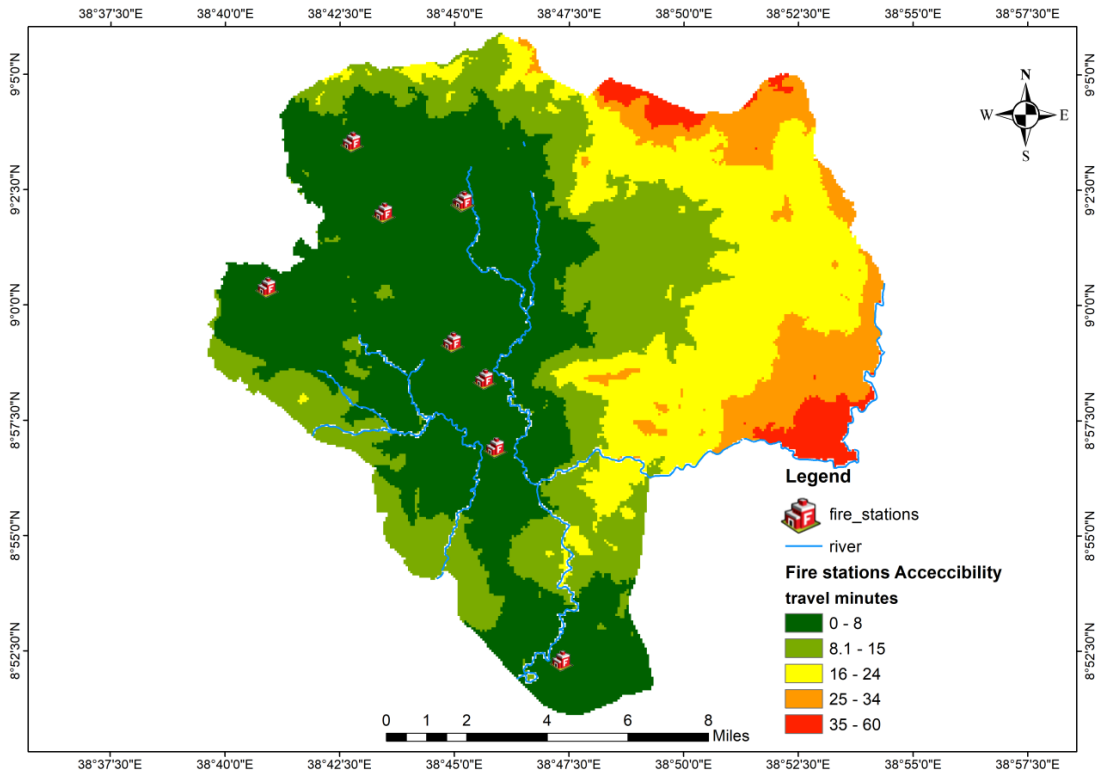


Figure 4.1 Fire stations spatial accessibility map

The generated result has addressed this issue.

According to the accessibility analysis, fire stations serve 45.18% of the city in an 8-minute response time. This coverage zone covers just 19,307.17 hectares out of a total of 42,768.34 hectares. Figure 4.2 shows area could be covered in 8minute response time.

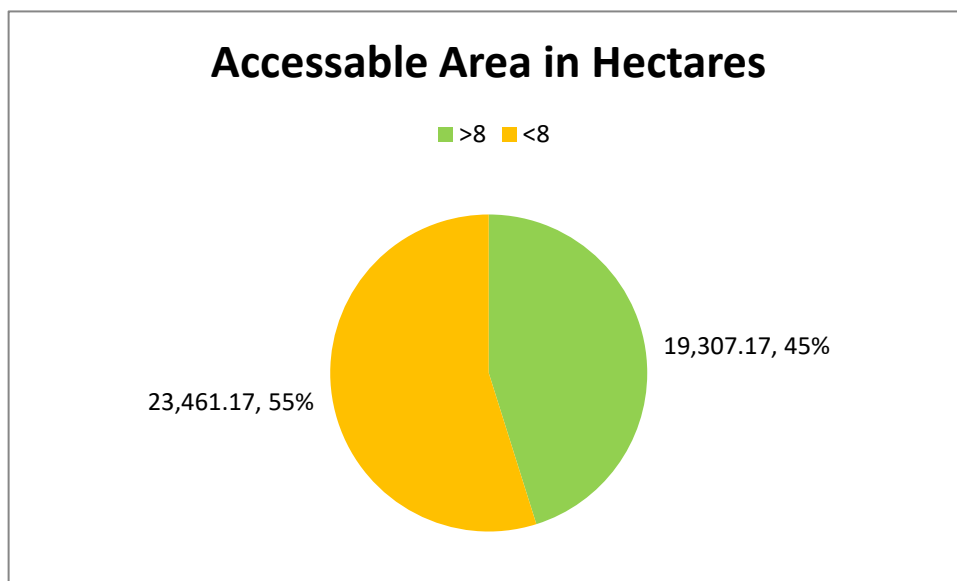


Figure 4.2: Coverage of fire stations in 8 minutes

Table 4.1 Comparison of accessibility between sub city based on Coverage within 8 minutes

No	Layer	Poptotal	Poptraveltime_8	Popcoveredpercent_8
1	Arada Sub City	284288.4	282102.9	99.23125
2	Kirkos Sub City	290765.4	287010.2	98.70851
3	Lideta Sub City	310128.2	300812	96.99599
4	Yeka Sub City	330762.6	96997.45	29.3254
5	Lemi Kura Sub City	253362.6	0	0
6	Akaki Kality Sub City	193233.5	139495.8	72.19028
7	Addis Ketema Sub City	475153.3	472168.4	99.37179
8	Gulele Sub City	391180.8	301222.8	77.00346
9	Bole Sub City	270369.7	73211.98	27.07847
10	Kolfe Keranyo Sub City	372055.6	310516	83.45958
11	NifasSilk Lafto Sub City	345673	245358	70.97981

Table 4.1 and Figure 4.3 show zonal statistics of fire station coverage per sub city. In this analysis, zonal coverage of fire station for different sub cities ranges from 0 percent to 99.37percent coverage depending on 8-minute response analysis. Fire station coverage across various sub-cities is explained as follows: Arada sub city has a total population of 284,288; out of this, 282102.9 get coverage within 8 minutes, and on the other hand, the remaining population can't get service for a fire emergency within the time standard. The fire station percentage coverage of Arada sub city is 99.23, which indicates almost all residents get service in 8 minutes. Also, 98.7% of Kirkos sub-city residents get service within an 8-minute response time. Among those subcities, none of the Lami Kura subcities get service within response time. In the sub-cities of Lideta, Yeka, Akaki Kality, Addis Ketema, Gulele, Bole, Kolfe Keranyo, and NifasSilk Lafto, emergency services are provided with the following coverage percentages within an 8-minute response time: 97.00%, 29.33%, 72.19%, 99.37%, 77.00%, 27.08%, 83.46%, and 70.98%, respectively. Among the subcities, Addis Ketema, Arada, and Kirkos Lideta have the highest zonal coverage. In comparison, subcities like Kolfe Keranyo, Gulele, Akaki Kality, and Nifas Silk

Lafto exhibit better coverage percentages (ranging from 70% to 83%) than Yeka and Bole, which have relatively poor coverage (27% to 29%). Unfortunately, Lemi Kura Kura has no zonal coverage at all.

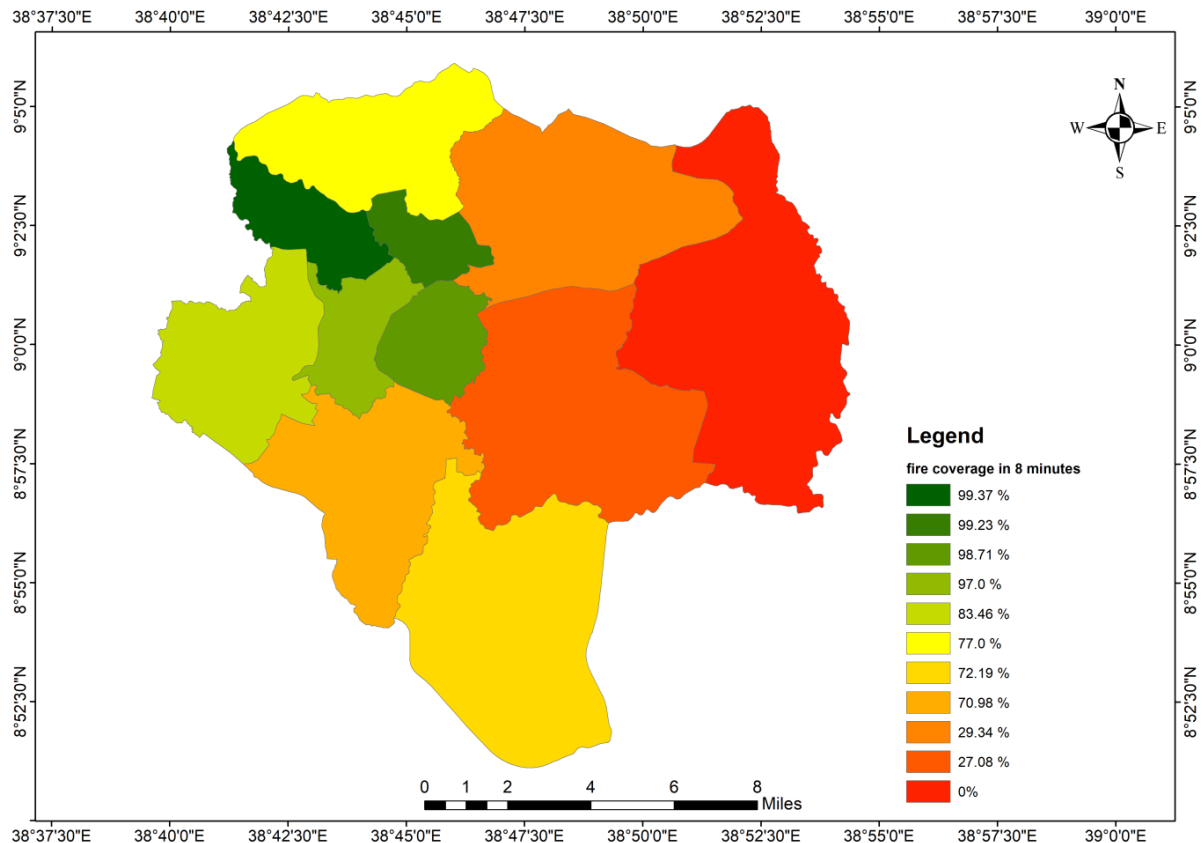


Figure 4.3 zonal coverage maps of fire stations.

#### 4.1.2. Optimal Paths Selection for Emergency Services

Optimal selection was based Traffic speed model. The traffic speed model was modeled based on historical speed limit data gathered by the Addis Ababa traffic management agency. Esri's traffic speed factors, which encompass stop-and-go, slow, moderate, and free-flow conditions, guided the classification of the historical traffic data. These classifications correspond to traffic speed ratios ranging from 0 to 0.45, 0.45 to 0.65, 0.65 to 0.85, and 0.85 to 1, respectively. The speed ratio ranges from 0 to 1. A 0 value indicates there is congestion on the road segments, while a 1 value indicates free flow. The speed ratio of the study area is calculated based on the above concept, and the result is shown in figure 4.4. Table 4.2 indicates the street daily profile, which shows historical traffic information for days of the week. For example, the historical traffic data for the line segment with object ID 1 on Monday is presented in Table 4.2 and corresponds to Profile 2. The highlighted value in

Table 4.3 provides a link to the hourly traffic information for Monday, which is displayed in Table 4.3.

Table 4.2 Street daily profile

OBJE CTID *	SPFR EEFL OW	PRO FILE _1	PRO FILE _2	PRO FILE _3	PRO FILE _4	PRO FILE _5	PRO FILE _6	PRO FILE _7	Edg eFC ID	Edg eFI D	Edge FrmP os	Edge ToP os
1	40	1650 1	1	2751	5501	8251	1100 1	1375 1	7	72	0	1
2	40	1650 2	2	2752	5502	8252	1100 2	1375 2	7	73	0	1
3	40	1650 3	3	2753	5503	8253	1100 3	1375 3	7	83	0	1

Table 4.3 shows how traffic conditions varied over time in the city. The table illustrates how traffic conditions changed over time in the city1. It provides information on the duration of the stoplight signals for different traffic movements at an intersection between two busy roads.

Table 4.3 Daily profiles.

OBJECTID *	SpeedFactor_0000	SpeedFactor_0100	SpeedFactor_0200	SpeedFactor_0300	SpeedFactor_19 00	SpeedFactor_20 00	SpeedFactor_21 00	SpeedFactor_22 00	SpeedFctor_23 00
1	1	1	1	1	0.989	0.989	0.995	1	1
2	1	1	1	1	0.979	0.983	0.993	1	1
3	1	1	1	1	0.978	0.98	0.991	1	1
4	1	1	1	1	0.97	0.977	0.991	1	1
5	1	1	1	1	0.96	0.977	0.99	1	1
6	1	1	1	1	0.984	0.986	0.994	1	1
7	1	1	1	1	0.946	0.954	0.981	1	1

During the night, the major roads in the city experience the following traffic patterns: From 22:00 (4:00 AM local time) to 4:00 (10:00 PM local time), the roads become free, with less congestion. Starting from 5:00 (11:00 PM) until 21:00 (3:00 AM local time), the roads become busy and experience heavier traffic. Figure 4.4 depicts the traffic speed model of the city on Monday, April 22, 2024. The line segments on the map with different colors illustrate the traffic condition of major roads on Monday at 9:20 a.m.

Red represents congested roads; orange represents slow traffic; yellow represents moderate traffic; and green indicates free flow. The network analyst extension uses desktop time to display the traffic status of road segments

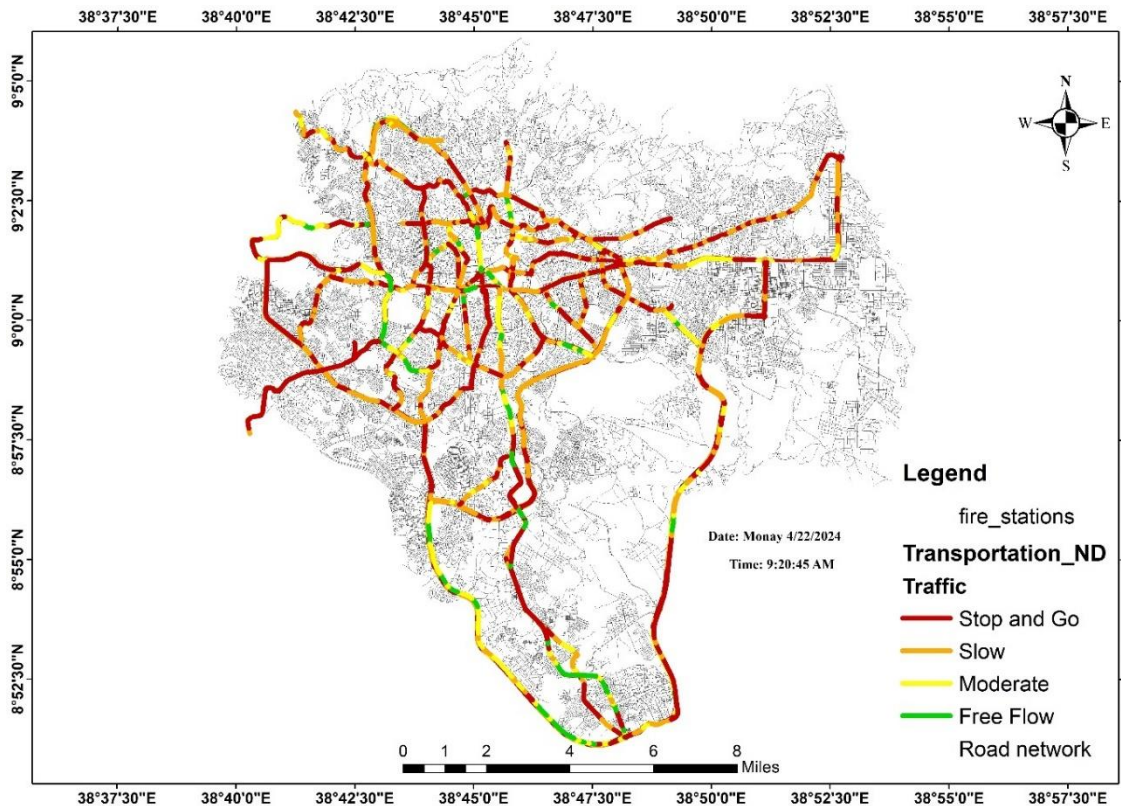


Figure 4.4 Traffic speed model

When developing the traffic model, several assumptions were made to create a realistic representation of traffic conditions. the assumption that travels speeds follow a weekly trend. Travel speeds on a road stretch are expected to be similar at different times of the week. Traffic flow follows typical patterns, such as higher volumes during peak hours and lower volumes at night. Congestion occurs at bottlenecks, intersections, and areas with limited road capacity. And Lane changes, turning movements, and merging behavior are considered.

There are two approaches to choosing the optimal path for travel: one without taking traffic into account and the other with it. In both approaches, routes were selected from fire station to fire incident place, and the difference between them is displayed below. The Addis Abeba fire and emergency accident central office has an officer who can answer calls from accident scenes. The caller will also provide information on the accident, including the nearest landmark. The GIS officer in the central office uses the nearest land mark to locate the nearest fire station. the nearest fire department notified via phone call will investigate the accident using the nearest landmark. At this point, the most direct routes to the accident

location and the nearest hospital will be chosen. Ambulance and fire engines will use maps and directions to find the best path to the accident location (Alebele (2015). Figures 4.2, 4.3, and 4.4 indicates route selection process.

Without Considering Traffic Conditions, in this approach the best route was chosen based on the least distance from the start to the end point. Aspects like distance, and speed limits were considered. However, it didn't consider real-time elements like traffic jams, road blockages, or accidents. Consequently, while the chosen route might be the shortest in terms of distance, it might not be the quickest or most effective when considering time. Figure 4.5 and Table 4.4 depict the route details from the fire station to the fire incident location. The travel time required to reach the scene is 5.9 minutes, covering a total distance of 4.538 kilometers.

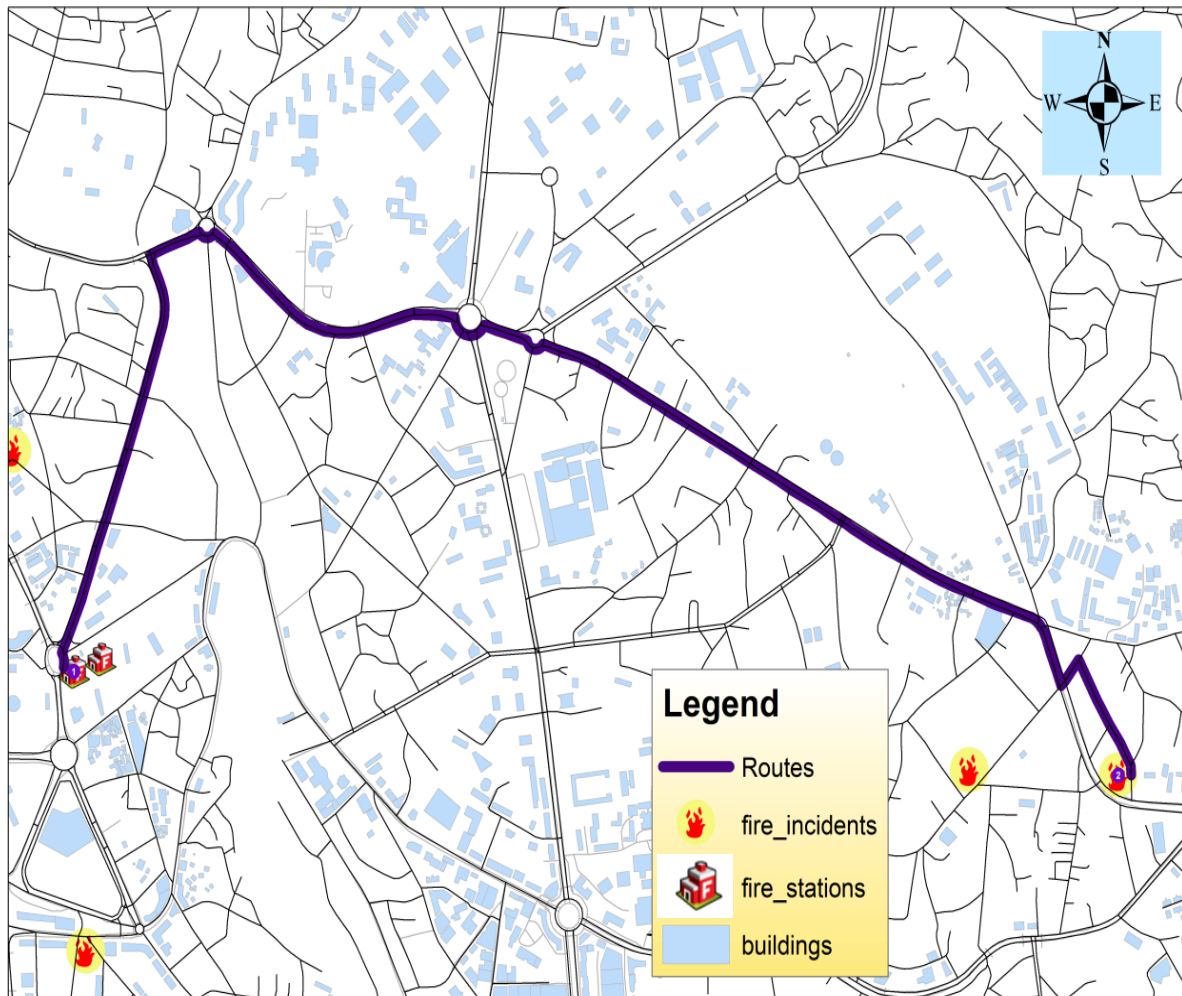


Figure 4.5 Route selection process from fire station to fire incident place without considering traffic.

Table 4.4 travel information from fire station to fire incident place without considering traffic

From	To	Travel Time (minute)	Distance (km)
AA. City Administrative Council Office (Fire)	Fire incident	5.484587	4.538

Considering traffic condition, this method incorporates historical traffic data into the route selection process. In order to get realistic travel time from fire station to fire incident traffic data was considered. Figure 4.6 shows the selected optimal route by considering traffic condition of the area. In this analysis, the travel time has been chosen as the impedance factor, the start time of travelling was 9:20 AM which is the morning rush hour traffic on the road network in city. Table 4.6 illustrates a calculated route originating from the labeled starting point, ‘AA. City Administrative Council Office (Fire) and terminating at the destination marked as ‘Fire incident 1.’ The objective was to determine the most efficient route between these two locations, by taking into account traffic conditions at 9:20 AM on Monday. The resulting travel time for this route is 13.9 minutes. There were two stops encountered along the route, which contribute to the additional travel time compared to the previous route. The total distance covered is 4.538 kilometers. This indicates how congestion on road affect response time during fire emergency.Route selection process is the same in all part of the city but mapping all selected route cause redundancy.so to show route selection process of the city one incident place and fire station was selected and mapped.

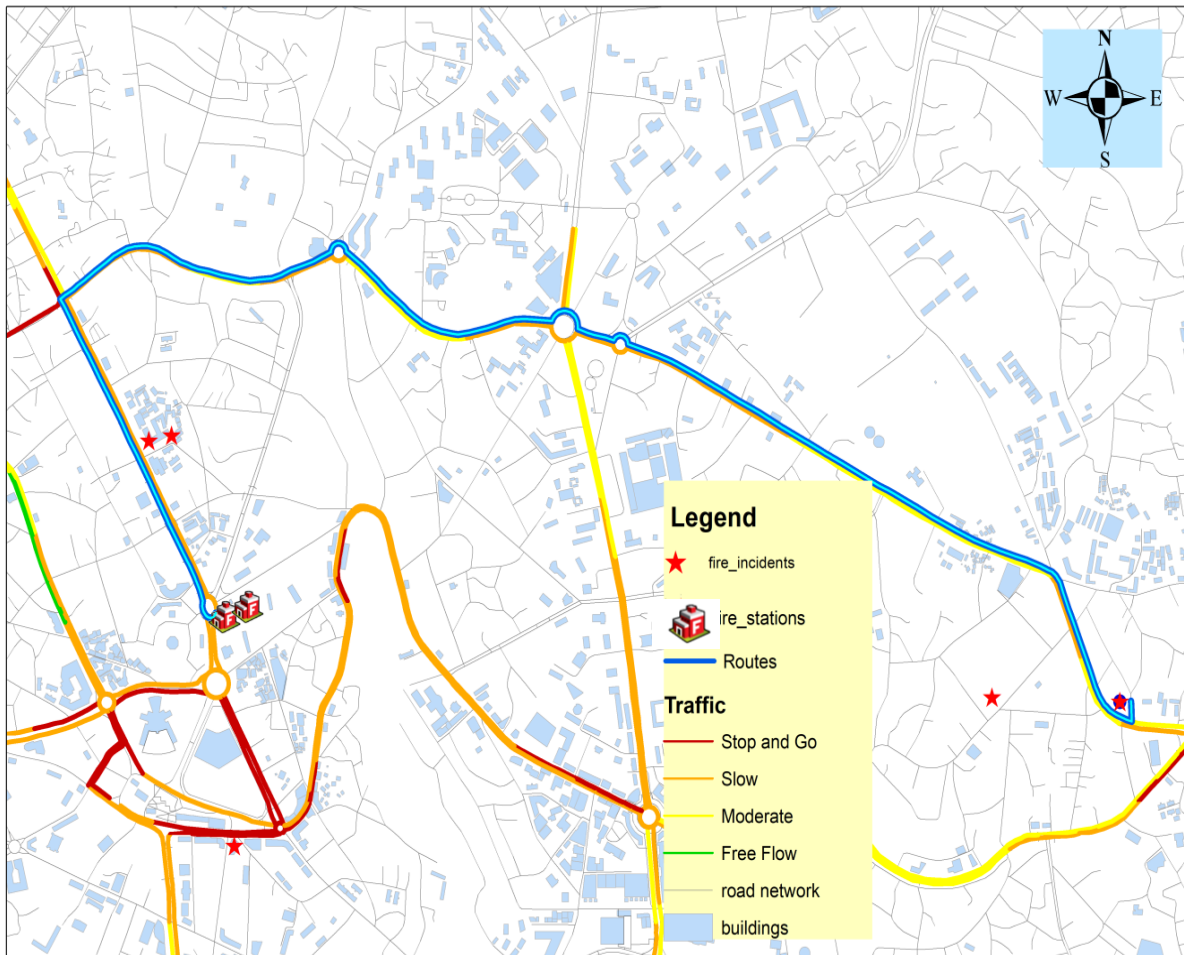


Table 4.6 travel information from fire station to fire incident place considering traffic

From	To	First Stop ID	Last Stop ID	Stop Count	Travel Time (minute)	Distance (km)
AA. City Administrative Council Office (Fire)	Fire incident 1	1	2	2	13.9022	4.538

#### 4.1.3 Nearest Healthcare Center Location Identification in Relation to Fire Incidents

In urgent fire emergencies, quick and effective actions are crucial to minimize harm and save lives. One critical factor is the accessibility of healthcare facilities near the incident location. Network analysts play a vital role in identifying the closest health facility and calculating the optimal route from the incident site to that facility. The network analyst determines which health facility is closest to the incident site. Then compute the most efficient route between the health facility and the incident location. Figure 4.7 illustrates that Kebena Health Center

is the closest facility to the incident site, located 1.03 km away. The travel time to reach Kebena Health Center from the incident location is 32.62 minutes.

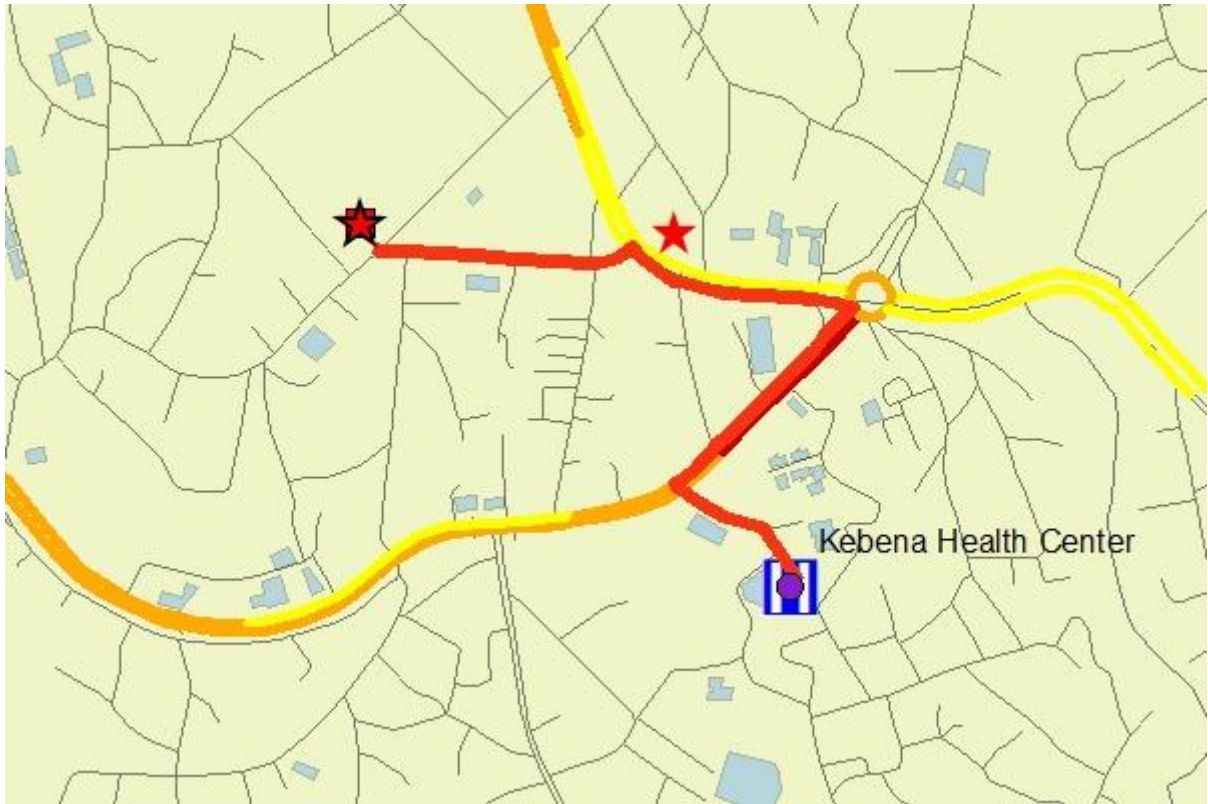


Figure 4.7 closest health facilities

During emergencies, knowing the drive directions is crucial for drivers. ArcGIS Network Analyst extension generates detailed drive directions for each selected route. Figure 4.8 provides turn-by-turn instructions from the fire incident place to Kebena Health Center, including information on turns, base maps, remaining time, total travel time, and distance. By following these steps, emergency responders can efficiently navigate to the nearest health facility, ensuring timely assistance for those affected by the fire.

<a href="#">1:</a>	Start at Location 1			<a href="#">Map</a>
<a href="#">2:</a>	Go southwest	7 m	< 1 min	<a href="#">Map</a>
<a href="#">3:</a>	Make sharp left	291 m	15 min	<a href="#">Map</a>
<a href="#">4:</a>	Turn right on Shewareged Gedle Street	265 m	4 min	<a href="#">Map</a>
<a href="#">5:</a>	Make sharp right on Queen Elizabeth Street	284 m	4 min	<a href="#">Map</a>
<a href="#">6:</a>	Make sharp left	185 m	9 min	<a href="#">Map</a>
<a href="#">7:</a>	Finish at Kebena Health Center			<a href="#">Map</a>
Total time: 33 min				
Total distance: 1.0 km				

Figure 4.8 drive direction indicator to fire incident place

Table 4.7 closest health facilities to the fire incident

No	Name of health facilities	Travel time	Total distance in km.
1	Kebena Health Center	32.62	1.03
2	Janmeda Health Center	38.30	1.82
3	Abuare Health Center	49.10	1.36

## 4.2. Discussion

In this study, a route from a fire station to a fire incident place was selected by the network analyst tool of arc GIS by both considering traffic and without considering traffic information, and the difference was revealed. The spatial accessibility of the fire stations is examined using a tool called Access Mod.

The study reveals that the selected route from the AA. City Administrative Council Office to the fire incident location took 13.9022 minutes when traffic information was considered, covering a distance of 4.538 km. The closest facility is Kebena Health Center, located 1.03 km away, with a travel time of 32.62 minutes. Fire stations are concentrated in the central and northwestern areas, serving 45.18% of the city in an 8-minute response time, covering 19,307.17 hectares out of 42,768.34 hectares. This highlights the importance of strategically locating fire stations to minimize response times during emergencies. However, the coverage of fire stations within an 8-minute travel time varies significantly across different sub-cities. Arada, Kirkos, Lideta, Eka, Lemi Kura, Kaki Kality, Addis Ketema, Gulele, Bole, Kolfe Keranyo, and NifasSilk Lafto all have different levels of fire station coverage. Previously worked research on accessibility of fire stations based on 8-minute response time by Temesgen (2022) 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. km<sup>2</sup> 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 276.10km<sup>2</sup> (53.15 %) of the city are served out of a total of 519.458 km<sup>2</sup>. 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. Thus, the results of the current study show differences with those of earlier studies that focused on road network analysis. The previous researcher's work on network analysis for locating fire stations and emergencies in Addis Ababa City, done by Temesgen (2022), didn't consider factors like train information travel scenarios to get realistic accessibility result. so current study fairly disagreeable with previously worked researches. In summary, the research explored optimal paths for emergency services, especially in relation to healthcare centers. to improve emergency response efficiency and reduce property losses and casualties. The findings provide valuable insights for urban planning and disaster management in Addis Ababa.

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The current study attempts to determine the most efficient routes for fire emergency services and the closest health facilities to a fire incident using the arc GIS network analyst extension tool and assess the spatial accessibility of fire stations using the access mod tool for Addis Ababa city.

The final outcome was achieved by implementing coverage at fire stations. The variation in coverage within an 8-minute travel time was significant across different sub-cities in Addis Ababa. The findings of the present research indicate that the route from the fire station to the fire incident location, covering 4.538 km, takes 13.9 minutes while considering traffic information and 5.49 minutes when traffic information is ignored. This proves how congestion affects travel time during emergency response.

Sub-cities like Arada, Kirkos, and Addis Ketema demonstrate excellent coverage, with over 98% of their populations having access to a fire station within the specified time frame. This high level of coverage ensures efficient emergency response and accessibility to fire services. On the other hand, Yeka, Lemi Kura, and Bole sub-cities face challenges in coverage, with Lemi Kura having no coverage at all within the 8-minute travel time. These areas require urgent attention and strategic planning to improve emergency services and ensure the safety of their residents. Sub-cities like Akaki Kality, Gulele, Kolfe Keranyo, and NifasSilk Lafto have moderate to good coverage, indicating room for further improvement. Enhancing the spatial accessibility in these areas can lead to more efficient emergency responses, minimize property loss, and reduce injuries and deaths.

In conclusion, while some areas in Addis Ababa have good fire service coverage, there are others where significant improvements are needed. A comprehensive and strategic approach to improving the spatial configuration of fire stations can help ensure efficient emergency responses across all sub-cities. This is crucial for protecting lives and properties and ensuring the overall safety of the city's residents.

Finally, the current study confirmed that the geographical information system (GIS) is more capable and efficient to apply for road network analysis for fire emergency response. Geospatial technologies have recently emerged as a front-runner in solving global

problems and fulfilling human needs; effective application of these technologies results in a safe environment.

## **5.2 Recommendation**

Based on the finding of the research the following are the main recommendations

- Addis Ababa Fire and Disaster Risk Management Commission should utilize GIS for emergence response, assessing accessibility and improving program.
- For sub-cities with low coverage like Yeka, Lemi Kura, and Bole, strategic placement of additional fire stations could significantly improve coverage.

### **As a suggestion for future researchers**

This study suggests future research in identifying the optimal path for aiding fire emergency services should focus on:

- Real-time traffic data: Enhance route planning models by integrating live traffic information and studying its impact on travel times and route choices.
- Impedance factors: Understand how road quality, traffic rules, and driver preferences affect route choice and response time for more practical solutions.
- Junctions and U-turns: Investigate their role in route planning, especially in urban areas with complex road networks, to improve response times.

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## APPENDICES

### Appendix 1. Location of fire stations in Addis Ababa

No.	fire station name	Lat.	Lon.
1	Akaki Kaliti Fire Station (Fire)	8.87155	38.789
2	Bethel Fire Station	9.00646	38.6819
3	Nefas Silk Lafto Fire Station	8.94861	38.7649
4	Kirkos Sub City Fire Station (Kera) (Fire)	8.98663	38.7492
5	??? ???	9.05894	38.7127
6	Addis Ketema Sub City Fire Station (Mesalemia) (Fire)	9.03344	38.7243
7	Addis Ababa City Administrative Council Office (Fire)	9.03734	38.7526
8	Addis Ababa Fire Stations Head Quarters	9.03757	38.7532
9	Akaki Kaliti Fire Station (Fire)	8.87155	38.789
10	Tigist Fire Fgning Equipment (Fire)	8.97322	38.761

### Appendix 2. Location of Governmental health facilities in Addis Ababa

FID	Name	Lat.	Long.
0	Woreda 03 Health Center	8.988015	38.6776 8
1	Alembank Health Center	8.997854	38.6837 5
2	Keranyo Health Center	9.019396	38.6919 8
3	Woreda 06 Health Center	9.00293	38.6984 1
4	Worda 05 Health Center	8.993918	38.7050 3
5	Dagim Hidase Health Center	9.025971	38.7166 6

6	Woreda 09 Health Center	8.998455	38.7171 5
7	Shegole Health Center	9.063696	38.7192
8	Selam Health Center	9.05135	38.7196 2
9	Weroda 2 Health Center	8.967133	38.7211 6
10	Abebe Bikila Health Center	9.047927	38.7219 7
11	Kuas Meda Health Center	9.03654	38.7227 8
12	Woreda 3 Health Center	9.022142	38.7230 4
13	Addis Ketema Health Center	9.033715	38.7236 7
14	weroda 1 Health Center	8.947792	38.7255 5
15	Absiniya Health Center	9.025503	38.7278 5
16	Millinium Health center	9.030883	38.7283 2
17	Selam Health Center	9.054168	38.7296 4
18	Hidase Fire Health Center	9.007676	38.7322 6
19	Abnet Health center	9.021067	38.7324 7
20	Felege Mels Health center	9.044942	38.7334 5
21	W/ro Beletshachew Health Center	9.014876	38.7339
22	Teklahamanot Health Center	9.01257	38.7345 9
23	Lideta Health Center	9.00515	38.7347 9
24	Addisu Gebaya Health Center	9.05849	38.7373 9

25	18 Health center	9.027469	38.7375 7
26	Wereda 07 Health Center	9.037758	38.7379
27	Ras Emeru Health Center	9.037629	38.7398 8
28	Addis Machin Spare Part Manufacturing Industry Health center	9.006828	38.7403 8
29	Semegne Kebed Health Center	9.046458	38.7404
30	Moyale Health Center	8.991782	38.7410 2
31	Semen Health Center	9.05272	38.7420 3
32	Semen Health Center	9.052722	38.7421 2
33	Weroda 5 Health Center	8.972948	38.7421 5
34	Weroda 11 Health Center	8.930728	38.7422
35	Ginbot 20 Health center	9.03108	38.7422 8
36	Hiwotamba Health Center	8.996974	38.7433 3
37	Weroda 12 Health Center	8.948432	38.7459 6
38	Hidasie Health Henter	9.064422	38.7472 1
39	Kirkos Health Center	9.002515	38.7482 9
40	Guto Meda Health Center	9.049265	38.7500 5
41	wereda 6 Health center	8.971491	38.7500 7
42	Feresmeda Health Center	8.992303	38.7507 5
43	weroda 10 Health Center	8.959754	38.7510 2

44	Afinchober Health Center	9.044995	38.7511 9
45	Arada Health Center	9.036608	38.7527 2
46	Tibeb Bekechene Health Center	9.060222	38.7530 7
47	Addis Hiwot health Center	9.06826	38.7560 2
48	Shiromeda Health Center	9.055246	38.7581 1
49	Felegehiwot Health Center	8.985671	38.7589 8
50	Entoto Fana Health Center	9.066131	38.7607 5
51	Bashawolid health center	9.030839	38.7614 6
52	Goteramasalecha Health Center	8.988084	38.7619 8
53	Mesholekiya Health Center	9.001105	38.7622
54	Weroda 9 Health Center	8.963163	38.7642 8
55	Saris health Center	8.956078	38.7648 6
56	Maychew Health Center	9.046286	38.7648 9
57	Janmeda Health Center	9.041329	38.7664 7
58	Gelan Health Center	8.880027	38.7668
59	Bata Health Center	9.02699	38.7673 5
60	Kality Health Center	8.900978	38.7673 7
61	Kazanchise Health Center	9.013517	38.7723 1
62	Wereda 01 Health Center	9.061167	38.7727 7

63	Korea Zemachoch Metasebiya Health Center	9.042522	38.7753 1
64	Kebena Health Center	9.031843	38.7765
65	Abuare Health Center	9.028024	38.7778 7
66	Bole 17/20 Health Center	8.98727	38.7806 1
67	Selam Frie Health center	8.865168	38.7821 9
68	Bulbula Health Center	8.95331	38.7824 8
69	Entoto No.2 Health Center	9.060075	38.7826 7
70	Sertie Health Center	8.887309	38.7828 4
71	Entoto No.1 Health Center	9.044608	38.7847 5
72	Akaki Health Center	8.871114	38.7893 5
73	Chefe Health Center	9.022501	38.7903 9
74	Yeka Health Center	9.025532	38.7951 9
75	Bole 17 Health Center	9.002281	38.8024 3
76	Dil Fere Health Center	9.003586	38.8102 3
77	Gerji Health Center	8.990164	38.8213 1
78	Wereda 10 Health Center	9.04214	38.8220 3
79	Kotebe 02 Health Center	9.030735	38.8296 3
80	Goro Health Center	8.996956	38.8320 1

81	Amoraw Memmorial Health Center	9.012258	38.8366 4
82	Werda12 Health center	9.040468	38.8446 3
83	Raye Health Center	8.992976	38.8506 8
84	Samit Health Center	8.992927	38.8605 7
85	Abado Health Center	9.066056	38.8688 4
86	Woreda 14 Hedase Health Center	9.057295	38.8731 7
87	Woreda 2 Health Center	9.038412	38.8772 2
88	Meri Health Center	9.013832	38.8826 4
89	Arabsa Health Center	8.98114	38.8874 5
90	Bole Cafe Health Center	8.994257	38.8930 1
91	Alert General Hospital	8.9852	38.7110 9
92	St Paulo's Comprehensive Specialized Hospital	9.04978	38.7252
93	Tikur Anbessa Comprehensive Specialized Hospital	9.02009	38.7486 9
94	St. Peter General Hospital	9.074857	38.7575

### Appendix 3. Street daily profile structure

Field	Field name examples	Data type	Description
Edge feature class identifier	EdgeFCID	Long integer	Identifies the feature class that the street feature is stored in.
Edge feature identifier	EdgeFID	Long integer	Identifies the street feature.
Edge from position	EdgeFrmPos	Double	<p>Works with EdgeToPos to determine the direction of travel or side of the street. Zero represents the start of the line feature, as determined by its digitized direction. One denotes the other end.</p> <p>For example, an EdgeFrmPos value of 0 and an EdgeToPos value of 1 would indicate the right side of the line feature (assuming right-hand traffic). The traffic profiles in the same record would only show traffic on that side of the street.</p> <p>Any decimal values provide a position along the feature's digitized direction, allowing the Dissolve Network tool to preserve accurate street profiles once edges are dissolved together.</p>
Edge to position	EdgeToPos	Double	Works with EdgeFrmPos to determine the direction of travel or side of the street.

Base Speed Field	BaseSpeedKPH	Float or double	It is free-flow speed in kilometers per hour.
Sunday Profile Field	Profile_1  Sunday Profile	Short or long integer	The object ID from the Profiles table that best represents the traffic pattern on Sundays for the portion of the street identified by EdgeFCID, EdgeFID, EdgeFrmPos, and EdgeToPos.
Monday Profile Field	Profile_2  Monday Profile	Short or long integer	The object ID from the Profiles table that best represents Monday traffic.
Tuesday Profile Field	Profile_3  Tuesday Profile	Short or long integer	The object ID from the Profiles table that best represents Tuesday traffic.
Wednesday Profile Field	Profile_4  Wednesday Profile	Short or long integer	The object ID from the Profiles table that best represents Wednesday traffic.
Thursday Profile Field	Profile_5  Thursday Profile	Short or long integer	The object ID from the Profiles table that best represents Thursday traffic.
Friday Profile Field	Profile_6  Friday Profile	Short or long integer	The object ID from the Profiles table that best represents Friday traffic.
Saturday Profile Field	Profile_7  Saturday Profile	Short or long integer	The object ID from the Profiles table that best represents Saturday traffic.

**Appendix 4.** Scenario table

Class	Label	Speed	Mode
1	Sparse forest	4	Walking
3	Settlement	5	Walking
4	Dense_Forest_land	3	Walking
5	Moderate_Forest_land	3.5	Walking
7	Grassland	4	Walking
8	Cropland	3	Walking
1001	Collector	30	Motorized
1002	Local	15	Motorized
1003	Principal arterial	50	Motorized
1004	Sub arterial	40	Motorized