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Optimization of Firefighting capacity using Network Analysis: Case Study of Kathmandu Valley

By:

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Optimization of Firefighting capacity using Network Analysis: Case Study of Kathmandu Valley" submitted by Siddartha Amatya in partial fulfillment of the requirements for the degree of Master in Disaster Risk Management.

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ABSTRACT

Despite the fact that fire is the most common and economically costly disaster, fire response and preparedness appear to be significantly limited, particularly in the Kathmandu valley. Only four operational fire stations, excluding army and aviation authorities, are presently responding to fire disasters in the valley. Due to this, it is impossible for these firefighters and fire brigades to arrive at the accident scene on time. As a result, people suffer bigger losses, including the danger of losing their lives, which not only stresses them out but also diminishes confidence of firefighting units due to the public's unwelcoming conduct upon their delayed arrival.

This thesis studies about the current response time capacity of the fire station inside Kathmandu valley using service area of network analysis in QGIS software. Furthermore, the optimal number of locations for fire station is calculated using Allagash method using python programming. It is found that at least 56 number of fire station or fire truck at stand by position at several locations is required to serve population optimally inside Kathmandu Valley. However, more numbers of fire stations are required if international standard of 240 seconds of response time is followed. The number of stations required can be decreased if the speed of truck can be increased by improving condition of roads and road appurtenances.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FLP	:	Facility Layout Problems
GIS	:	Geographic Information System
GLPK	:	GNU Linear Programming Kit
GPS	:	Global Positioning System
Km	:	Kilometer
KMC	:	Kathmandu Metropolitan City
Kmph	:	Kilometer Per Hour
Ktm	:	Kathmandu
LSCP	:	Location Set Covering Problem
MCLP	:	Maximum Covering Location Problem
NFPA	:	National Fire Protection Association
OD matrix	:	Origin-Destination Matrix
QGIS	:	Quantum GIS
SFPE	:	Society of Fire Protection Engineers
TIN	:	Triangulated Irregular Network

CHAPTER 1: Introduction

1.1 Background

Fire is one of the most severe disasters in urban areas. It is one of the major disasters even in the worldwide context. More than 180,000 people are killed by fire or fire related injuries each year. Fire death and injuries are faced mostly by low- and middle-income countries which accounts for more than 95%. (World Bank, 2020)

During periods of rapid urban development, the risk of urban fires may increase. Inadequate fire protection and mitigation measures in urban planning, infrastructure, and construction dramatically increase the likelihood of fire ignition, spread, and conflagration. Improved urban planning, infrastructure, building design, construction, and materials, fire suppression capabilities, and education and training are all required to reduce fire risk. Appropriate enabling legislation, well-designed and implemented building and fire regulations, and adequate capacity to conduct building fire safety plan review and construction inspection are all proven approaches to reducing fire risk through building and fire regulation. (World Bank, 2020)

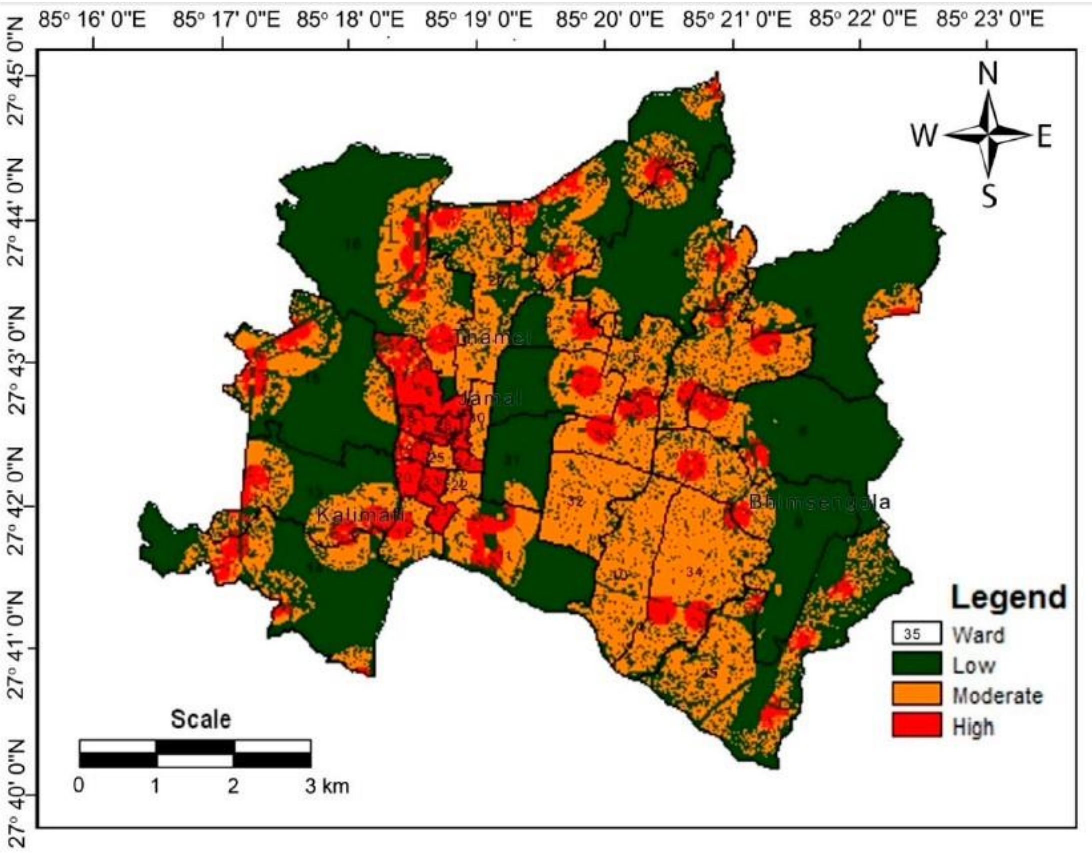
Nepal is considered to have a large amount of fire disasters every year for a very long period of time. Fire has been causing around 5% of severe disabilities to its victims in Nepal. This number is higher in highly dense areas with poorly developed urban settings with a large number of plastic disposals which assists the fire spreading. (Bhattarai, et al., 2021)

In Kathmandu Valley, fire is one of the most frequent disasters. There are several fire cases each year. However, there seems to be very little or no law relating to fire management in Urban areas. There are only some building codes which cover some aspects of fire in the building. There are various fire control measures taken in order to manage fire disasters. Some of them are exit signs at large buildings and halls, fire extinguishers in large buildings and public buildings, firefighters and fire brigades, etc. Special measures and rules are taken into consideration in highly hazardous places like petrol pump stations, airports, etc.

Even while fire kills fewer people than other major disasters such as earthquakes, floods, and landslides, the average loss of property due to fire is considerable. The Kathmandu Valley is becoming more prone to fire as a result of unplanned urbanization and population growth. Systematic studies, such as fire potential mapping and risk assessment, are required to control fire concerns. (Chhetri & Kayastha, 2015)

Sachin Kumar Chhetri and Prabin Kayastha has studied potential fire hazards of Kathmandu Metropolitan City and developed a map with the help of Analytic Hierarchy Process (AHP) method. The map is based on data from land use, population density and fuel station. It is also validated with past fire events. It shows that there is 58.04%

area with low fire potential, 32.92% moderate and 9.04% area with high potential of fire. The mentioned map is shown in Figure 1.



Source: (Chhetri & Kayastha, 2015)

Figure 1 Fire Potential Zonation map of Kathmandu Metropolitan City.

Despite the fact that fire is the most common and economically costly disaster, fire response and preparedness appear to be significantly limited, particularly in the Kathmandu valley. Only four operational fire stations, excluding army and aviation authorities, are presently responding to fire disasters in the valley. The fire stations, on the other hand, merely use standard station management practices, proper firefighting equipment, and operational issues common among frontline urban firefighters. (Bhattarai, et al., 2021)

The total response time includes call processing time, turnout time, and travel time (Moore-Merrell, 2019):

- Call processing time – the time passed between when the call was received at the Concerned department and when the first unit was dispatched.
- Turnout time – the time passed between when a unit is dispatched and when that unit's status changes to responding
- Travel time – the amount of time that elapses between when a unit begins to respond and when it arrives on the site

If the fire fighters cannot reach the destination within a specific time period, there is bound to be a large amount of property loss. Therefore, there is a very essential need of analyzing if the current number of fire stations in the city is of the required number or not. The distance from the fire station to the destination is one of the influencing factors for the response time. There are other factors as well which affect the response time, such as population density, accessibility, land zones, traffic condition, time, socio-culture and administration and operation. (Al-Jarallah & Dossary, 2015)

Around 50 false calls were made on average every day in the fire station, causing a lot of stress among the firemen, to the point where they were angered by their own phone calls. However, after a few years of tenancy, many of them developed resiliency (Bhattarai, et al., 2021). This indicates that the response of fire fighters should depend on other information sources before responding to the call. The research paper also indicated that since the majority of the calls were fake, firefighters would have a tougher time determining which calls resulted in true accident reports. The firefighters would only leave for the rescue mission after double-checking with local police, traffic, or volunteers, which in turn increases their entire response time toward the incident location.

1.2 Need and Importance of the Study

Fire is such an entity that can increase exponentially if left for a longer period. A fire is sometimes characterized as "doubling in size every minute." On a graph, the extent of such a fire would result in a curving line like the one illustrated in Figure 2. (The Fire Brigades Union, 2010)

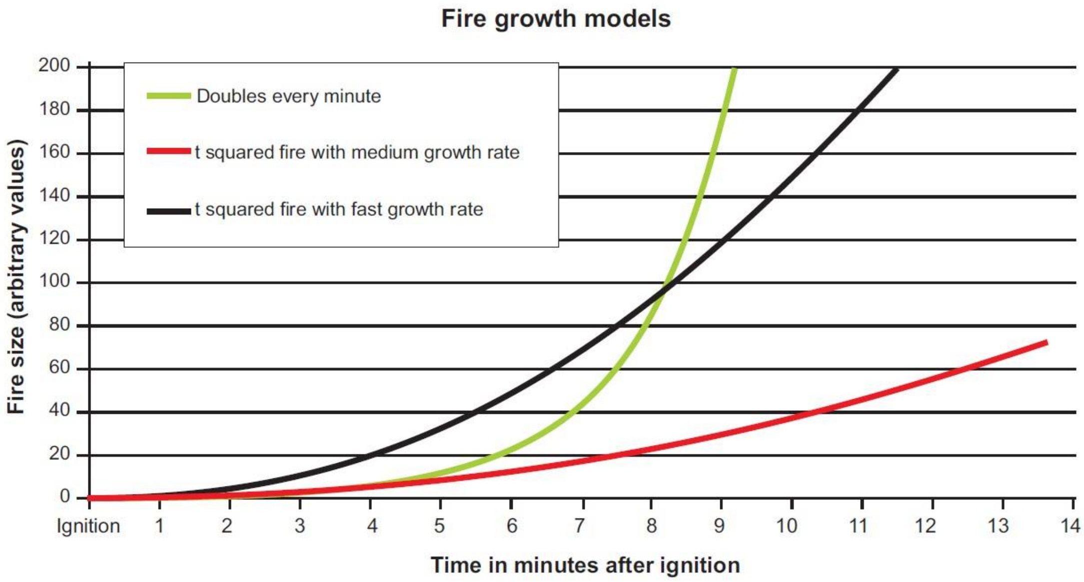


Figure 2 Graphical representations of fire growth

(Source: The Fire Brigades Union, 2010)

The crucial thing to notice in the Figure is that the rate at which any fire grows in magnitude grows with time. For example, the fire with fast growth rate increases in size by roughly 12 units between minutes 3 and 4, then by almost 40 units between minutes 9 and 10. This shows that, initially fire may not be strong enough to destroy property or cause human casualties, but after over 10 minutes of fire, every minute can cause more harm and is more hazardous. Therefore, response time before the increase in fire is essential.

The moment when a small fire grows so large that it ignites everything flammable in the room is the tipping point which is known as flashover. It's extremely unusual that this will occur five minutes after ignition. However, while it is possible that it happened nine minutes after ignition, it is much more likely that it will happen ten minutes later. Though this is only a broad generalization and does not apply everywhere, however, the situation cannot be negated as every minute can cause more severe damage as well as death. (The Fire Brigades Union, 2010)

Kathmandu's urban landscape is rapidly evolving. Kathmandu has become a megacity, with new neighborhoods and districts being added all the time. Several high-rise structures have been constructed throughout the city in recent decades to support the city's fast population increase. The rapid growth and development of Kathmandu has resulted in an increase in the frequency of fire-related emergency events (Chhetri & Kayastha, 2015). However, to cope up with this rapid growth, there is a limited number of firefighting stations which is further hindered with high rise buildings as well as increase in traffic flow.

The relationship between resource deployment, response time, and good results is a symbiotic one. If fire department response times and effective reaction force assembly times are both low, it is more likely that sufficient resources were deployed, which is associated with improved risk event outcomes. In contrast, if reaction times and effective response force assembly durations are prolonged, it is more likely that insufficient resources were deployed, resulting in more undesirable outcomes. (Moore-Merrell, 2019)

If a department devotes a significant portion of its overall resources to assignment in the same area for several hours each day, it may endanger other areas of the city by displacing resources outside their immediate response zone, resulting in longer response times for units responding from a larger distance. Because of the high number of occurrences and the frequency of overlapping crises, department leaders may decide that additional resources are required to offer an effective and efficient emergency response. (Moore-Merrell, 2019)

It is therefore seen as an important topic to be researched in this area. The response time from receiving a call to arriving at site to start emergency work must be researched thoroughly so that it can be shortened from further researches. It can not only save lives and property but can also give people a sense of safety from future fire hazards.

1.3 Problem Statement

The Juddha Fire Brigade (Kathmandu Fire Brigade), Kathmandu's only fire department, was previously under the Ministry of Home Affairs, but was eventually handed over to Kathmandu Metropolitan city following a Cabinet of Ministries resolution in 2008. Since then, it has been used for firefighting as well as search and rescue in natural catastrophes under the authority of the Kathmandu Metropolitan city. Its office is near Basantapur Durbar Square on New Road. (Kathmandu Metropolitan City, 2009)

Juddha Samsher, the then Rana Prime Minister, erected this fire station in 1938, four years after the great earthquake in 1934. The fire engines were imported from the United Kingdom. Later on, the fire station was given the Prime Minister's name. The city's population was only 60,000 at the time, and the residences were largely concentrated surrounding the Durbar Square, which was originally the King's palace. Houses were only around five storeys tall at the time. Since then, neither the technology nor the firefighting system have advanced significantly (Kathmandu Metropolitan City, 2009) . In Kathmandu, Lalitpur, and Bhaktapur, fire hydrants were placed at key intersections during 1938. The majority of these Juddha, Bhim, and Bir 'dhara' were demolished during the road expansion project, and the ones that remain have no mains connections. (Shrestha D. K., 2012)

In the present context, Nepal Disaster Report from 2019 shows that fire is the most prevalent throughout the country amongst all the disasters that have occurred from 1978 to 2018. In the 40 years of this period, there were 12,694 incidents causing 1,755 deaths and 2,176 injuries. Furthermore, 90,044 houses were damaged affecting 265,962 families. (Ministry of Home Affairs, 2019)

One of the main reasons for delayed firefighting service arriving at destination is traffic congestion and second reason is bluff calls. To avoid bluff calls, the firefighting team has to verify the information through other sources like the local police department. This leads to a further delay of 2 minutes. (Pyakurel D. , 2018)

Furthermore, due to the heavy traffic on Kathmandu's crowded roads, it is impossible for these firefighters and fire brigades to arrive at the accident scene on time. As a result, people suffer bigger losses, including the danger of losing their lives, which not only stresses them out but also diminishes confidence of firefighting units due to the public's unwelcoming conduct upon their delayed arrival. (Bhattarai, et al., 2021)

1.4 Research Purpose

There are many cases of urban fire each year inside Kathmandu valley. During the last one year (from November 2020 to 2021) there were 63 recorded cases of fire inside Kathmandu metropolitan city only (Nepal Disaster Risk Reduction Portal, 2022; Nepal Disaster Risk Reduction Portal, 2022). This data excludes other districts inside Kathmandu valley and also other municipalities inside Kathmandu district. From this, it can be seen that there is an essential need to see if the current fire stations assigned are in adequate quantity.

With this, following research questions needs to be studied to research the area properly.

- Is the present response time of fire brigade sufficient to serve the firefighting demand of the valley?
- How many additional fire stations can serve the valley optimally with current road network?

This research paper studies about the current capacity of the fire station inside Kathmandu valley using Network Analysis in GIS software and Allagash model using Python programming. The objectives of this research are:

- To analyze response time of fire brigade departments using GIS to reach different destinations within Kathmandu Valley.
- To optimize the response time by analyzing the total number of required stations and their locations.

1.5 Validity of Research

The Kathmandu valley's population is more vulnerable to fire disasters, owing to a lack of resources and fire stations. The oldest of the fire stations, Juddha, serves millions of people in the Kathmandu valley (Bhattarai, et al., 2021). Chief of Kathmandu fire brigade has mentioned that there is a need for more fire engines and fire stations in the valley. Local governments must have a fire station that can respond first quickly in the event of a fire. (Rai, 2019). This indicates that there is a severe need for fire stations and the current number of stations is very less which has increased the response time to fire event locations in dire situations. Therefore, there is a significant need to study the current fire station capacity to determine the extent of response toward fire.

1.6 Limitations of Study

There are some limitations in the study. The speed of most of the road section is calculated based on actual motorcycle speed and for the sections that could not be travelled, the speed was calculated based on similarity of road categories provided by open street map. The result can differ if the method of speed calculation for fire truck is different. This study uses vector data of roads downloaded on April,2022 from open street map and hence does not take present condition like under-construction or newly formed roads into account. Another constraint is that, this study uses open-source program Allagash to calculate number of required fire stations and for this concave hull is used to determine the polygonal area of service for each point. Due to this, if any other method is used for determining the polygonal area or if different method is used to calculate the optimal number of facilities, the result might differ to some extent. Furthermore, random points were taken for analyzing and determining the optimal locations of fire stations. This study has used 2000 random points throughout the valley to obtain as many locations as possible for the optimal location calculation and hence minimize the error that can happen due to a smaller number of candidate sites.

CHAPTER 2: Literature Review

2.1 Origin of Fire

Fire has been existing on earth since the existence of the plant life forms in the planet itself. The plants provide two of the three ingredients required for fire to exist that are oxygen and fuel. The third component is a heat source which has most likely been available throughout the planet's history. Lightning is the most common source of heat, although it can also come from volcanoes and sparks from rock falls or meteorite strikes. The oxygenated atmosphere was sufficient to enable fire by the beginning of the Paleozoic Era (540 million years ago), but the lack of terrestrial plant fuels limited the possibilities of fire. However, there is evidence of fire in the Silurian origins (24.6 million years ago) of terrestrial plants. (Scott & Glasspool, 2006)

Although fire appears to have existed since plants first colonized land, evidence that fire has altered landscape biogeography and had profound impacts on ecosystem function dates back to the late Tertiary. Indeed, the enormous increase in charcoal deposition in aquatic habitats is frequently cited as proof of fire's emergence as a major ecosystem event. (Pausas & Keeley, 2009)

As hunting and gathering societies transition to agricultural-grazing societies, then to industrial societies in temperate habitats, there are distinct and persistent fire-regime changes. While humans have changed fire regimes since the dawn of time, major changes in fire regimes have occurred in recent decades as a result of large adjustments in human population, notably in terms of urbanization, socioeconomic factors, and land use planning. (Pausas & Keeley, 2009)

2.2 Cases of Urban Fires

Throughout history, devastating urban fires have occurred. Fire has been caused by various natural as well as manmade causes. Cities have been bombed, sacked, and burned during wartime. Earthquake damage, storm winds, accidents, explosions, and arson have all caused fires. Fire during world war has been seen most prominently as war aimed to fire and destroy cities as well as industries. (Brode & Small, 1986)

Several cases of large urban fires have been recorded throughout history. The London fire in 1666 is one of the greatest fires on record. The fire was caused in an area of 2 Km^2, however the human casualty from the fire was very less as compared to area. In less time, the Chicago fire of 1871 killed more people and destroyed a wider area. Following the 1906 earthquake, the San Francisco fire claimed more lives and displaced 100,000 people. The explosion in Halifax, Nova Scotia, sparked numerous flames; the casualty estimates include both the explosion and the fires. The devastating firestorm in Hakodate, Japan, in 1934 claimed the lives of many people. Many fires broke out in Texas City, Texas, after a fertilizer ship exploded in Galveston Bay (Brode & Small, 1986). Table 1 shows some of the major fires before the end of the 20^{th} century.

Table 1 List of some historical large scale urban fires

City	Year	Deaths	Area Burned (km2)	Comments
London	1666	8	1.8	Burned 4 days; 32,000 homes lost
New York City	1835			
Charleston, S.C.	1838			
Pittsburgh	1845			
Philadelphia	1865			
Portland, Maine	1866			
Chicago	1871	50	8.6	Burned 1 day; 98,500 homeless; 17,500 homes lost
Boston	1872			
San Francisco	1906	452	12.0	Earthquake- generated explosions and fires; 30 ignitions; burned 3 days; 100,000 homeless
Halifax, Nova Scotia	1917	2,000		
Tokyo	1923			
Tokyo	1925			
Tokyo	1932			
Niigata, Japan	1925			
Yamanaka, Japan	1931			
Hakodate, Japan	1934	2,000		Generated fire storm
Takaoka, Japan	1938			
Boston	1942	1,000		Explosion and fire; burned 3 days; 3,000 injured; 300 missing
Muramatsu, Japan	1946a			
Texas City	1947	510		Fertilizer ship explosion
Chungking, China	1949	1,000		
Brussels	1967	250		Burned 6 hours
Chelsea (London, England)	1973			400 homes lost
Anaheim, California	1982			500 apartments and 1 firehouse destroyed
Philadelphia	1985			2 blocks of row house gutted

Source: A Review of The Physics of Large Urban Fires (Brode & Small, 1986)

Urban fires can strike even the most modern cities. In April 1982, a wind-whipped fire rushed through Anaheim, California, destroying 500 apartments in a matter of hours.

In early 1985, a flash bomb detonated on a row house in Philadelphia, causing two city blocks to burn out. An arson fire nearly destroyed an industrial part of Passaic, New Jersey, in September 1985. These instances demonstrate how catastrophic urban fires can originate in a variety of ways. Although property damage was considerable, there were few victims in most of these fires. Evacuation and relocation away from the threat was achievable when the fires developed from one or a few starting locations. (Brode & Small, 1986)

Some of the major urban fires have occurred in the past decade as well. Some of the examples below show the recent fire in the 21^{st} century. (WION, 2017)

Shanghai fire, 2010

On November 15, 2010, a 28-story high-rise building in Shanghai (built in 1997) caught fire. The fire was caused by sparks from welding done by illegal personnel, according to reports. The structure housed 440 people, 50 of whom died in the fire. The fire burned for more than four hours, requiring the deployment of almost 100 fire vehicles to assist in the rescue effort. (WION, 2017)

Figure 3 Shanghai Fire, 2010

Source: WION News

Paris fire, 2005

A fire raged through a residential complex housing African immigrants on August 26, 2005, killing 17 people, the majority of them were children. Starting at the ground floor stairway, it raged for three hours in this six-story building. The fire required more than 200 firemen to put out. (WION, 2017)

Dhaka Fire, 2010

On June 3, 2010, more than 100 people died in the Nimtali district of Old Dhaka. A malfunctioning electrical transformer is thought to have started the incident. A wedding party was held on the roof of one of the buildings, resulting in a large number of injuries. The fire was caused by chemicals and combustible polymers kept in surrounding stores. According to an official report, "the feast was cooked on

Figure 4 Dhaka Fire, 2010

Source: WION News

makeshift stoves right adjacent to a chemical warehouse, which heated up the extremely combustible chemicals." Among the dead were more than 40 members of the wedding party. The fire broke out at 10:30 p.m. and raged for more than three hours. (WION, 2017)

Kathmandu, 2017

Figure 5 Kathmandu Fire, 2017

Source: Kathmandu Post, 2017

On Saturday night of September 30, 2017, a major fire broke out in a squatter settlement in front of a fruit market in Kathmandu's Balkhu, destroying at least 40 dwellings. According to the Kathmandu Post, the fire began with an oil lamp and quickly spread to nearby homes. Three persons were reportedly hurt in the incident, and the contents of 40 homes were reduced to ashes as a result of the fire. The fire also caused damage to a nearby church. The Nepal Army's five fire brigades were mobilized to put out the fire, according to the article. (Joshi, 2017)

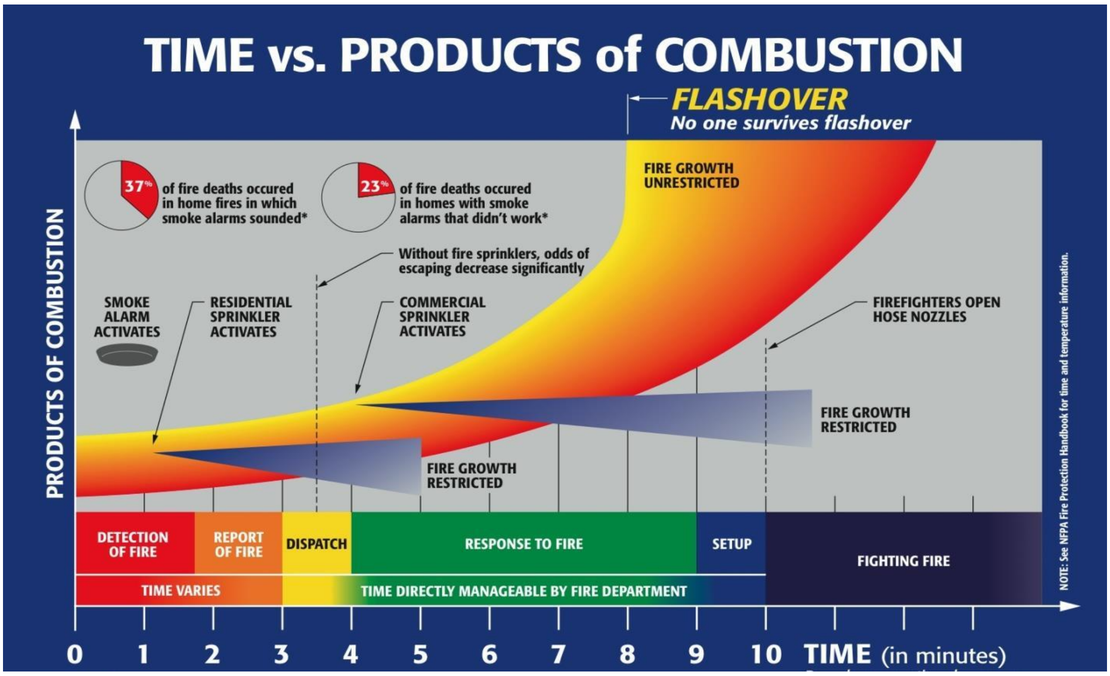
2.3 Characteristics and effects of Fire in Emergency

When an emergency is reported, the most important factor is time. As time passes, the fire will spread, reducing the chances of successfully removing the residents. The amount of time between the commencement of the fire and the start of the fire suppression has a clear correlation with the fire damages. Most residential fires go through the same stages, regardless of how quickly they spread. When the fire has completely consumed the room, this is one of those stages. The Flashover is the name for this level. There are numerous elements that influence when flashover occurs. The type and amount of fuel, the location of the fuel in the room, size of the room, ignition type, weather conditions, and other factors are among them. (Al-Jarallah & Dossary, 2015)

The time it takes for a flashover to occur might range from less than 4 minutes to more than 10 minutes. For common combustibles, flashover occurs when the temperature reaches 500°C and the incident heat flux at floor level is 20 kW/m2. (Al-Jarallah & Dossary, 2015). It is considered as one of the most feared occurrences among firefighters. Firefighters are taught how to spot the indicators of a flashover. If all of this high risk might happen to a qualified professional, such as a firefighter, it will be even worse if regular residents are exposed to it.

The Figure 6 from SFHE handbook for fire protection engineering shows the time taken by fire to start flashover and also the time required for response work to start.

Figure 6 Fire Growth Over Time and Sequence of Events That May Occur from Ignition to Suppression.



(Source: SFPE Handbook 2005)

2.4 Evolution of Fire Fighting

The first initiatives at firefighting can be tracked down back to the second century. Ctesibus, an Egyptian from Alexandria, developed a basic hand pump that could squirt a jet of water at the period, but the concept was lost until the fire pump was reinvented around 1500 AD. After being nearly destroyed by uncontrollable firestorms, ancient Rome established a fire department largely composed of roughly 7,000 paid firefighters. These fire departments not only responded to and fought fires, but they also patrolled the streets and had the power to levy corporal punishment on all those who infringed fire and safety codes. (Merrimack Fire and Rescue, n.d.)

Even though the firefighting is traced to the Egyptian period, it was lost in time. Later a proper fire fighting started from Rome around 2000 years ago. As in the Egyptian period, this firefighting system also dispatched around 500 Vigilant Corps every night. They watched for fire and crime and were also given badges to be recognized by everyone. However, the system was later modified by emperor Nero in 60 AD and became profit oriented. This led the system to fail in a large fire in 64 AD. During the same time, Britain invaded Rome, which led the concept of firefighting to flourish with the British system as well. However, due to frequent wars, the system could not come into full effect. It was only implemented later in the 1600s. (Spell, 2021)

This pattern was followed by other countries in Europe as well. The system had organized firefighting and bucket brigades with critical development of the first dedicated fire engine. Manual pumps were overtaken by suction-and-force pumps drawn by a group of horses by the 17th century. The engine was outfitted with a newly invented adjustable leather hose with brass couplings, allowing for a greater range of water. Insurance companies saw saving structures as a profit motive. Sponsoring fire departments and rescuing only structures covered by insurance and marked by them was a profitable combination that allowed for the expansion of the fire brigade and increased community protection. While none of these advances were able to prevent the Massive Fire of London in 1666, it was obvious that a different model for firefighting in the modern paradigm had emerged. By the turn of the twentieth century, it was evident that such large private organizations and their supporting fire departments would require government monitoring rather than big commercial control. (Spell, 2021)

2.5 History of Fire in Kathmandu City

2.5.1 Lichchhavi Period

There was a large settlement during the Lichchhavi period between Tukucha and Dhobikhola, which was the capital of the Lichchhavi period. Because it was so large, the city was known as Bishalnagar. The city was discovered to have been destroyed by fire with no evidence. In reality, during the reign of Raghavdev (879 AD), a fire in old Bishalnagar made people's lives extremely difficult. Everyone became homeless. They had lost all of their assets. That was such a massive fire that people still remember it today, despite the fact that it occurred more than eleven hundred years ago. The old Lichchhavi capital, as well as the ancient palace Managriha and Kailnshkut Bhawan, were completely destroyed in that fire. People began performing Mhapuja on that day to commemorate the fact that they had saved their lives from a massive fire. (Amatya, 2018)

2.5.2 Singha Durbar Fire, 1977

Singha Durbar was constructed by Shumsher shortly after he was appointed Prime Minister. It began as a small private estate but grew in size during construction. Shumsher subsequently sold this property to the Government of Nepal for 20 million Nepali rupees as the Prime Minister's official residence. Singha Durbar had seven courtyards and 1700 rooms with marble floors, painted ceilings, silver furniture, and expanses of crystal lighting before the 1973 fire. On July 9, 1973, a massive fire engulfed Singha Durbar, blanketing all three wings of the palace except the front oriented wing. Cannon was used to destroy three wings facing north, south, and west to prevent the front wing from catching fire. Following the extinguishment of the fire, the entire area was reconstructed on the previous old foundation. (Bhandari, 2014)

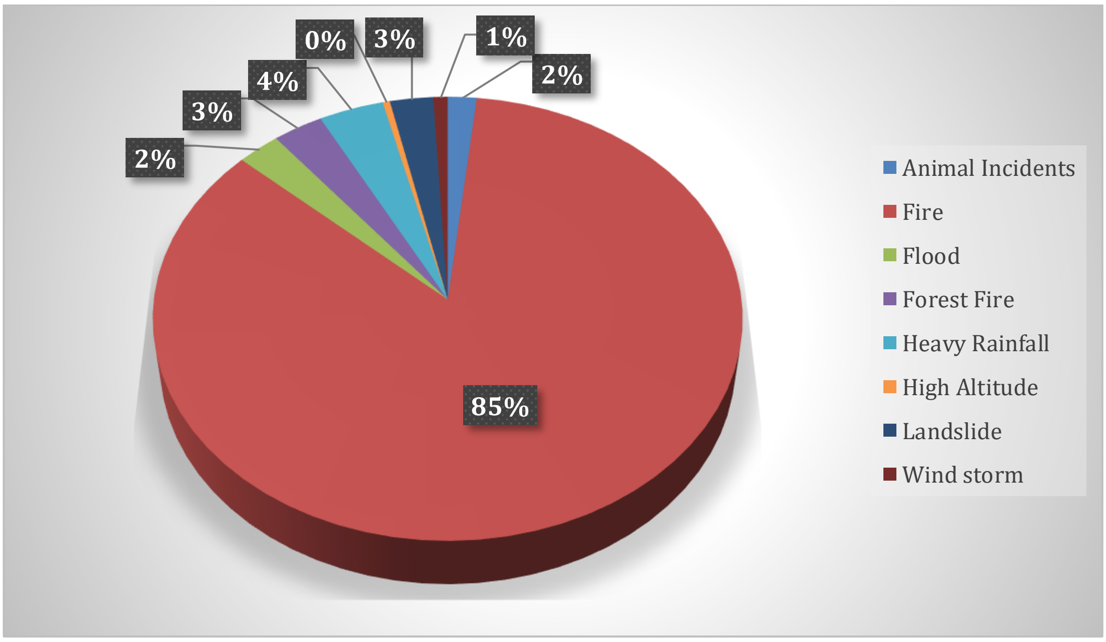
The front portion of the courtyard was only saved and renovated after the fire on July 4, 1974, while the remainder of the courtyard was constructed over the old foundation. Because of seismic concerns, none of the seven courts were built. The roofing was replaced around 1998, and the wooden bracings were strengthened with tie rods. Following the fire, the decorations on the top floor's ceiling were redone. Singha Durbar's cleanliness was also checked. Trucks of bird droppings were taken down from the building during this process. Because of the fire, the Corinthian columns, with their beautiful flower composition and sharp flutes, lost their sparkle. (Bhandari, 2014)

2.6 Present Risk of Fire in Kathmandu

Prajapati in his thesis study "An Evaluation of Fire Safety Measures in High Rise Residential Buildings: A Case of Kathmandu Valley, Nepal" has stated that according to the Metropolitan Police Office, short-circuits cause the majority of fires in Kathmandu Valley. Other causes of fire incidents include kitchen fires, improper handling of matches and lighters, electrical shorts in vehicles, improper handling of an oil-fed lamp in a prayer room, and so on. The primary causes of fire outbreak are short-circuiting, overheating of electronic devices, fluctuating voltage and electric spark after a sudden continuation of power supply just after load-shedding, poor handling of flammable lamps, and cooking gas leakage. Metropolitan Police Office or Juddha Barun Yantra receives one call per day to respond to fire incidents on average. (Prajapati, 2018)

Disaster Risk Reduction Portal of Nepal recorded 233 numbers of various disasters in the year 2021 AD in Nepal. Out of all the incidents, fire disasters were seen as most frequent. 198 number of fire cases were recorded between the period of January 2021 to end of 2021 (Nepal Disaster Risk Reduction Portal, 2022). The Figure 7 shows the graphical pie chart representation of various disaster counts in Kathmandu valley in terms of percentage. This shows the current risk of fire in Kathmandu valley as it has the highest record of incident count.

Figure 7 Disaster incident record in Kathmandu Valley in Percentage



Source: Pie chart created with incident data from DRR Portal, 2022

According to conclusion made by Prajapati in his thesis study, there are several gaps in provisions made in National building code in sector of fire safety of Nepal. A slight priority appears to be given to means of escape, while management and institutional aspects such as training, drill, fire audit, policy documents, space after fire, and reconstruction strategy appear to be neglected.

There is very low level of awareness among occupants of buildings about fire safety measures. Because the institutions did not conduct fire drills and had not been trained in fire safety preparedness, knowledge of fire safety preparedness was low. There is a lack of awareness at the high-rise building level. (Prajapati, 2018)

As there is lack of proper knowledge on firefighting measures among the population and buildings are also lacking on such measures, there is need of looking for other measures to fight fire. One of such measure is improving the condition of present fire brigade.

During earthquake which can affect entire city, Kathmandu valley can have large flow of transit evacuation which can result in vehicle speed of 12 Kmph at worst and 15 Kmph at best case scenario. (Pyakurel, Goerigk, Dhamala, & Hamacher, 2016). The similar situation can also arise if the city is engulfed with massive fire encompassing whole city as a worst-case scenario.

2.7 Fire Brigade Present Scenario

The only fire brigade in Kathmandu, The Juddha Fire Brigade (Kathmandu Fire Brigade), was previously operated by the Ministry of Home Affairs before being handed over to KMC following a Cabinet of Ministries decision in 2008. Since then, it has been used for fire suppression as well as search and rescue operations in disasters under the guidance of the KMC. Its new office is on New Road, near Basantapur Durbar Square. Juddha Samsher, the then-Rana Prime Minister, established this fire station in 1938, 4 years after the large earthquake in 1934. The fire engines came from England. The city had a population of only 60,000 people at the time, and most of the houses were concentrated near the Durbar Square, which was once a royal palace. Houses were only about five floors tall at the time. Since then, neither technology nor the firefighting system has advanced significantly. (Kathmandu Metropolitan City, 2009)

Prajapati in his research paper stated that, until now, the Juddha Fire Brigade has been operating with limited manpower and no proper training. In total, 39 people work in the office, including 11 police officers from the Armed Police Force, 10 city police officers from the Kathmandu Metropolitan City Enforcement Division, and 18 from the Ministry of Home Affairs. A task force is made up of 9 firefighters, including the driver. It can take up to 5 hours to put out a fire. A fire in a straw store near the Pashupati temple once lasted 4 to 5 days. It took 7 hours to put out a fire in a house near the Naryanhiti Museum, which was once the Royal Palace. The property loss in that particular instance was approximated to be above NRs. 5 million. The fire station also serves neighboring cities such as Lalitpur, Bhaktapur, and Kirtipur, as well as the adjacent Villages. The Kathmandu Fire Brigade also serves municipalities and placess up to 30 kilometers away, including Kirtipur Municipality, Panauti, Lubhu, and Sankhu. In the past, there have been approximately 350 cases per year, including search and rescue when people drown in a well. (Prajapati, 2018)

A thesis by Gautam in 2022 has identified water as a prime suppressing material for fire at household level in valley. Therefore, a response system based on water is recommended by the researcher. Further, Kathmandu valley has high risk of fire due to various factors such as, LPG gas distributers near residential areas and high rise building without fire safety equipment. Other risk factor includes building material type, building occupancy, density. Accessibility, fuel sources and electrical lines. (Gautam, 2022)

A researcher in Pulchowk campus in year 2019 studied about the current capacity of fire station in Kathmandu Valley and found various conclusions. The study was conducted for the current capacity of fire station in term of infrastructural capacity, managerial capacity, financial capacity and institutional capacity. During the study, it was found that the current situation of fire station was extremely lacking in almost all the situations. During the study, there were only 3 fire station inside the valley and it covered only 1.3% of the valley with proper travel time of 4 minutes. The Kathmandu valley should have at least 113 fire engines capable of firefighting according the standard set by NFPA. (Niraula, 2019)

Various cities have varying number of fire stations. Some of the major cities are listed below:

Table 2 Number of fire station in various cities worldwide

City	**Fire station count**	**City area (Km^2)**
Kathmandu Valley (All three districts)	4	933.4
Delhi	64	1483
New York	218	783.8
London	102	1572
Toronto	83	630.2
Vancouver	20	115
Tokyo	81	627.6
Paris	81	105.4
Los Angeles	106	1299

From the table above as well, one can see that number of fire station in Kathmandu valley is severely lacking. Most of the cities worldwide has focused their resources on urban fire by deploying fire station at various location of the city. However, Kathmandu valley which also has the capital city Kathmandu has very less number of fire station managing the whole valley.

Questionnaire Survey with Chief of fire station was conducted in fire brigade head office located in Newroad. The question and answer of the survey is attached in appendix of this thesis. Currently, there are 4 fire stations in use. They are Juddha Barun yantra, Newroad, Fire station and training center, Ramhiti(Kathmandu ward-6), Juddha Barun yantra, Lalitpur and Juddha Barun yantra, Bhaktapur. Fire truck from army can also be deployed on request and has helped in some of the fires as well. Fire station inside airport can also be deployed on request for nearby areas. While some municipalities initiated using fire truck at the beginning, however, they stopped functioning with time due to lack of resources. Budanilkantha municipality handed over their truck to army due to lack of manpower. Chandragiri municipality also stopped serving due to lack of manpower. Currently, there seems to be minimal chances of municipalities using fire truck. The Kathmandu fire brigade has made plan to extend service to 3 more places. However, they are not yet implemented. The places are Balaju, Min bhawan and Kalanki.

Fire truck faces difficulties due to traffic congestion, potholes as well as wires hanging around in the city area. These factors severely increase the response time. Firefighting motorcycles are also being used regularly. However, they can only be used in small fire incidents such as fire on electric poles or other such small fire where smoke extinguishers can be used.

During peak hours of Kathmandu valley, speed of fire truck ranges from 20 Kmph to 35 Kmph. Most of the road user are educated and provide access way for emergencies vehicles, hence the speed can be maintained to 20-35 Kmph in peak hours. However, speed in very narrow road is severely less. Some pedestrian only type of road cannot even be accessed by fire truck.

Furthermore, it has also been researched that average speed of motorcycle in Kathmandu valley is 29.79 Kmph with standard deviation of 6.72 Kmph in one way 3.6m roads, two way undivided 3.25m roads have speed of 24.35 Kmph with standard deviation of 6.63 Kmph and two-way undivided road with width 2.95m has 20.25 Kmph with standard deviation of 5.25 Kmph (Shrestha A. K., 2012). From the survey questionnaire with fire department as well as study of past research studies, it can be found that speed of motorcycle in Kathmandu valley is similar to the speed of emergency vehicles.

2.8 International Practices for Fire Fighting Response

An international non-profit organization called National Fire Protection Association (NFPA) researches about various fire safety protocols and has various standard handouts as well as various books relating to fire hazards.

For not less than 99% of dispatched incidents, NFPA Standard 1710 establishes a 40 second alarm answering time and 106 second of alarm processing time (which amounts to total of 146 second of total call processing time). It also provides an 80 second "turnout time," and a 240 second "travel time" which totals to 520 second of response time (5 minute and 20 seconds) for more than 90% of the fire incidents. (NFPA, 2019)

The first fire truck should have 240 seconds (4 minutes) of travel time. Second truck should arrive at 360 seconds or less travel time (6 minutes). There is also a provision of full alarm assignment which occurs at 480 seconds for normal buildings and 610 seconds for high rise buildings. (NFPA, 2019)

During the various research studies, it has been found that response time of 10 minutes is taken in various cities as a maximum response time. This kind of study provides the minimum number of fire station required for the city. A study in Madurai city conducted by Central University of Tamil Nadu shows that fire station should have maximum of 10 minute of travel time and has also developed optimal numbers of fire station required for the city. (Balasubramani, Gomathi, & Prasad, 2016)

A research study conducted by Renkas, Popovych, & Rudenko mentions that the maximum time for response of fire truck for a city is 10 minutes, while the maximum time for the countryside is 20 minutes. The time it takes to arrive at the scene of a fire varies by country and can range from 5 minutes to more. This time may be doubled in rural areas. In Ukraine, for example, state fire departments should be located in such a way that the time of arrival does not exceed 10 minutes in the city and 20 minutes in the countryside. (Renkas, Popovych, & Rudenko, 2022)

Some studies regarding response time planning are also made with 5 minute of travel time. A study made by researchers for optimizing number of fire station in Istanbul metropolitan municipality has made their study based on 5-minute response time. (Akta¸s, Özaydın, Bozkaya, Ülengin, & Önse, 2013)

2.9 GIS for Fire Fighting

While city development leads to increased economic growth, it also increases the risk of fire. Larger volume, complicated function, high crowd density, and increased fire risk are all new characteristics of urban buildings (Xin-ming DONG, 2018). At the same time, the buildings are near together, making it possible for a continuous fire catastrophe to occur. Furthermore, the internal circuit facilities of these buildings are significantly aging, making them easier to create fire and lacking in fire extinguishing and rescue capabilities. Therefore, the old fire protection plan cannot meet the requirements of the rapidly developing area of Kathmandu.

Routes are now plotted using GIS navigation tools for network analysis. These tools are also used to handle transportation issues such as accessibility and service area determination. For mapping service areas, GIS applications provide analytical tools. It is used to determine transportation accessibility, influence zones, and risk zones. The findings are displayed in a map format. Polygons are used to define service regions, with accessibility values specified at regular intervals. (Flisek & Lewandowicz, 2019) This received cartographic result can be used to plan various network problems such as selecting optimal sites for new projects, determining serviceability extent of current site locations, etc. As such, this study can be used for fire station serviceability at the present situation as well.

Data from GIS and analytical techniques are frequently used in disaster management planning. Any delay in a fire service station responding to a fire or other emergency could escalate the situation. It becomes evident that pre-planning actions will play a critical role in the appropriate deployment of critical resources to deal with fire risk situations (Balasubramani, Gomathi, & Prasad, 2016). GIS can also be used to measure accessibility in terms of distances or trip times, as well as to analyze accessibility against a set of criteria. This kind of study has been made for determining response time of ambulance services as well by various researchers.

A model of the road network and base points are used to create an algorithm for selecting service areas. The position of an object (facility) whose accessibility will be assessed is referred to as a base point (Flisek & Lewandowicz, 2019). Fire stations are identified as base points for this research purpose. The adopted distance time, such as the maximum distance that a fire truck can travel to reach an object (facility) within a particular time restriction, is used to determine accessibility.

The algorithm determines the effective reach of the road network from a starting location at a certain time cost in the first stage. It constructs a star pattern with selected road segments extending from the base location. The program then creates a Triangulated Irregular Network (TIN) based on the points in the road network. Weights from the road network are allocated to the TIN's vertices, which are equal to, for example, the road distance from the base point. Linear data from the road network can be extrapolated to surface data using the TIN (space between roads). In the chosen time cost intervals, TIN data is interpolated to build service area polygons. Various research projects have employed such assessments to solve transportation, economic, social, security, and other issues. (Flisek & Lewandowicz, 2019)

2.10 Network Analysis in GIS

Network analysis is a GIS operation that examines datasets from a spatial or real-world network. Network analysis and location-based analysis explore the features of natural and man-made networks in order to comprehend the behavior of flows inside and around such networks. It employs edge-node architecture to depict real-world information networks.

Network analysis has long been regarded as one of the most difficult challenges in the field of transportation, utilities, and drainage. Any system that aspires to genuinely depict the complexities and functional structure of networks must account for the many various types of movement that occur via segments in the mesh, as well as the unique properties of different types of interlinked linear structures. Most aspects of surface vehicle transportation networks, such as direction of flow, capacity, speed constraints, traffic control mechanisms, and traffic itself, can be correlated with linear segments of networks via their attributes. Networks are made up of linear features that are linked together to form systems that allow data to flow between the connected linear features (McHaffie, Hwang, & Follett, 2019). Network analysis is being used in various sectors. Shortest distance to specific location is one of the major analyses carried out by the use of Network Analysis.

You can use GIS capabilities to calculate the shortest driving route between two or more places, find the closest facility (through a road network), and build buffers based on driving distance rather than a circular radius. These forms of network analyses are used by a wide range of professionals, including emergency responders, delivery businesses, and real estate salespeople. (Shellito, 2021)

A network analysis is essentially a collection of interconnected lines. These lines indicate trains, rivers, roads, sewer lines, pipelines, telephone lines, and other networks that must be analyzed. It might be either direct or indirect, as well as planned or unplanned. The movement of people, the connectivity and accessibility of railways, roads, pipelines, and telephones, the flow of matter and energy, and the movement of commodities and services are all investigated by networks.

Various operations can be operated in GIS such as; (GISGeography, 2022)

a. Point-to-point analysis

The most common routing concern is a point-to-point analysis. It consists of a series of locations used to determine the best route based on a combination of criteria such as shortest route, fastest route or nearest location based on route structure and speed limits.

b. Coverage Area analysis

Service areas of any facility are found based on the coverage area of the facility. For example, houses that fall under 5-minute travel distance from a fire station.

c. Optimize Fleet

The goal of this network analysis tool is to determine the most efficient delivery, repair, transit, or fleet service route. When dealing with the traveling salesman situation, this product is appropriate for servicing a batch of orders. Additionally, controlling fleets of vehicles and drivers is the most effective way to reduce overall operating costs.

d. Optimal site selection

Optimal site selection considers the need to find the best location given a variety of characteristics. It can, for example, assist in determining where new fire stations should be built based on existing fire stations and demand.

e. Origin-Destination matrix

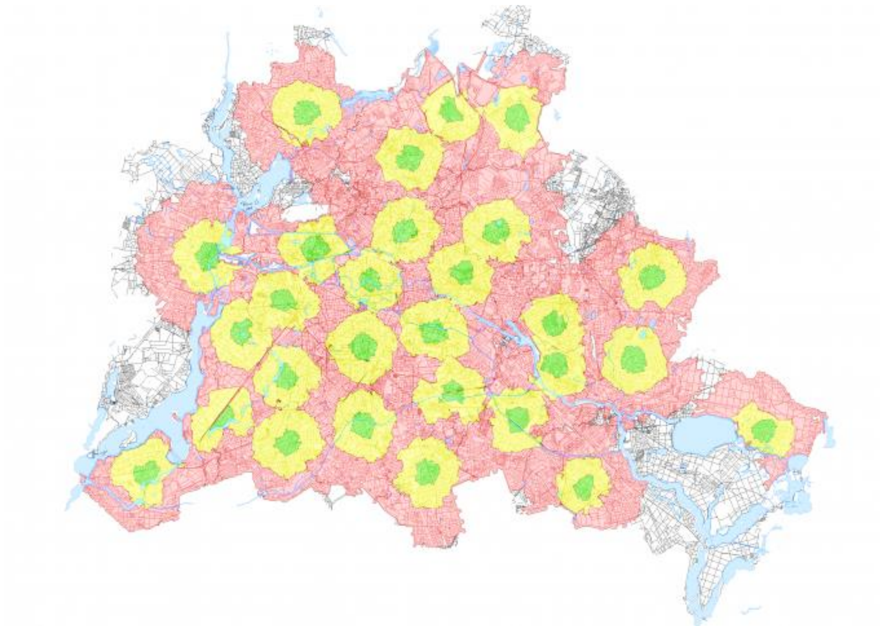
To find the distances between several locations in two different sets, this form of network analysis uses two sets of locations. The OD Cost Matrix calculates the cheapest path among several origins and numerous destinations.

2.11 Service Area Analysis

In network analysis, a service area or drive time polygon is used to establish which sections of a network are close to a specific place or facility and hence "served" by that site. The service area for a network is a polygon (or series of polygons) specified by the network's resistance factor like actual driving distance or driving time (Shellito, 2021).

Based on driving time, Figure 8 depicts several service regions for fire stations.

Figure 8 Example of Fire stations' service areas, based on driving response times



Source: (GISGeography, 2022)

The various colors in service zones indicate which portions of the network may be reached in a particular period of time from the fire station.

Service areas are used to establish a facility's accessibility and can be considered upon as buffers surrounding the facility point, however the buffer is confined by network parameters rather than being a huge circle. A circular 1-kilometer buffer around a fire station, for example, is likely to differ dramatically from locations on a network that may be accessed within 1 kilometer of driving along urban roads. Service areas are used to determine which areas of a network can be reached by emergency vehicles in a specific period of time, which parts of a network are within a certain walking distance of a store, and which portions of a network are within a certain walking distance of an institution. (Shellito, 2021)

2.12 Location Optimization

Location optimization models are aimed at locating facilities in order to efficiently meet demand. These models are critical in the management, planning, and decision-making of both public and private service systems. As a result, location optimization models are now included in a variety of GIS tools, both closed and open source. Because of their transparency and reproducibility, open-source tools are advantageous. (Chen, Murray, & Jiang, 2021)

The study about comparision of various location optization model conducted by Chen, Murray, & Jiang in 2021 researched about four different models namely, ArcGIS, PySpatialOpt, Maxcovr and FLP Solver. The study concluded that, in terms of way to solve optimality, scalability, and distance types, PySpatialOpt and Maxcovr surpass FLP Solver and ArcGIS. In many ways, the distinctions between these methods are noticeable. In terms of problem assumptions, open-source solutions are more adaptable than ArcGIS because they support a wider range of space and distance metrics. Furthermore, in contrast to FLP Solver and ArcGIS, PySpatialOpt and Maxcovr use exact methods and mathematical solvers like GLPK to solve location cover problems. (Chen, Murray, & Jiang, 2021)

Software documentation is essential to ensuring that the code can be used by others and that the cases can be replicated or reproduced. Documentation is another important consideration when choosing open-source GIS software. While the documentation for PySpatialOpt and FLP Solver is extensive and clear, documentation for the MCLP in Maxcovr is limited. This is also true for ArcGIS, which has no documentation explaining why, when an LSCP is not attainable, the model turns up a facility setting that encompasses only those demands that can be met. (Chen, Murray, & Jiang, 2021)

This thesis study also utilizes the open-source model named Allagash, which is an updated version of PySpatialOpt. The model also solves with the help of mathematical solver, GLPK and runs alongside open-source project Geopanda which is a geospatial operator working with the help of Python Programming. (Pulver, 2021)

CHAPTER 3: Research Methodology

3.1 Introduction

Research Method to be used in research depends on the research paradigm which has three main components namely, ontology, epistemology and research methodology. A research paradigm is a model or method that a large number of researchers in the field regard as the norm on the basis of both validation and experience.

A research paradigm inherently reflects the researcher's beliefs about the world that he or she lives in and wants to live in. It constitutes the abstract beliefs and principles that shape how a researcher sees the world, and how they interpret and act within that world. (Kivunja & Kuyini, 2017) There are various forms of paradigm, in which, interpretive and positivist paradigm are considered to be two main paradigms for research. However, other paradigms such as constructivist and post positivist paradigm also exist which are similar to some extent with the interpretive and positivist paradigm respectively. Pragmatic paradigm focuses on solving the research problem by finding the gap in the research object by analyzing both natural science and social science fields.

The research is quantitative in nature as it looks at time and speed factor of fire brigade response time. It does not look at the qualitative nature of research. Furthermore, the research is based on simulation that is to be carried out using existing road data. Therefore, it uses natural science which is to be researched using scientific technology. Due to this, the research is under the post-positivist paradigm.

The ontological claim of this research is that the current number of fire stations is not sufficient to provide safety against fire hazards inside Kathmandu valley. There are many cases of fire each year inside Kathmandu valley and each year that can be heard in some news of massive fire disasters occurring which has caused large amounts of property damage and some cases of death and injuries as well.

In nearly every branch of science, systematic study contributes to advancement; as a result, research is frequently considered as a backbone of scientific advancement. The goal of research is to find answers to questions and learn new things. Research is a unique contribution to the body of knowledge that contributes to its growth. It is the search for truth by study, observation, comparison, and experimentation. In a nutshell, research is the pursuit of information through an objective and systematic approach of seeking a solution to a problem.

Psychology, biology, medicine, physics, and botany are just a fraction of the scientific subjects where study contributes to what one knows and how one thinks about stuff. Researchers do research to minimize the complexity of problems, understand the connection between seemingly unconnected events, and ultimately enhance the way a person live. Testing hypotheses, thorough observation and measurement, organized data analysis, and generating solid conclusions are all hallmarks of scientific inquiry in practically all fields of study. (Marczyk, DeMatteo, & Festinger, 2005)

A research methodology is a method for solving a research problem in a systematic manner. It can be thought of as a science that studies how scientific research is carried out. Research can be classified into either quantitative or qualitative research. Research is grounded on determining the quantity or amount of something. It can be used to describe phenomena that have a numerical value. Qualitative research, on the other side, is focused with qualitative phenomena, such as those involving or pertaining to quality or kind. For example, when one is trying to figure out why people behave the way they do. Based on the area in which the study is to be conducted, it can be field research, laboratory research, or simulation research (Kothari, 2004).

The simulation approach entails creating an artificial environment in which useful data and information can be created. This allows for the monitoring of a system's (or a sub-system's) dynamic behavior under controlled conditions (Kothari, 2004). Since this research study involves spatial data input into GIS and conducts analysis with the help of a computer system, this type of research falls under simulation research approaches.

When working on a GIS study, you must go through four different phases of conceptualization, or simulation, in order to complete it (Steinberg & Steinberg, 2015):

i. Analyze the situation you'll be studying in real life.
ii. Comprehend the idea in words that are suited for a computer-assisted analysis.
iii. Arrange the analysis in a logical sequence.
iv. Put the relevant software procedures into action.

3.2 Conceptual Framework

There are several aspects to consider when determining how many people a fire station can serve. The phrase "network analysis" in GIS refers to operations that look at traveling time, service areas, and other GIS issues that need knowledge of and comprehension of a road network (McHaffie, Hwang, & Follett, 2019). When investigating connections that follow specified pathways, network analysis is most suited. These are most typically associated with infrastructure or transportation in GIS. McHaffie, Hwang, & Follett in their book 'GIS An Introduction to Mapping Technologies' has provided an example of application of service area and location allocation for health service. This study can also be applied for fire station allocation with study of its service area as well.

GIS network analysis is a broad topic that involves numerous ideas and procedures from the domains of computer science and mathematics. Dijkstra's algorithm, developed by computer scientist Edsger W. Dijkstra in 1956, is particularly significant in this context because it is still employed in both computer science and GIS generations later. To determine the shortest distance between two sites based on the cost of travel, network analysis tools in GIS software still utilize a form of Dijkstra's algorithm. The method works by simulating all possible paths from a starting point to an endpoint and then selecting the cheapest option. (McHaffie, Hwang, & Follett, 2019)

In urban areas, the transit distance between people's homes and fire stations is affected by traffic conditions, traffic signals, one-way streets, and other obstructions. The distance between two points is referred to as a direct Euclidean distance. According to Euclidean distance, if you walked from one end of a park to another with nothing between two but grass, you will be able to walk in a straight line. Manhattan distance, on the other hand, denotes distances that may not be fully straight lines and may involve turns and twists comparable to those found on city roads. These kinds of problems are solved with the help of GIS software which utilizes Dijkstra's algorithm. (ESRI, 2022)

QGIS uses Dijkstra’s algorithm to analyze the network problems. (Graser, Mearns, Mandel, Ferrero, & Bruy, 2017) This algorithm is used for almost all the analysis for networks such as, Service area and shortest path.

Coverage modeling is commonly used to determine the best spatial configuration of a collection of facilities that provide some level of service to demand units. It is frequently necessary to "cover" demand within a certain time or distance. This study utilizes Allagash which is a python-based open-source programming for optimization of location. The solver for this program has been uploaded in github website. The location optimization commences by creating a service area matrix of all of the network's facilities and demand point locations. The most recent version of Allagash supports the Location Set Covering Problem (LSCP) and Maximum Covering Location Problem (MCLP) models only. This study uses the LSCP for the optimization of fire stations. (Pulver, 2021)

Algorithm used while solving problem related to Service area and Location optimization are as follows:

3.2.1 Dijkstra's algorithm

On a weighted graph, the classic Dijkstra's algorithm solves the single-source, shortest-path issue. Dijkstra's approach maintains a collection of junctions, **S**, whose final shortest path from **s** has already been computed, in order to discover the shortest path from a starting position **s** to a destination site **d**. The procedure discovers the shortest-path estimate of all neighbors of this junction that are not in **S**, adds it to the set of junctions **S**, and updates the shortest-path estimates of all neighbors of this junction that are not in **S**. The process is repeated until **S** contains the destination junction. (ESRI, 2022)

3.2.2 Service area

To successfully navigate the network, the Service Area function uses Dijkstra's algorithm. The goal of this function is to generate a vector containing all of the network layer components that can be reached within a specified time or distance from a point on the map. The service area solver can generate lines. (QGIS, 2022)

Further, the obtained service area lines can be made into polygon form by various methods like convex hull, polygonise or concave hull. This thesis study has made polygon with the help of convex hull and uses the data for further processing in location optimization of fire stations.

3.2.3 Location Optimization

The facility (fire station in our case) location problem is solved by location optimization. Such that, given N number of candidate facilities and M weighted demand points, select a subset of the facilities, P, whereby the total amount of the weighted distances out of each M to the nearest P is minimized. This is a N Choose P combinational problem with an extremely large candidate solution. Examining all possible combinations will not yield optimal results. Even a simple problem like 100 (N) choose 10 (P) has over 17 trillion possible solutions (ESRI, 2022). This study utilizes python programming Allagash by pairing with output obtained from service area of QGIS. Allagash is an updated version of PySpatialOpt program which is an open-source program that runs with support of GLPK, a mathematical solver and Python programming. (Pulver, 2021)

During the study, service area is created for two thousand locations points throughout the valley and demand points are also taken. The demand points are taken as buildings, cultural sites and fuel pumps. During the python programming for LSCP using Allagash, the service areas as well as demand points are taken as input and solved with the help of GLPK solver which is also an open-source program that runs along with python. (Pulver, 2021)

3.3 Method and Techniques

The research study consists of two major steps to identify the current coverage area of fire stations and solve the problem of lack of number of fire stations. These two steps can be studied with GIS network analysis tools, namely service area analysis and location optimization analysis. The research study uses a simulation method of analysis to complete the research problem. For this various real-world data are taken into account to create spatial data for computation in GIS software for network analysis.

For the study of service areas various spatial vector data are required. Two of the main vector data are the road network which includes type of road, one way road data and vehicle speed in the road sections and existing location of fire station facilities. For the study of location optimization, field study of probable fire station locations is required. Numerous fire station locations will be taken based on study of various documents as well as visits to sites for open spaces.

3.3.1 Spatial Data Collection

Road Network

Road network is the most crucial part of the network analysis. Without the data on the road network none of the process can be progressed further. Therefore, spatial data in vector form is required for the analysis.

GIS software uses Shapefile or geodatabase for the storage of vector data. Vector data for the road network can be obtained from the survey department of Nepal. The road network contains various types of road and data for one way and two-way lanes. Various types of classes of road found in the road network attribute table are construction, living street, primary, primary link, residential, road, secondary, secondary link, service, tertiary, tertiary link, trunk and unclassified.

3.3.2 On Field Survey and Data entry into GIS

Vehicle speed

Vehicle speed varies by various factors. It can be different even for the same class of road. The speed can depend on several factors such as time of the day, business area, residential area, type of road, condition of road, etc.

Vehicle speed for various road sections can be found from study of various research papers relating to traffic study in Kathmandu valley. On the other hand, it can also be manually found by driving a motorbike through traffic during peak hour. Some of the data on speed can be verified by interviewing with duty officers at fire stations.

Fire station facilities

For further planning of the fire station for future development, the current number of fire stations and its coverage area needs to be identified. For this problem first and foremost, the location of the fire station in the present context is required. By doing this, the area that the fire station can serve can be identified.

Locations of fire stations in the city area can be found manually as well as by asking the local people. The coordinates of the existing fire stations will be recorded and entered into GIS with the collected coordinates.

Probable Fire station facilities

For the development of fire stations, various candidate locations for future planning of fire stations are required. However, not all of the locations can serve as ideal places for helping the public. To search for the optimal locations for planning, several candidate locations need to be identified so that it can be further analyzed to give a minimum and optimal number of fire stations with required constraints of time limit.

Location analysis of fire station also requires demand points where the fire station is required to be served. Demand points are those points where the required facility is to be served. These areas can be taken as normal building areas, fuel pump locations as well as cultural sites.

3.3.3 Analysis

After collection of all required data, the analysis of the network can be done. For finding the coverage area of a fire station, a service area tool is used. The tool can provide a polygonal area of coverage for specified period of travel time or distance. For the additional number of fire stations required, location optimization models can be used. It helps by identifying the optimal number of stations out of several candidate locations.

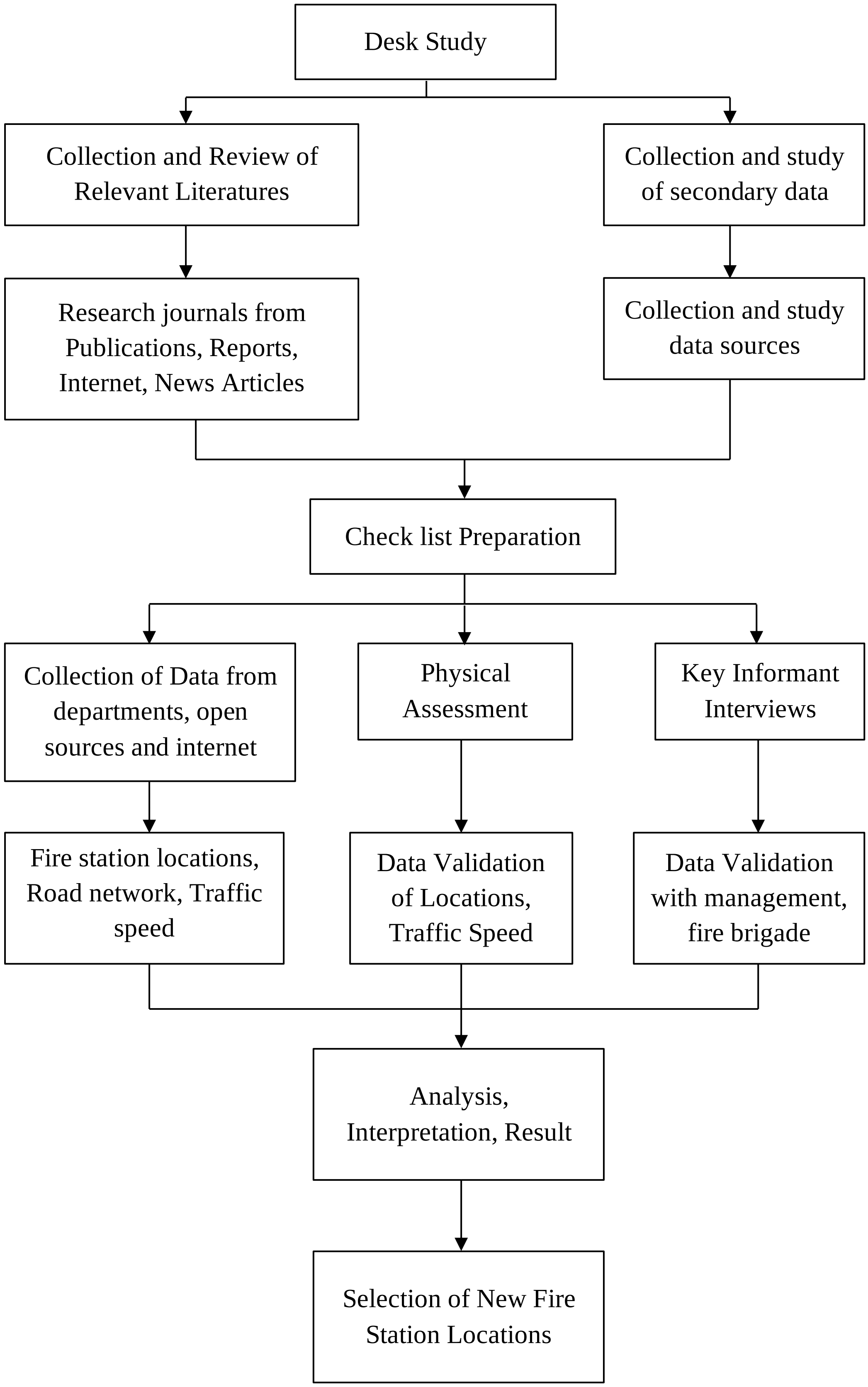
Service area tool

Service area tool utilizes the data of the Road network with speed included in it and the fire station location. It provides the result of distance traveled for specified time periods which can be further converted to polygonal form with help of concave hull tools in QGIS.

Location optimization model

Location optimization model refines the optimal number of fire stations from several numbers of candidate locations to provide the necessary number of fire stations required to function properly in the urban area of Kathmandu.

3.4 Flow Chart diagram for methodology



3.5 Data Collection

Both primary and secondary data are required for this research and they were acquired through data from survey department, key informants' interviews, books, internet, and articles and physical assessment of road segments.

Primary Sources

Primary data like the road network, buildings, cultural sites as well as location of petrol pump and its information was collected from the open sources like open street map. Speed on the road was taken by manually visiting various road segments and driving through peak hours. For the study purpose, assumption for road speed was taken for most parts of the roads. Location coordinates of the existing fire station were taken manually by visit to site and with the help of a GPS device.

Secondary Sources

Secondary data were collected from various sources for literature review and other project implementation works. Speed at road for emergency fire truck was also taken with survey questionnaire from fire department and validated with manual driving of motor bikes at various locations. Different sources of literature such as books, articles, journals and researches were studied to get theoretical information about the fire safety measures. These were also used for studying various methodology to find the service area and location optimization models of fire stations.

CHAPTER 4: Data Analysis and Results

This thesis studies the fire station service area in Kathmandu Valley. The spatial data has been obtained from various sources such as internet open sources open street maps, *geofabrik.de*, *data.humdata.org*, *opendatanepal.com*. Coordinates are obtained from google map and verifying by manually visiting. Speed is obtained from manual driving through peak hour as well as past research paper data and validating it with survey questionnaire taken with fire department.

4.1 Service Area

Service area can be obtained by calculating the total time required to travel through the road network to or from the provided facility. For Fire station, the fire trucks require to serve the population, therefore, the service area is taken for travel distance from fire station to various locations around the station. For this, the required data are location of stations, road network and its parameters like one way street data, road speed to obtain the time of travel in each road segments. Following are the parameters taken in solving the service area and the final result obtained for the service area of the fire stations in Kathmandu Valley.

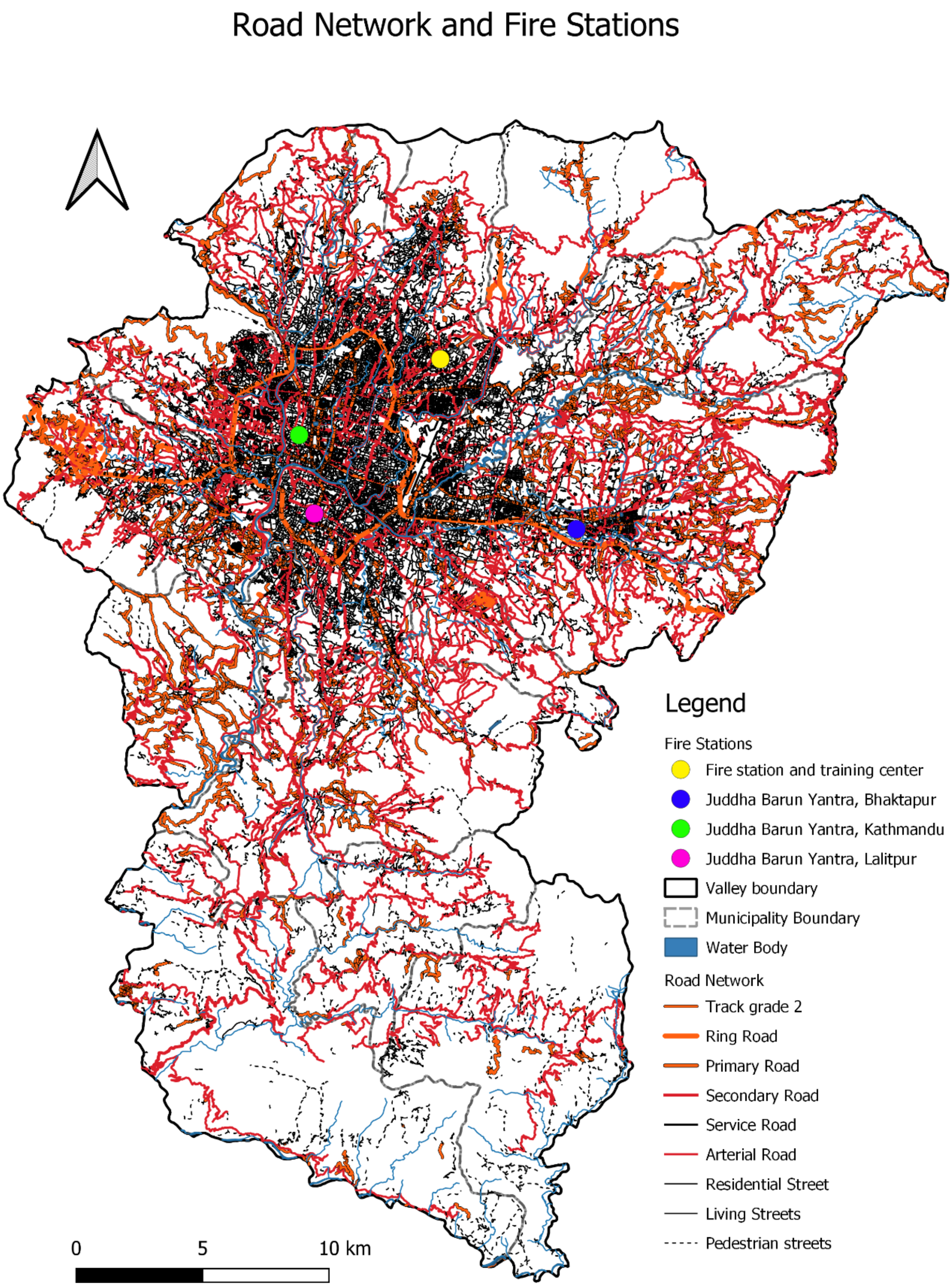
4.1.1 Location of Fire Stations

Fire station has been located from google maps and has been verified manually by visiting the site. Four locations have been identified inside Kathmandu valley, i.e., Juddha Barun Yantra Office, Newroad, Fire Station and Training center, Ramhiti, Juddha Barun Yantra Office, Lalitpur and Juddha Barun Yantra Office, Bhaktapur.

4.1.2 Road features

Road network for Kathmandu valley was taken for the study. For this study purpose, the road network is clipped with the boundary of three districts namely, Kathmandu, Lalitpur and Bhaktapur. The road network used in this study has various road classifications. It consists of various road categories such as, construction, living street, primary, primary link, residential, road, secondary, secondary link, service, tertiary, tertiary link, trunk and unclassified. The categories have been compiled and grouped as Ring Road, primary roads, secondary roads, service road, arterial road, residential streets, living street and pedestrian street according to speed in this research study. Figure 9 shows the road and river network in Kathmandu valley with various road class categories.

Figure 9 Road Network with fire station location of Kathmandu Valley



The road types are taken from open street map and is categorized according to feature of road. Parameter of categorization of each road type is as given in Table 3:

Table 3 Parameter for categorization of roads

Road Class	Description
	Major roads
trunk	Ring Road
primary	Primary roads, typically national.
secondary	Secondary roads, typically regional.
tertiary	Tertiary roads, typically local.
	Minor Roads
unclassified	Smaller local roads
residential	Roads in residential areas
living street	Streets with priority to pedestrians
pedestrian	Streets for Pedestrian only
	Links for Major roads
trunk link	Roads that connect from trunk road to another of the same of lower category.
primary link	Roads that connect from primary road to another of the same of lower category.
secondary link	Roads that connect from secondary road to another of the same of lower category.
tertiary link	Roads that connect from tertiary road to another of the same of lower category.
	Very small roads with less traffic
service	Service roads for access to buildings, parking lots, etc.
track	For agricultural use, in forests, etc. often consisting of gravel roads.
track grade1	Asphalt or heavily compacted
track grade2	Asphalt road
track grade3	Broken asphalt road
track grade4	Gravel road
track grade5	Earthen Road
	Paths unsuitable for 4-wheel vehicles
bridleway	Stone paved paths
cycleway	Cycling Paths
footway	Footpaths
steps	Flights of steps on footpaths

Source: OpenStreetMap Data in Layered GIS Format by Frederik Ramm

The road segment length has been calculated in the attribute table for the analysis purpose. Further, for research study purposes, speed of each road segment has been obtained based on manual bike survey during peak hours as well as study research by Hemant Tiwari. The speed of roads in major roads of Kathmandu valley ranges from 22 Kmph to 31 Kmph (Tiwari, 2015). The speed taken has been validated with speed in field as experienced by fire truck driver with the help of open-end questionnaire survey with fire department. Fire department experiences speed of fire truck ranges from 20Kmph to 35 Kmph during peak hours in Kathmandu valley. Most of the road user are educated and provide access way for emergencies vehicles, hence the speed can be maintained to 20-35 Kmph in peak hours. However, speed in very narrow road is severely less.

With this study, following Table 4 data has been put into effect:

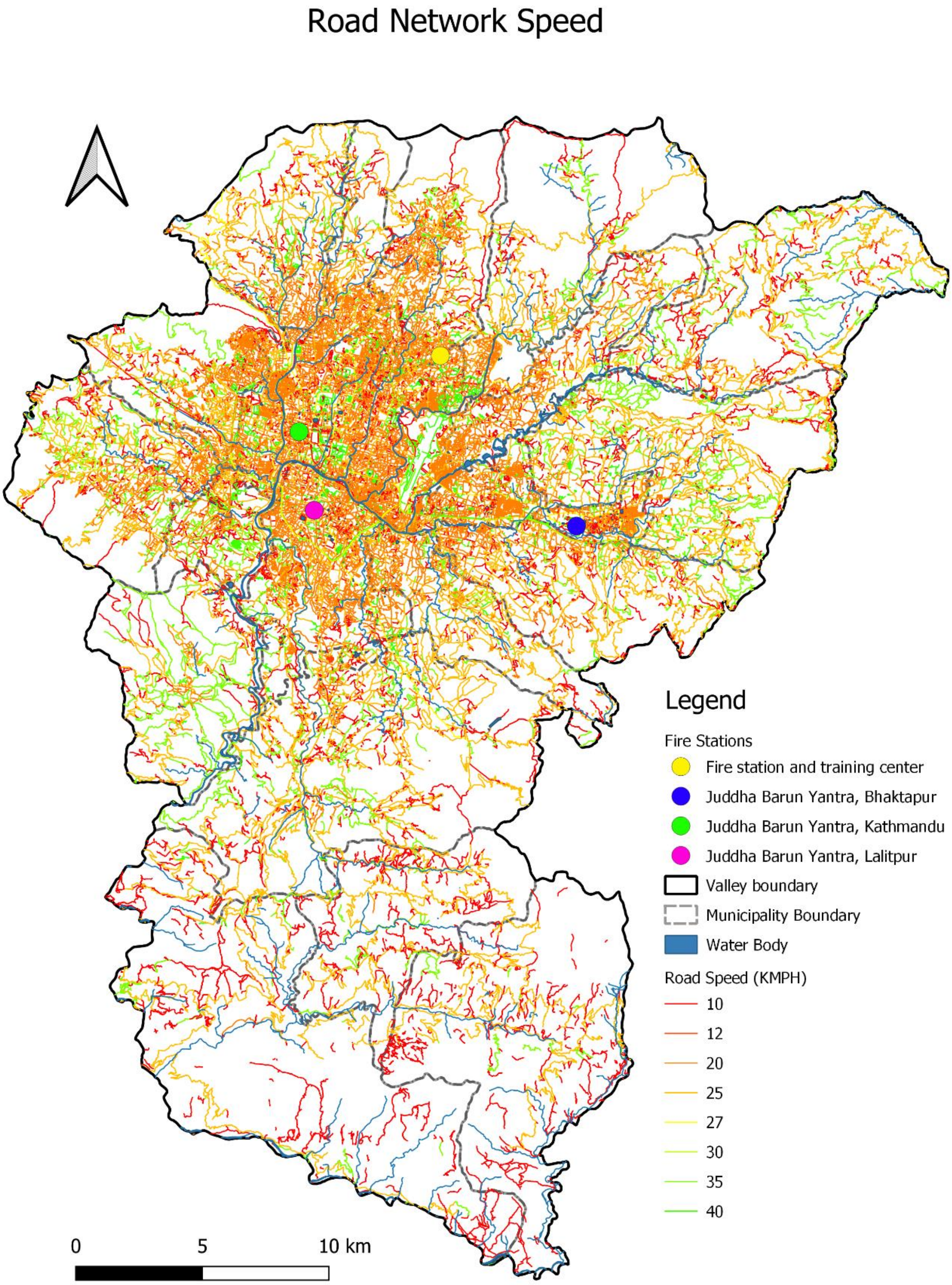
Table 4 Implemented speed for analysis

Categories	Road Class in GIS Attribute table	Speed Implemented (Kmph)
Track grade 2	Track, Track grade 2	35
Ring Road	Trunk, Track grade 3	30
Primary Road	Primary, Primary link	27
Secondary Road	Secondary, Secondary link	25
Service Road	Service, Track grade 1	40
Arterial Road	Tertiary, Tertiary link, Track grade 4	25
Residential Street	Residential, Track Grade 5	20
Living Streets	Living Streets	12
Pedestrian streets	Birdleway, Cycleway, Footway, Path, Pedestrian, Steps	10

Most of the road sections can be accessed by 4-wheel vehicles. The speed of most of the road sections has been obtained based on manual bike survey during peak hour and other roads which could not be travelled are based on similarities of road type categorized on Table 3. However, living street has more priority for pedestrian and hence the vehicles can access the road with very less speed. Therefore, the speed of 12 Kmph has been adopted in such streets as the vehicles can flow with slow speed even with access provided by pedestrians. On the other hand, pedestrian streets have almost no access to vehicles and hence, the vehicle has to be parked at some distance away and water pipe has to be transferred manually. Hence the road has been taken with speed of normal human running speed. Furthermore, the fire stations also have motorcycle for small fire suppressions. Due to this, the small roads like pedestrian street can have some level of suppression going on during the time the firefighting equipment with pumps attached can be prepared for firefighting activities. Therefore, taking account that the suppression activity reaches the location in a very slow speed, the speed of 10 Kmph has been adopted in such paths.

The implemented road speed as shown in Table 4 has been mapped in GIS and is shown in map in Figure 10.

Figure 10 Implemented speed for analysis



4.1.3 Service Area Extent of Fire Station

Service area is analyzed with input of fire station location and time taken by fire truck to cover each road segment. The service area has been analyzed for the existing fire stations in Figure 9 with speed taken as per Table 4. The time taken to cover each section of road was found with formula:

$$T = \frac{D \times 60}{V \times 1000}$$

Where,

D= Length of each segment in meters

V= Speed of Vehicle in Kmph

T= Time taken by vehicle to cover the segment in minutes

Table 5 Sample of Road Attribute Table for Road Network Analysis in GIS

Class	Name	Direction	Length	Speed	Minute
Residential	Tabo Marg	B	146.62	20	0.44
Residential	Machindra Ajima Galli	B	169.70	20	0.51
Residential	Naglok Marga	B	419.17	20	1.26
Secondary	Sinamangal Road	B	161.09	25	0.39
Secondary	Devkota Sadak	B	144.59	25	0.35
Tertiary	Bode to Purano Thimi	B	763.68	25	1.83
Tertiary	UN Park Lane	B	938.95	25	2.25
Primary	Ram Shah Path	F	355.31	27	0.79
Primary	Kanti Path	F	6.67	27	0.01
Residential	Machali Road	T	62.08	20	0.19

Where,

Each road name is only a segment of the road from one node to another.

Direction F= One Way Road from left to right

Direction B= Two-way Road

Direction T= One Way Road from right to left

Length= Length of the segment in meters

Speed= Speed taken in Table 4 in Kmph

Minute= Calculated time with length and speed for each segment in minute

In the current scenario, the four fire stations serve the entire valley as well as some parts beyond the valley area as well. However, further 2 minute is taken in call processing time and turnout time. (Pyakurel D. , 2018) Therefore, in the service area taken the calculation is done for 8 minutes as it corresponds to 10 minutes of response time.

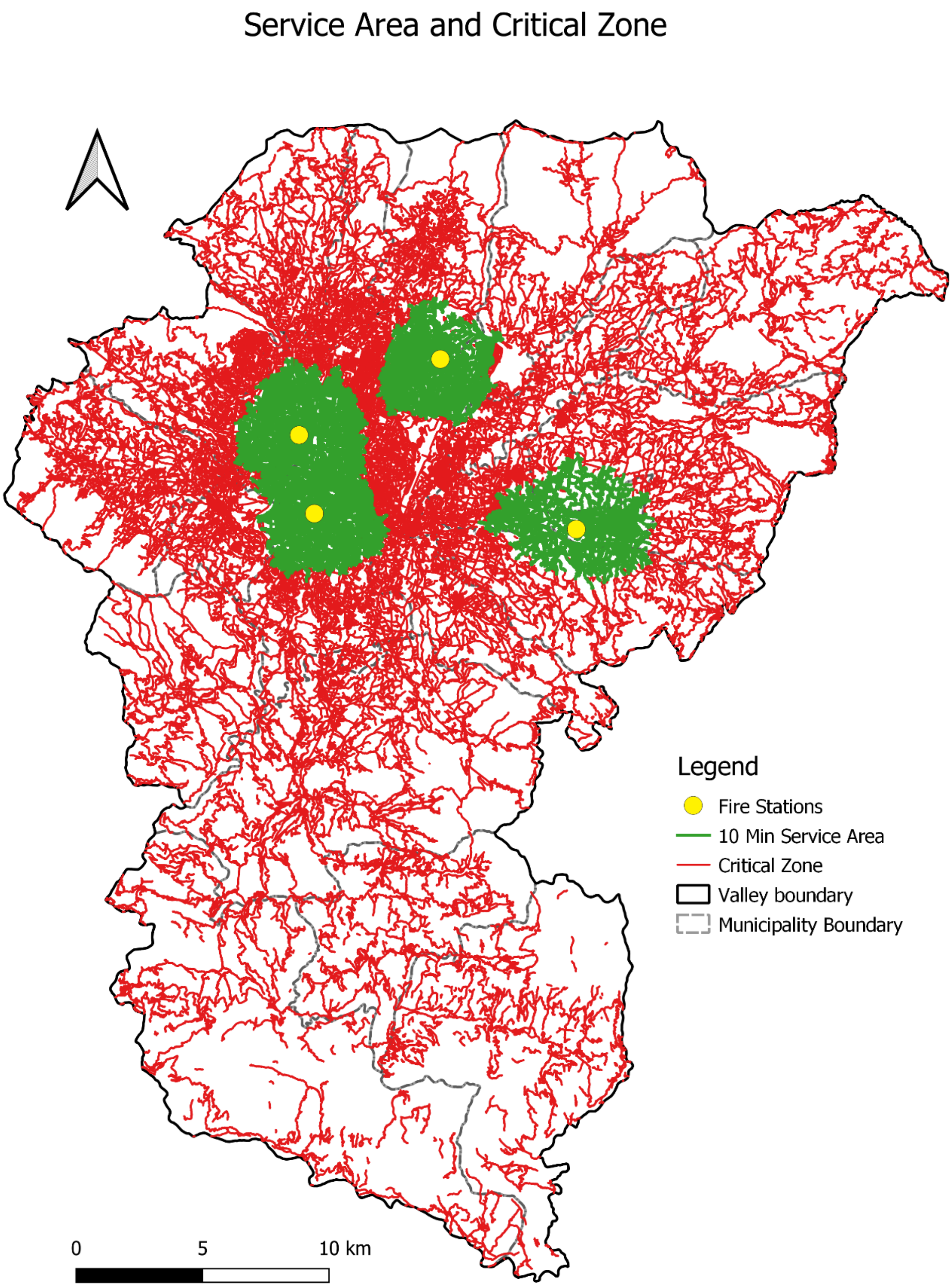
The fire station requires quick response to function properly. Various studies have shown that response beyond 10 minute is very dangerous as it can give rise to flashover.

Service area study for fire stations is taken for response time of up to 10 minute and beyond that time is considered a critical zone. (Balasubramani, Gomathi, & Prasad, 2016). Taking reference to the study, this research has also analyzed response areas for 10 minutes. However as mentioned before, 2-minute call processing time and turnout time has been taken and analyzed after deducting the time. Hence, GIS is used for travel time calculation excluding the pre-works (call processing and turnout time) of the fire station. Figure 9 shows the safe response time for which a fire truck takes less than 10 minute to reach its destination. The service area was converted into polygon with the help of convex hull tool. It is also found that the current fire station serves only 81.01Km^2 of total valley area.

Process code used in QGIS software is shown in coded form as follows:

QGIS Process Code: qgis_process run native:serviceareafromlayer --distance_units=meters --area_units=m2 --ellipsoid=EPSG:7030 --project_path=D:/Pulchowk Campus/GIS and Remote Sensing Application/Thesis/Qgis/net.qgz --INPUT='D:/Pulchowk Campus/GIS and Remote Sensing Application/Thesis/UTM/Valley Road Planarized.shp' --STRATEGY=1 --DIRECTION_FIELD=oneway --VALUE_FORWARD=F --VALUE_BACKWARD=T --VALUE_BOTH=B --DEFAULT_DIRECTION=2 --SPEED_FIELD=Speed --DEFAULT_SPEED=25 --TOLERANCE=0 --START_POINTS='D:/Pulchowk Campus/GIS and Remote Sensing Application/Project/Projected files/Firestations.shp' --TRAVEL_COST2=0.133333 --INCLUDE_BOUNDS=false --OUTPUT_LINES='D:/Pulchowk Campus/GIS and Remote Sensing Application/Thesis/Qgis/service_area.shp'

Figure 11 Safe Response zone and Critical Zone



4.2 Location Optimization

This thesis utilizes open-source model, Allagash model which is an upgraded version of PySpatialOpt and works along with Python programming and a mathematical solver GLPK. The model works with Geopanda to take spatial vector data (Pulver, 2021). To work with the model, several numbers of service area polygons are required which can be obtained from other GIS software. It also requires the input of demand points for allocating the required numbers of fire stations in required locations.

4.2.1 Service Area Polygons

For location optimization, the data required are several numbers of candidate sites for proposed station and demand points. For this research, 2000 numbers of random candidate site are taken throughout the valley so that maximum locations can be utilized to calculate the optimal number of locations required in the valley.

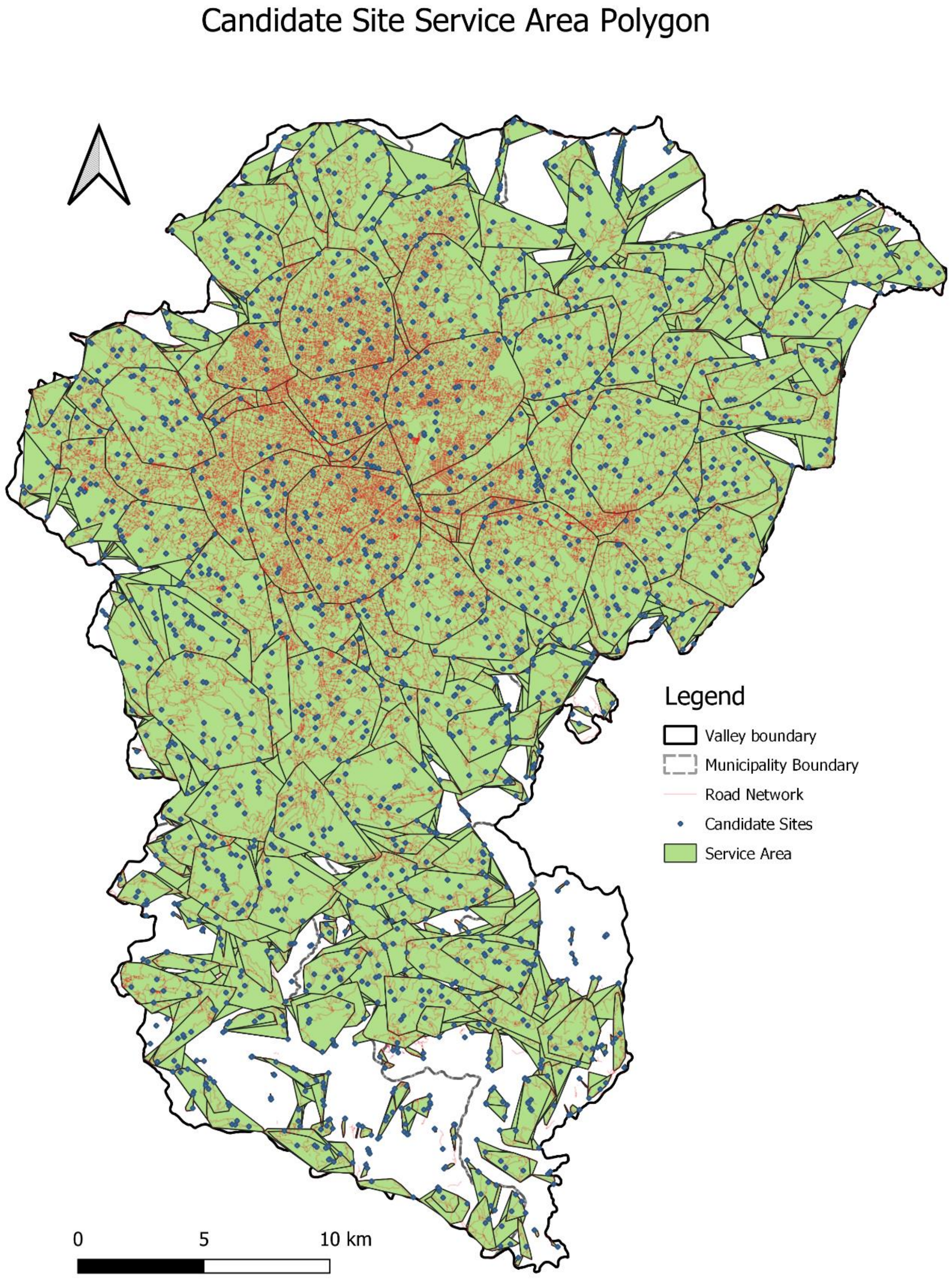
During the number of candidate selection, firstly 300 number of sites were chosen. However, the service area result obtained from the 300 numbers of random points could not cover all the demand points. Therefore, 1000 points were taken for the analysis. The 1000 points were successful in obtaining optimal number of stations for 8-minute travel time. However, during the solving of 4-minute travel time which is required for NFPA standard, the service area of 4-minute travel time could not cover all the demand points throughout the valley. There were some gaps in the service area.

Due to this, 5000 numbers of random points were taken for the next step. However, the GLPK solver took too much time to process the data and could not complete the calculation. Therefore, 2000 number of points were taken and tested for all the required data. The 2000 points taken in random covered all the demand points throughout the valley and hence was taken for all the calculations for consistency of result processing. During the random point selection, QGIS research tool was used for the selection of locations. The input parameters taken were vector data of whole valley and minimum distance of 100 meter between each random point. The points obtained was then moved toward nearest road section so that the service area could be taken with ease.

QGIS provides service area in line vector format. Therefore, to work with Allagash model, the vector data has to be changed into polygon to obtain service area polygon. The obtained line vector has been converted to polygon vector with the help of convex hull tool, which outlines the outer area of points or line triangulation.

The Figure 12 shows the service area polygons taken for the calculation of location optimization.

Figure 12 Service Area Polygons for Candidate Sites



4.2.2 Demand Points

Demand points are locations that requires more attention of fire station and it requires quick response to the site. A typical facility location problem entails selecting the best of several potential locations, under constraints which need that demands at multiple points be serviced by the investigated facilities.

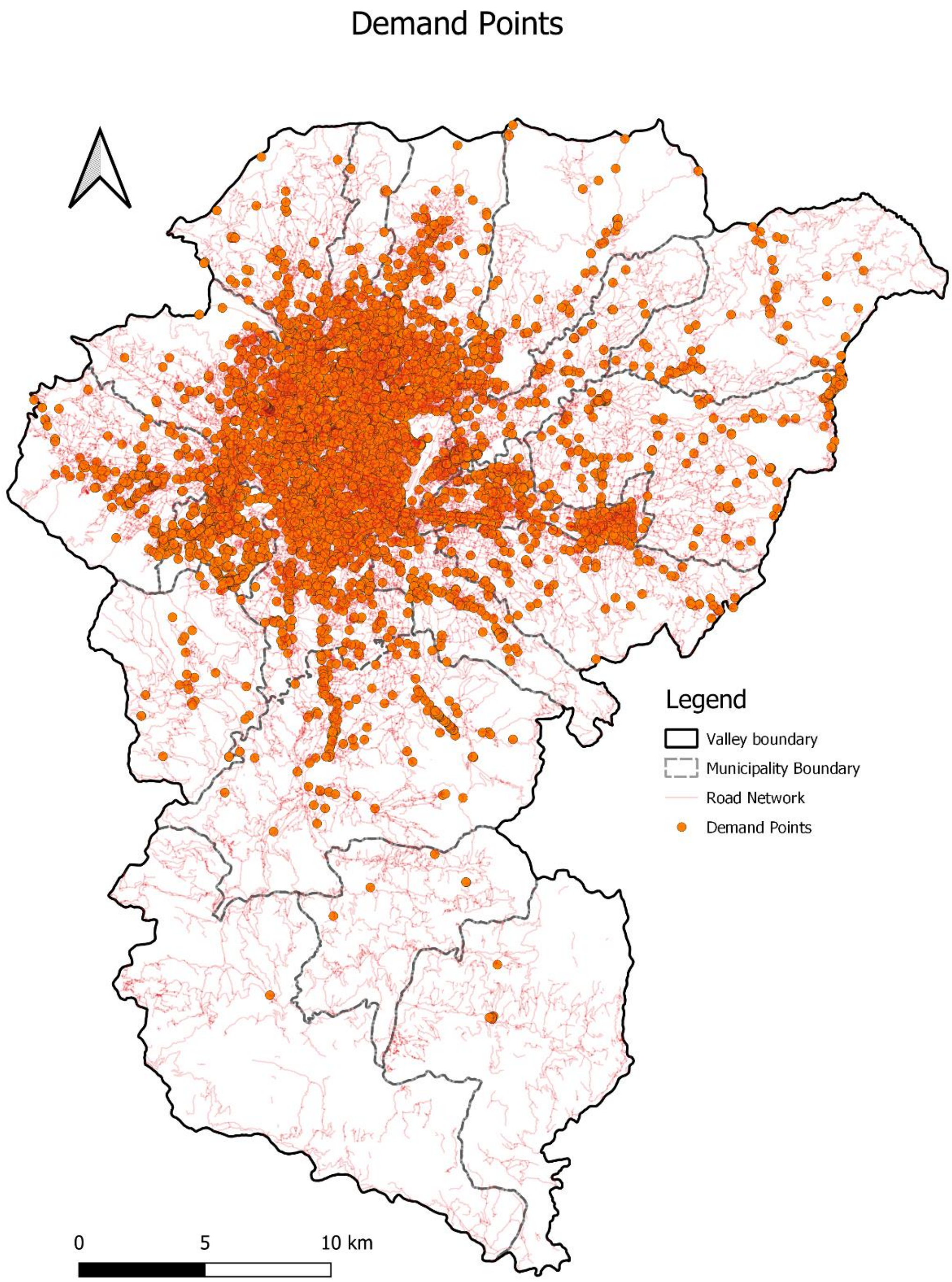
It is found that the fire is more susceptible and hazardous in area with high population density and area with fuel pumps. An explosion or fire in a single fuel station caused by sparks can severely damage a huge number of structures within a 500 meter of radius. (Chhetri & Kayastha, 2015). The opensource map, open street map was used to extract the main areas with small as well as large business areas which can represent the existence of settlement areas with high population density. The population was identified to be dense at the core area inside ring road and its periphery. The settlement of population at the southern side of the valley was found to be very low. The spatial point data for fuel station was also taken from open street map for the whole valley. The fuel station is sparsely located throughout the valley at various locations.

Furthermore, the cultural sites also require more attention as it can be seen that even with suppression activities, A fire in a straw store near the Pashupati temple once lasted 4 to 5 days. It took 7 hours to put out a fire in a house near the Naryanhiti Museum, which was once the Royal Palace. (Prajapati, 2018) This is due to delayed response time which led to flashover causing uncontrollable fire situation. Cultural sites are one of the main sites that gives recognition to the country and has to be kept with safety for the identity of the country as well. Cultural sites represent the country's culture and history. Hence the sites are also identified as one of the demand points of fire response activities.

Therefore, the demand points in this research are taken as buildings points, cultural sites points and fuel pump station points. The demand points data required for this research is taken from open-source maps like open street map.

The figure shows the demand points taken for the calculation of number of fire station required.

Figure 13 Demand Points for Optimization of Fire Station



4.2.3 Python Coding for Location Optimization

The full coding and output file is attached in appendix of this thesis. The coding used to obtain final output for location optimization is provided in appendix. The coding has following main steps during execution:

- Loading library packages
- Loading service data files
- Loading demand point files
- Plotting all data to observe and check
- Creating coverage for data
- Creating Location set covering problem
- Solving the equation using GLPK
- Getting list of locations necessary for covering the demand as returned by solved equation
- Plotting the final result with final coverage and demand
- Getting output table in CSV file

4.2.4 Location Optimization Result

With Location optimization using Allagash, it was obtained that, Kathmandu valley required minimum of 56 numbers of fire stations or stand by locations. The analysis was done for maximum response time of 10 minutes. This means at least 56 number of stations is required to serve optimally to all the population of the valley within 10 minutes of response time.

Table 6 List of Selected Location of Fire Station after Optimization

Sn.	WGS84 45N Coordinates (EPSG:32645)	Longitude	Latitude
1	343292.728034, 3063083.53949	85.41094	27.68288
2	339752.677646, 3058353.74452	85.37568	27.63978
3	329926.443228, 3059743.98759	85.27592	27.65112
4	340485.476171, 3048728.8049	85.38438	27.55301
5	324085.172316, 3064824.36588	85.21598	27.69621
6	330115.494931, 3064502.94839	85.27716	27.69409
7	332882.24226, 3050837.5802	85.30711	27.57112
8	339959.18911, 3051772.68239	85.37865	27.58041
9	335170.556722, 3072182.06047	85.32735	27.76401
10	340636.249105, 3069402.47595	85.38317	27.73959
11	330268.080089, 3072615.94021	85.27756	27.76732
12	338797.429973, 3074101.00867	85.36388	27.78177
13	345878.108315, 3071256.66158	85.43609	27.75693
14	351811.848338, 3071759.21352	85.49622	27.76213
15	328353.76048, 3066622.54305	85.259	27.71299
16	327681.805495, 3053846.2354	85.25402	27.59762
17	332532.277525, 3042204.72475	85.30476	27.49317
18	342007.176319, 3043464.91126	85.40048	27.50568
19	333856.624673, 3074666.10904	85.31368	27.78626

20	328469.587932, 3062374.45888	85.26078	27.67467
21	333295.776144, 3068740.90147	85.30881	27.73273
22	347210.955968, 3074920.82562	85.44914	27.79015
23	334999.407415, 3047476.70637	85.32901	27.54105
24	337459.747434, 3062072.69504	85.35194	27.67306
25	340801.96697, 3042405.27987	85.38842	27.49598
26	341947.340436, 3058988.75753	85.39784	27.64577
27	325235.679622, 3066645.57102	85.22738	27.7128
28	355355.207962, 3072788.41916	85.53205	27.77181
29	331911.361009, 3067895.1895	85.29489	27.72492
30	330416.250564, 3052920.4293	85.28184	27.58961
31	345823.271207, 3075382.057	85.435	27.79415
32	340900.809034, 3054028.09141	85.38789	27.60088
33	348692.760565, 3068499.25028	85.46499	27.73237
34	343308.889751, 3056916.69513	85.4119	27.62723
35	353934.311059, 3068256.09335	85.51818	27.73075
36	343478.47458, 3067383.17957	85.41226	27.7217
37	350160.388934, 3060290.00708	85.4809	27.65845
38	348846.036035, 3057954.58916	85.46788	27.63722
39	337776.822183, 3051989.2198	85.35652	27.58211
40	328716.548298, 3055446.33817	85.26427	27.61219
41	333607.50417, 3061176.83039	85.31302	27.66451
42	345937.23205, 3060937.08781	85.43802	27.66381
43	350656.291039, 3064190.20161	85.48545	27.6937
44	353045.84909, 3065813.23171	85.50947	27.70861
45	348061.907432, 3065587.27496	85.45897	27.70602
46	336984.739613, 3056748.49	85.34785	27.62496
47	337492.876233, 3068588.02105	85.3514	27.73186
48	334801.384461, 3066075.17116	85.32445	27.70886
49	335795.501134, 3074737.47413	85.33334	27.78715
50	340758.105003, 3073386.92467	85.38387	27.77556
51	333910.821753, 3056454.52107	85.31675	27.62193
52	344694.563401, 3074043.90143	85.42372	27.78195
53	340094.747548, 3064811.06657	85.37829	27.69809
54	353500.484374, 3070123.31558	85.51356	27.74756
55	333848.640239, 3054048.89265	85.31645	27.60022
56	341746.714182, 3077790.66062	85.39332	27.81541

Figure 14 shows locations allocated based on demand points using networks analysis. Figure 15 shows allocated locations of Ring Road and periphery areas.

Figure 14 Minimum Optimal number of Fire station for the Valley

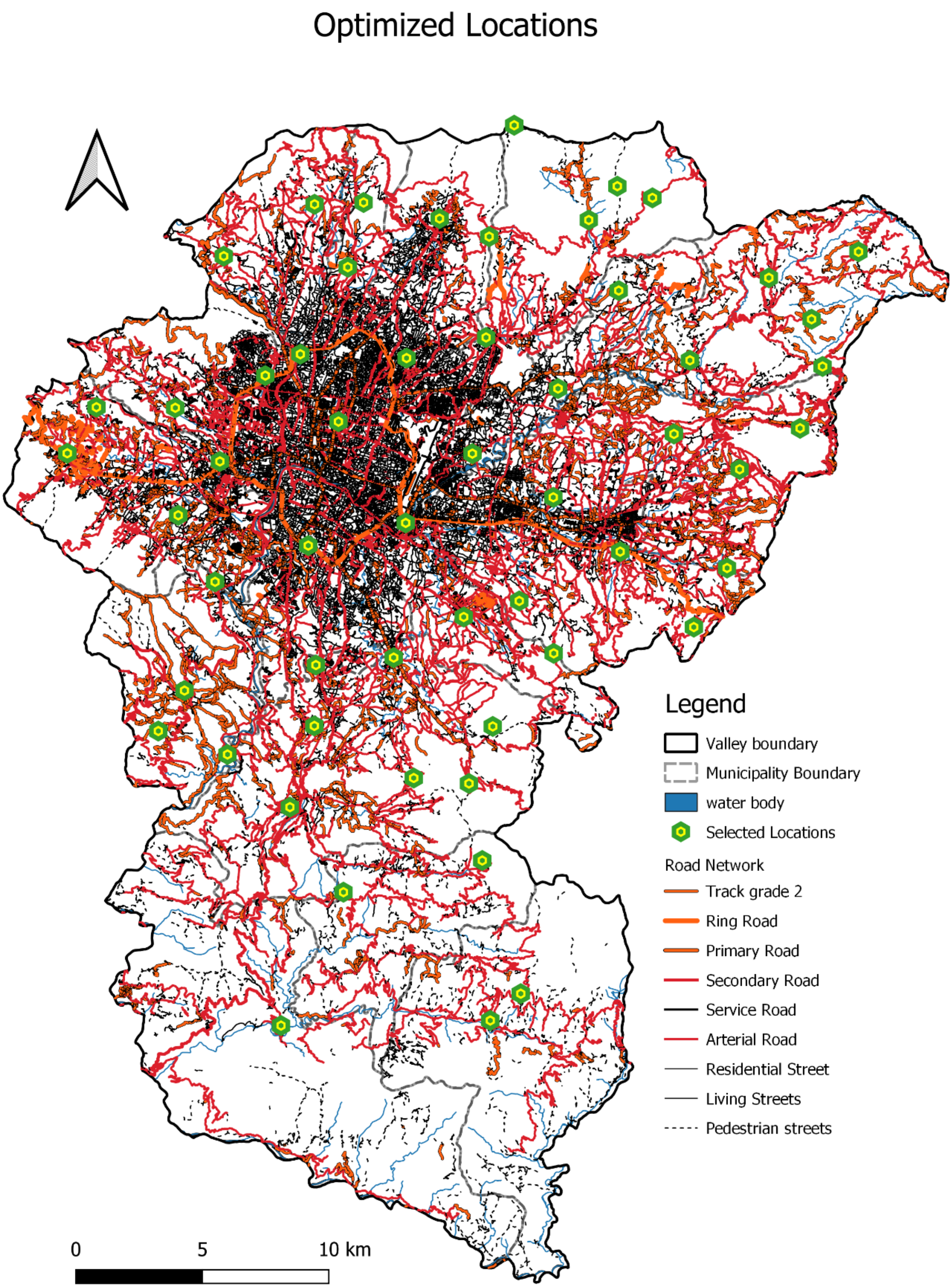


Figure 15 Location of Fire stations needed inside Kathmandu Metropolitan City

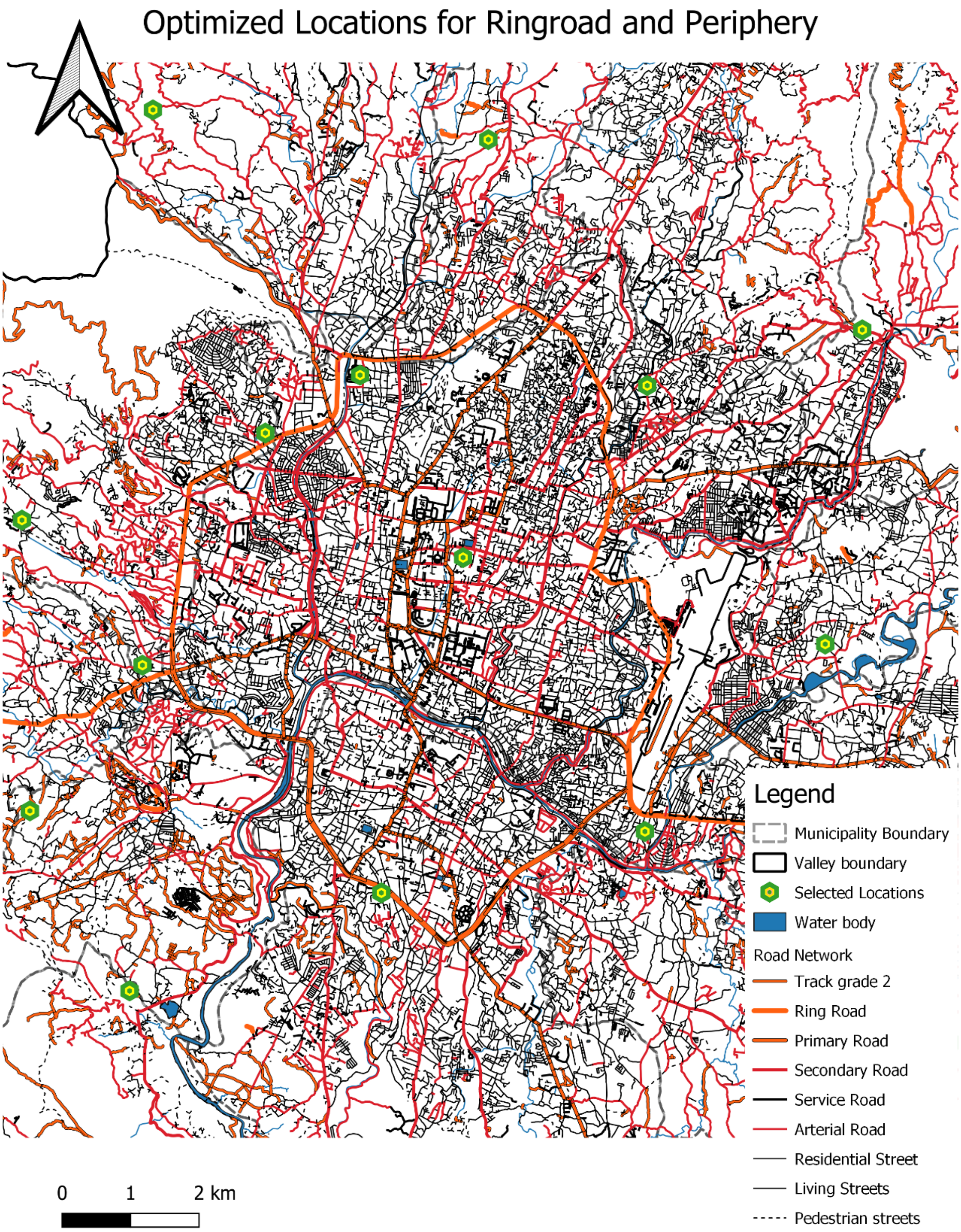


Table 7 Number of Fire station located municipality wise by analysis

Municipality	**Stations located**	**Municipality Area (Km^2)**
Bagmati	1	111
Bhaktapur	0	7
Budhanilakantha	3	35
Chandragiri	2	44
Changunarayan	4	63
Dakshinkali	4	43
Godawari	7	96
Gokarneshwor	5	58
Kageshwori Manahora	3	27
Kathmandu	3	49
Kirtipur	1	15
Konjyosom	2	44
Lalitpur	1	36
Madhyapur Thimi	0	11
Mahalaxmi	1	27
Mahankal	2	82
Nagarjun	3	30
Shankharapur	5	60
Suryabinayak	5	42
Tarakeshwor	2	35
Tokha	2	17

The station counts in Table 7 is varying in different municipality. This is due to various reasons like size of municipality as well as demand due to number of settlements and other demand criteria. Some outskirts of Kathmandu valley have hilly area where road does not connect directly with each other and has to move by going around the road. This creates more response time. Due to this, those regions require more stations. In some municipality, although its area is large, due to having low population and demand, small number of fire station can also serve the population with ease.

The obtained number of fire station when compared with other cities mentioned in Table 2, it can be observed that the allocated number is within the similar fire station count as other cities.

By this analysis, it can be seen that, it is necessary to have fire truck deployed to stand by at various locations inside the city so that it can work at any required time. When one fire truck is working at fire, nearby fire truck can also help by coming during emergency period.

4.3 Location Optimization in Various Scenario

Location optimization for other scenario is done with same method as in heading 4.2 Location Optimization.

4.3.1 Optimization by Standard of NFPA

National Fire Protection Association has provided an international standard for response to firefighting. It has set out that travel time for first fire truck to arrive at site is 240 seconds, i.e., 4 minutes. (NFPA, 2019) This setup for fire response has been set out in very few developed cities throughout the world. This response time can provide safety to travel time of fire truck so that it can provide fire station a proper response toward fire response.

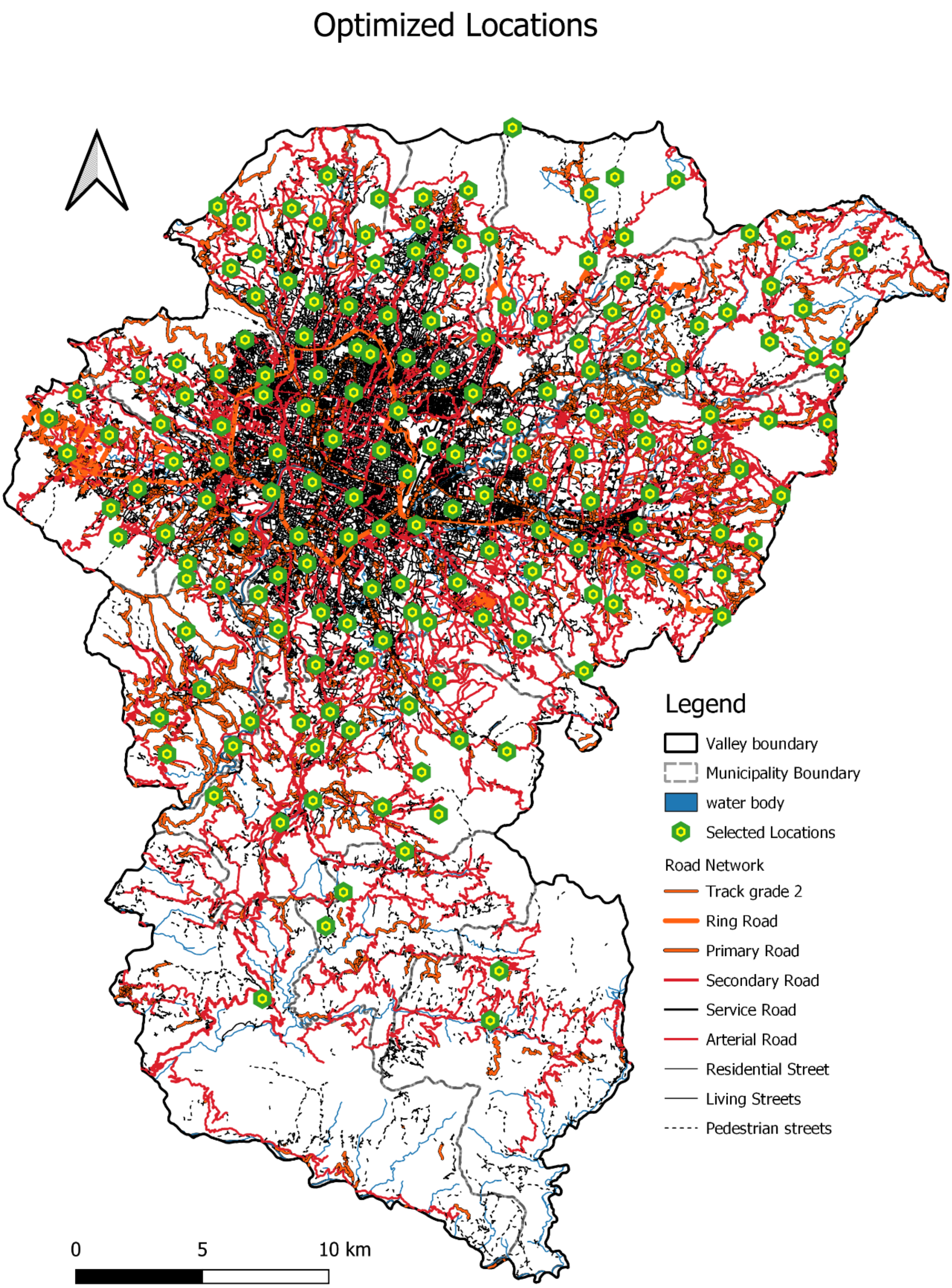
Location optimization has been done with same method as done in heading 4.2 : Location Optimization by taking service area of 4-minute response time. It was found that, the valley requires 173 number of fire stations throughout the city if the NFPA standard is followed. The Table 8 shows the Number of Fire station located municipality wise:

Table 8 Number of fire station municipality wise by NFPA Standard

Municipality	**Stations located**	**Municipality Area (Km^2)**
Bagmati	1	111
Bhaktapur	1	7
Budhanilakantha	10	35
Chandragiri	9	44
Changunarayan	15	63
Dakshinkali	6	43
Godawari	17	96
Gokarneshwor	10	58
Kageshwori Manahora	7	27
Kathmandu	16	49
Kirtipur	4	15
Konjyosom	2	44
Lalitpur	14	36
Madhyapur Thimi	4	11
Mahalaxmi	6	27
Mahankal	2	82
Nagarjun	9	30
Shankharapur	14	60
Suryabinayak	12	42
Tarakeshwor	10	35
Tokha	4	17

Figure 16 shows the location allocated based on demand points as per Figure 13 Demand Points for Optimization of Fire Station and service area of 4 minute.

Figure 16 Optimum Fire station as per NFPA Standard



4.3.2 Optimization when Speed Increased by 5 Kmph

During the open-end questionnaire with Chief of fire brigade, he has mentioned that the speed of fire truck is significantly reduced due to various factors such as traffic congestion, potholes as well as wires hanging around in the city areas. If these and any other factors that can hinder response of fire truck can be managed, it can help in decreasing the travel time by increasing the speed of trucks during response.

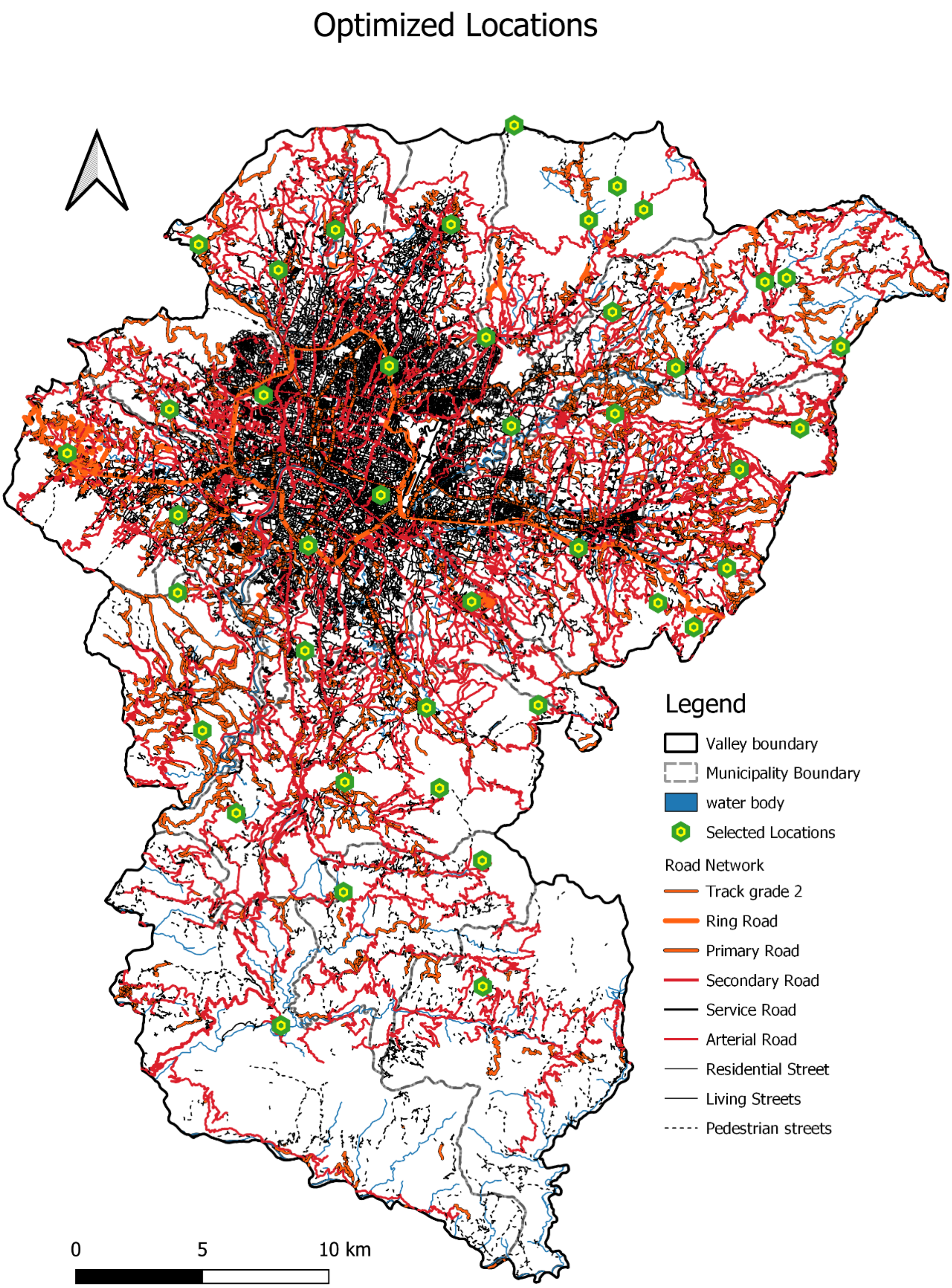
This optimization is done for additional increase of 5 Kmph speed to the speed mentioned in Table 4 Implemented speed for analysis. Location optimization has been done with same method as done in heading 4.2 : Location Optimization by taking service area of 8-minute response time with increase in speed of truck by 5 Kmph. It was found that, the valley requires 42 number of fire stations throughout the city if the speed of truck can be increased by 5 Kmph. The Table 9 shows the Number of Fire station located municipality wise:

Table 9 Number of fire station municipality wise when 5 Kmph Speed Increased

Municipality	**Stations located**	**Municipality Area (Km^2)**
Bagmati	1	111
Bhaktapur	0	7
Budhanilakantha	1	35
Chandragiri	1	44
Changunarayan	3	63
Dakshinkali	2	43
Godawari	5	96
Gokarneshwor	5	58
Kageshwori Manahora	2	27
Kathmandu	3	49
Kirtipur	1	15
Konjyosom	2	44
Lalitpur	2	36
Madhyapur Thimi	0	11
Mahalaxmi	1	27
Mahankal	1	82
Nagarjun	1	30
Shankharapur	4	60
Suryabinayak	4	42
Tarakeshwor	3	35
Tokha	0	17

Figure 17 shows the location allocated based on demand points as per Figure 13 Demand Points for Optimization of Fire Station and service area of 8 minute with increase in speed by 5 Kmph.

Figure 17 Optimum Fire Station when 5 Kmph Speed Increased



CHAPTER 5: Conclusion and Recommendation

5.1 Conclusion

At present, only 4 numbers of Fire stations are in operation inside Kathmandu valley. Furthermore, the neighboring municipalities and districts also use the same fire station during emergencies and hence there is a very lack of response time during fire disasters. There is already a very slow response time in many of the disasters which causes flashover. Flashover hinders the fire suppression activity even more and hence the response toward suppression itself take more time than what is required. This thesis has studied about the sufficiency of fire station inside Kathmandu valley. Following are the conclusion made based on the research question and analysis of this study.

Firstly, for the research question that, if the number of fire station in present context sufficient for the Kathmandu valley, it is noted that most parts of Kathmandu valley are in a critical zone as it lies beyond 10 minutes of response zone from the fire stations. The service area analysis of currently existing four stations shown in Figure 11 Safe Response zone and Critical Zone shows that the current fire stations serve only small portion of the valley and leaves most part of the valley in vulnerable situation. The service area of current fire station covers only 81.01 Km^2 (covers only 8.68%) out of total valley area of 933.4 Km^2. The effective response distance of current fire stations seems to be very low as it does not cover all the parts of Kathmandu valley which can leave the valley into hazardous situations if left alone. Moreover, the current fire stations in the city have to not only cover parts of city areas, but also the whole Kathmandu valley and sometimes beyond that area. There seems to be a significant need for improvement in the number of fire stations that need to be deployed in case of massive fire disasters.

Furthermore, if there is more than one fire disaster happening at the same time, the current fire stations cannot cover all the areas and has to depend upon the local population to take fire eliminating measures until the assistance from fire station can arrive at site.

Secondly, for the research question about number of fire stations that are required to optimally serve the total demand of Kathmandu valley, from this research, it is found that at least 56 number of fire stations are required for that fire brigade to function properly inside the valley. Fire station is required to be at least at 10-minute of response time zone. It should not exceed 10-minute time of travel else there will be chances of flash fire which will be even more difficult to take out and the fire extinguishing works might extend hours to subdue the fire. Due to this, the least amount of fire station location needed is calculated using 10-minute response time using the model. The result obtained in Figure 14 Minimum Optimal number of Fire station for the Valley using Allagash model was that, the valley required at least 56 numbers of fire stations throughout the valley.

However, if optimization is done as per NFPA standard, which requires 4 minute of travel time, it is found that 173 numbers of fire stations are required. Fire station requires their first truck to arrive at site within 240 second and second truck to arrive within 360 seconds. With this constraint, 173 number of fire station was found to be required by this international standard when optimized with Allagash Model.

Speed of fire truck can be increased by improving the condition of road in the valley to some extent. When assumption with an increase in speed by 5 Kmph to the current speed during peak hour, the optimized location for fire stations can be decreased to 42 numbers when the optimization is done with the help of Allagash Model. Hence, number of required fire station can be decreased if the speed of vehicles inside valley can be increased.

5.2 Recommendation

The response time of firetruck can be further improved by improving condition of existing traffic and road facilities. Potholes and overhanging wires severely reduce response time. Therefore, future researchers can research in this area for managing such hinderance as it can also improve the speed of response which can also provide reduction in minimum required numbers of fire stations.

Furthermore, future researchers can also study for installation of fire safety alarms at all houses and commercial areas that can notify fire stations at time of ignition. This type of alarm can serve as early warning system to the nearby fire station. This study can decrease the call processing time and turnout time which occurs before the start of travel time.

Future researchers can also use actual data such as travel time of fire trucks by using GPS trackers or actual road survey data and do comparative study with this study. The researchers can also use actual candidate sites instead of random sites by taking reference to this study to get actual implementable locations of probable fire stations. These methods can also overcome the limitations of this research.

Policy makers are also recommended to do proper study for additional locations for fire stations or fire truck at stand by position at several sites as soon as possible to serve the people within good response time. When addressing issues for number of required fire stations, it is also required to provide training for more numbers of fire fighters for the additional stations. Maintenance of current fire truck is also required in regular basis to keep them in functioning condition during fire disasters at any time.

CHAPTER 6: References

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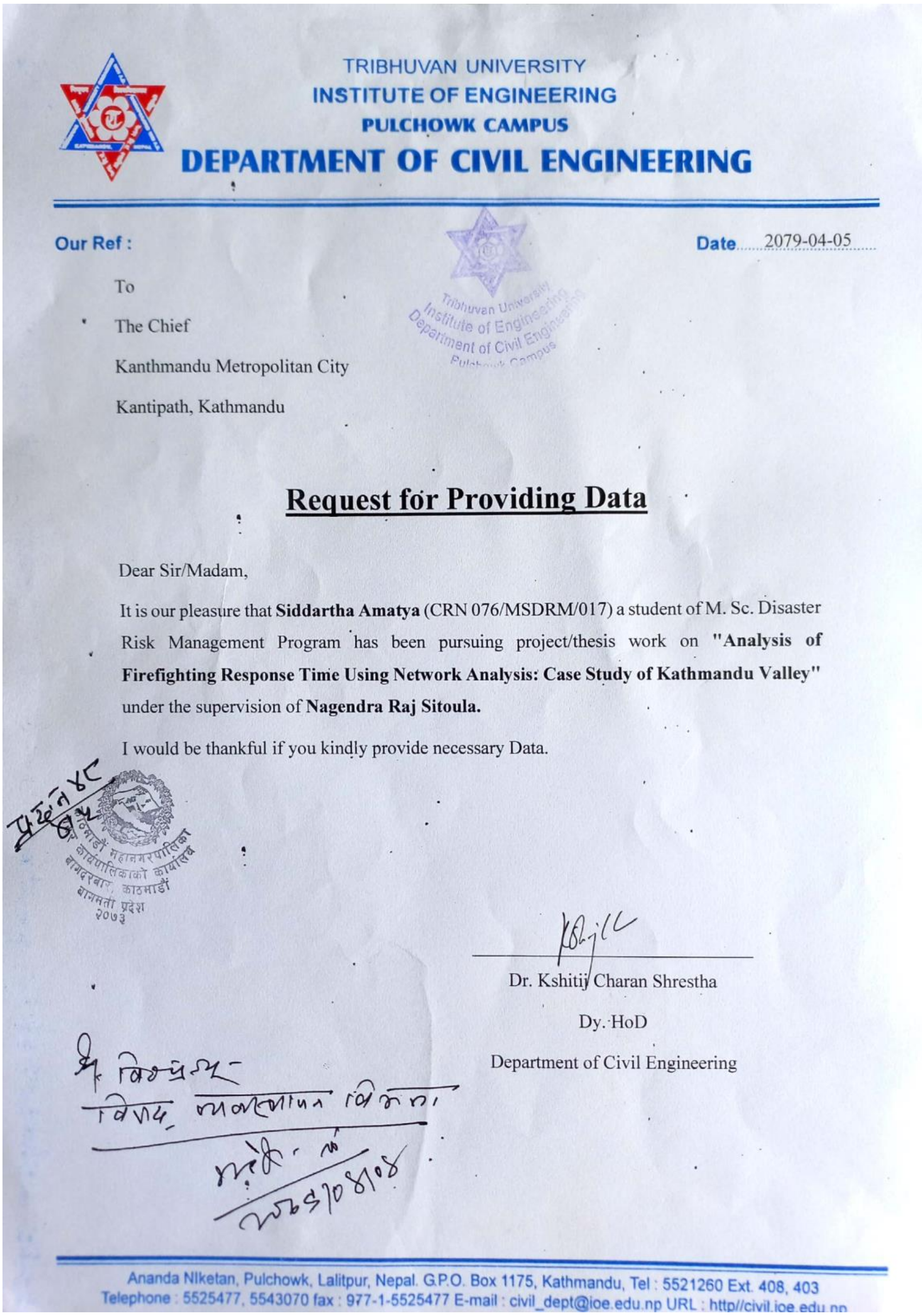
APPENDIX A: Letter for Request of Survey data



TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF CIVIL ENGINEERING

Our Ref :

Date 2079-04-05

To

The Chief

Kanthmandu Metropolitan City

Kantipath, Kathmandu

Request for Providing Data

Dear Sir/Madam,

It is our pleasure that **Siddartha Amatya** (CRN 076/MSDRM/017) a student of M. Sc. Disaster Risk Management Program has been pursuing project/thesis work on **"Analysis of Firefighting Response Time Using Network Analysis: Case Study of Kathmandu Valley"** under the supervision of **Nagendra Raj Sitoula.**

I would be thankful if you kindly provide necessary Data.

Dr. Kshitij Charan Shrestha

Dy. HoD

Department of Civil Engineering

Ananda Niketan, Pulchowk, Lalitpur, Nepal. G.P.O. Box 1175, Kathmandu, Tel : 5521260 Ext. 408, 403
Telephone : 5525477, 5543070 fax : 977-1-5525477 E-mail : civil_dept@ioe.edu.np URL : http//civil.ioe.edu.np

APPENDIX B: Survey Question and Answer at Fire Department

1. How many fire stations are in use inside Kathmandu valley? And where are they located?
   - Currently, there are 4 fire stations in use. They are Juddha Barun yantra, Newroad, Fire station and training center, Ramhiti(Kathmandu ward-6), Juddha Barun yantra, Lalitpur and Juddha Barun yantra, Bhaktapur. Fire truck from army can also be deployed on request and has helped in some of the fires as well. Fire station inside airport can also be deployed on request for nearby areas.
2. There was some news about municipalities to use fire truck in the future. What is the condition of fire truck with various municipalities?
   - While some municipalities initiated using fire truck at the beginning, however, they stopped functioning with time due to lack of resources. Budanilkantha municipality handed over their truck to army due to lack of manpower. Chandragiri municipality also stopped serving due to lack of manpower. Currently, there seems to be minimal chances of municipalities using fire truck.
3. Are there any plan of expansion of fire station inside the valley?
   - The plan to extend service to 3 more places has been made. However, they are not yet implemented. The places are Balaju, Min bhawan and Kalanki.
4. Are there any studies made about current fire truck capacity and researches related to it?
   - Very less or almost no studies are being done in this area. Therefore, there are no researches in good quantity found in subject related to fire station.
5. What are the difficulties faced by fire brigade during response time?
   - Fire truck faces difficulties due to traffic congestion, potholes as well as wires hanging around in the city area. Some fake calls also hinder in response as it is required to be verified. Sometimes, the people are not aware of phone number for fire brigade and calls police which is then it is again called to fire station by the police authority. These factors severely increase the response time.
6. There are some motorcycles inside station with firefighting equipment. Are they currently in use?
   - Yes, they are being used regularly. However, they can only be used in small fire incidents such as fire on electric poles or other such small fire where smoke extinguishers can be used.
7. What is the speed of fire truck during peak hours inside Kathmandu valley?
   - Speed of fire truck ranges from 20Kmph to 35 Kmph during peak hours. Most of the road user are educated and provide access way for emergencies vehicles, hence the speed can be maintained to 20-35 Kmph in peak hours. However, speed in very narrow road is severely less. Some pedestrian only type of road cannot even be accessed by fire truck.

APPENDIX E: Python Coding with Allagash Model

```
import warnings
warnings.filterwarnings('ignore')
import pandas as pd
import geopandas
import matplotlib.pyplot as plt
from shapely.geometry import Point, Polygon
import pulp
from allagash.coverage import Coverage
from allagash.problem import Problem, InfeasibleException,
UndefinedException
%matplotlib inline
```

In [3]:

```
path_to_data = "D:\\Siddartha\\For location analysis\\"
s1 = geopandas.read_file(path_to_data+"convex_hull4.shp")
s2= geopandas.read_file(path_to_data+"area2000.shp")
s1.head()
```

Out[3]:

	fid	Id	Name	type	start	area	perimeter	geometry
0	1.0	0	Fire station and training center	within	338835.9, 3068519.06	1.838585e+07	15764.742605	POLYGON ((339407.428 3065919.050, 336800.052 3...
1	2.0	0	Juddha Barun Yantra Karyalaya, Kathmandu	within	333239.47, 3065512.02	2.282098e+07	17448.106243	POLYGON ((332314.300 3062909.565, 330698.928 3...
2	3.0	0	Juddha Barun Yantra Karyalaya, Lalitpur	within	333843.783781, 3062418.90651	2.295140e+07	17649.648861	POLYGON ((333534.505 3059739.907, 332784.075 3...
3	4.0	0	Juddha Barun Yantra Karyalaya, Bhaktapur	within	344206.115116, 3061797.28635	2.459231e+07	18703.150830	POLYGON ((344824.188 3059467.734, 342429.736 3...

In [4]:

```
s2.head()
```

Out[4]:

	id	type	start	area	perimeter	geometry
0	0	lines	330860.991162, 3051361.41897	1.469556e+03	259.100526	POLYGON ((330853.958 3051235.040, 330843.602 3...
1	1	lines	344822.359896, 3076655.25357	NaN	NaN	None
2	2	lines	342726.342865, 3036981.43126	7.206134e+05	3558.432008	POLYGON ((342617.107 3036895.978, 342523.394 3...
3	3	lines	355247.078523, 3069841.11337	2.416027e+06	7340.963938	POLYGON ((353282.981 3068209.173, 353276.367 3...
4	4	lines	332522.132653, 3046031.19589	5.297786e+06	9584.034237	POLYGON ((332668.914 3044304.037, 332522.577 3...

In [5]:

```
s1["centroid"] = s1.centroid
s1
```

Out[5]:

	fid	Id	Name	type	start	area	perimeter	geometry	centroid
0	1.0	0	Fire station and training center	within	338835.9, 3068519.06	1.838585e+07	15764.742605	POLYGON ((339407.428 3065919.050, 336800.052 3...	POINT (338785.179 3068320.815)
1	2.0	0	Juddha Barun Yantra Karyalaya, Kathmandu	within	333239.47, 3065512.02	2.282098e+07	17448.106243	POLYGON ((332314.300 3062909.565, 330698.928 3...	POINT (333361.078 3065620.864)
2	3.0	0	Juddha Barun Yantra Karyalaya, Lalitpur	within	333843.783781, 3062418.90651	2.295140e+07	17649.648861	POLYGON ((333534.505 3059739.907, 332784.075 3...	POINT (333990.096 3062553.534)

	fid	Id	Name	type	start	area	perimeter	geometry	centroid
3	4.0	0	Juddha Barun Yantra Karyalaya, Bhaktapur	within	344206.115116, 3061797.28635	2.459231e+07	18703.150830	POLYGON ((344824.188 3059467.734, 342429.736 3...	POINT (344195.101 3062079.694)

In [6]:

```
s2["centroid"] = s2.centroid
s2
```

Out[6]:

	id	type	start	area	perimeter	geometry	centroid
0	0	lines	330860.991162, 3051361.41897	1.469556e+03	259.100526	POLYGON ((330853.958 3051235.040, 330843.602 3...	POINT (330857.223 3051292.852)
1	1	lines	344822.359896, 3076655.25357	NaN	NaN	None	None
2	2	lines	342726.342865, 3036981.43126	7.206134e+05	3558.432008	POLYGON ((342617.107 3036895.978, 342523.394 3...	POINT (342063.609 3037319.184)
3	3	lines	355247.078523, 3069841.11337	2.416027e+06	7340.963938	POLYGON ((353282.981 3068209.173, 353276.367 3...	POINT (354575.720 3069222.929)
4	4	lines	332522.132653, 3046031.19589	5.297786e+06	9584.034237	POLYGON ((332668.914 3044304.037, 332522.577 3...	POINT (332393.159 3046477.990)
...	...	...	...	...	...	...	...
1987	1995	lines	333694.902261, 3049422.0722	8.712573e+06	12371.388439	POLYGON ((334985.421 3048264.475,	POINT (333904.941 3049985.279)

	id	type	start	area	perimeter	geometry	centroid
						334716.025 3...	
1988	1996	lines	354112.010821, 3067845.39064	2.217690e+06	5920.792549	POLYGON ((354055.092 3066856.999, 353951.640 3...	POINT (353893.618 3067979.999)
1989	1997	lines	342309.850215, 3073518.87584	4.207125e+06	9051.678691	POLYGON ((343232.664 3072671.366, 340602.470 3...	POINT (341734.969 3073438.500)
1990	1998	lines	334985.884528, 3061567.43078	2.309319e+07	17575.864287	POLYGON ((335053.516 3058577.261, 334131.397 3...	POINT (335331.580 3061514.063)
1991	1999	lines	347932.690884, 3076910.43555	8.572265e+04	1169.111235	POLYGON ((347861.684 3076505.833, 347846.407 3...	POINT (347927.642 3076730.892)

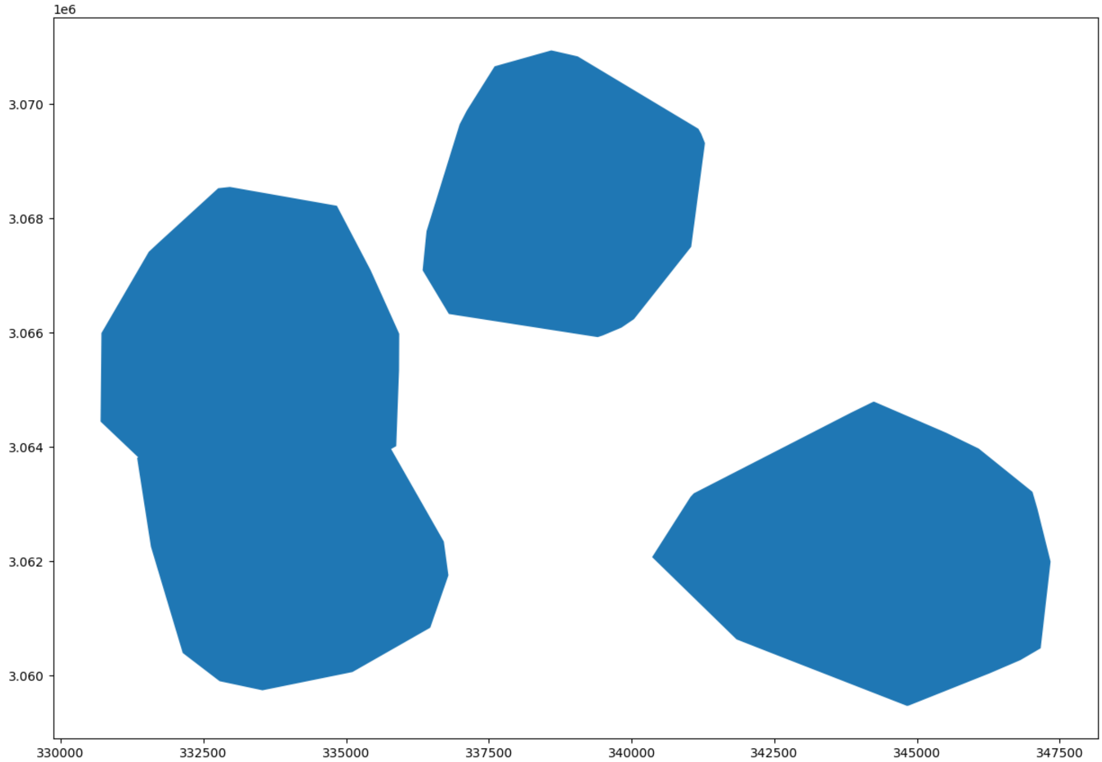
1992 rows × 7 columns

In [7]:

```
fig,ax = plt.subplots(figsize = (15,15))
s1.plot(ax=ax)
```

Out[7]:

```
<AxesSubplot:>
```



In [8]:

```
fig,ax = plt.subplots(figsize = (15,15))
s2.plot(ax=ax)
```

Out[8]:

```
<AxesSubplot:>
```

In [9]:

```
gd_demand = geopandas.read_file(path_to_data+"\\demand.shp")
#gd_demand = gd_demand.to_crs('EPSG:32645')
gd_demand
```

Out[9]:

	osm_id	code	fclass	name	layer	path	geometry
0	313140391	2301	restaurant	Wunjala	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (335204.796 3066676.019)

	osm_id	code	fclass	name	layer	path	geometry
1	316984536	2401	hotel	Madhuban	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (354546.784 3067525.955)
2	317040754	2401	hotel	Nirvana Garden Hotel	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (333351.760 3066525.595)
3	336927387	2084	college	Rigpa Shedra	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (329008.051 3055785.612)
4	339102258	2401	hotel	Dakshinkali Resort	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (329018.159 3054861.078)
...	...	...	...	...	...	...	...
15323	7103979485	5250	fuel	None	demand pump	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (325329.316 3064017.199)
15324	7342257385	5250	fuel	None	demand pump	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (341024.144 3067506.840)
15325	9226700217	5250	fuel	None	demand pump	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (333152.628 3065293.640)
15326	9622703394	5250	fuel	Petrol Pump	demand pump	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (334226.942 3052649.266)
15327	9642622543	5250	fuel	Petrol pump	demand pump	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (330137.526 3059473.910)

15328 rows × 7 columns

In [10]:

```
gd_demand["centroid"] = gd_demand.centroid
gd_demand.head()
```

Out[10]:

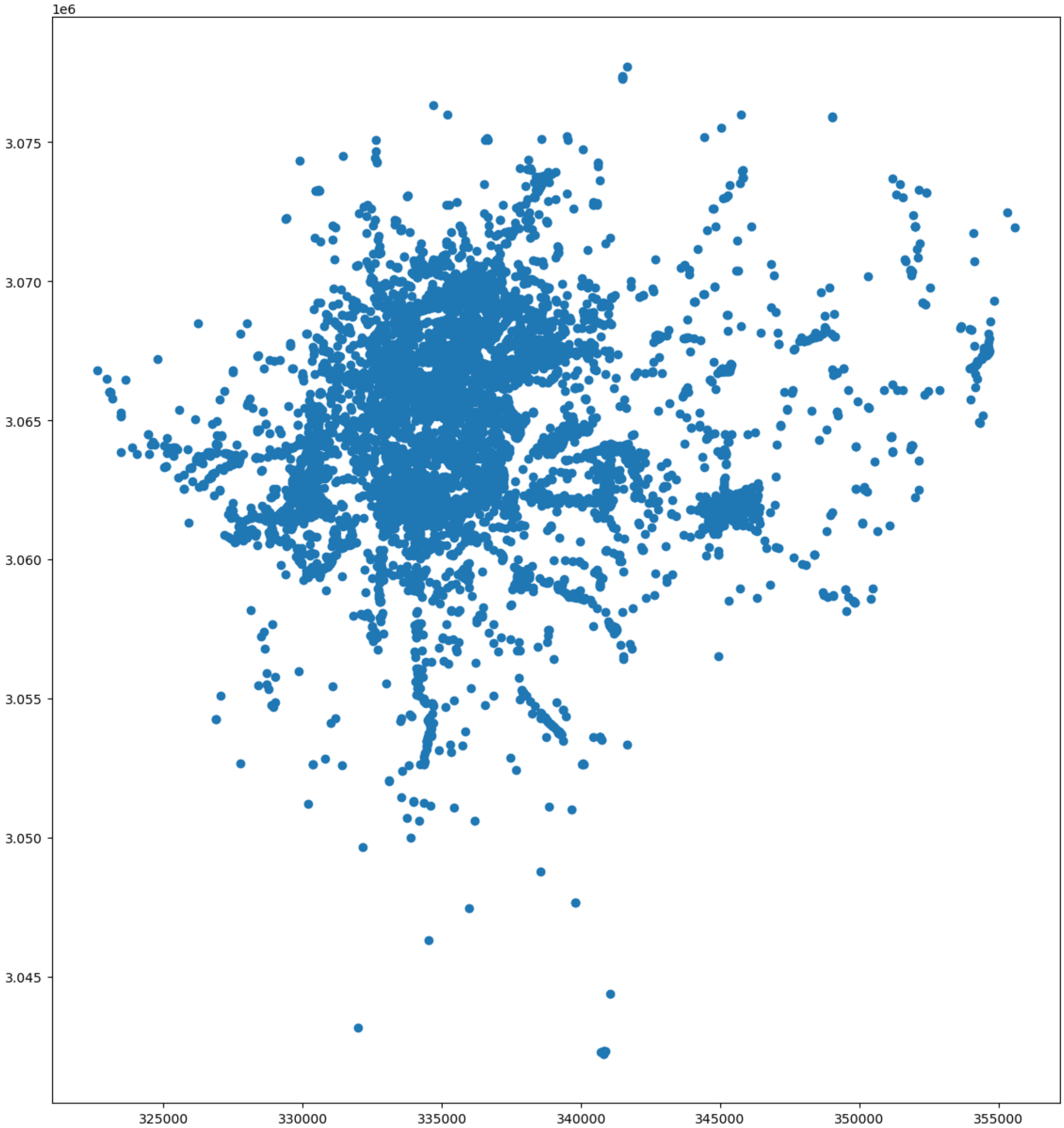
	osm_id	code	fclass	name	layer	path	geometry	centroid
0	313140391	2301	restaurant	Wunjala	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (335204.796 3066676.019)	POINT (335204.796 3066676.019)
1	316984536	2401	hotel	Madhuban	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (354546.784 3067525.955)	POINT (354546.784 3067525.955)
2	317040754	2401	hotel	Nirvana Garden Hotel	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (333351.760 3066525.595)	POINT (333351.760 3066525.595)
3	336927387	2084	college	Rigpa Shedra	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (329008.051 3055785.612)	POINT (329008.051 3055785.612)
4	339102258	2401	hotel	Dakshinkali Resort	demand building	D:/Pulchowk Campus/GIS and Remote Sensing Appl...	POINT (329018.159 3054861.078)	POINT (329018.159 3054861.078)

In [11]:

```
fig,ax = plt.subplots(figsize = (15,15))
gd_demand.plot(ax=ax)
```

Out[11]:

```
<AxesSubplot:>
```

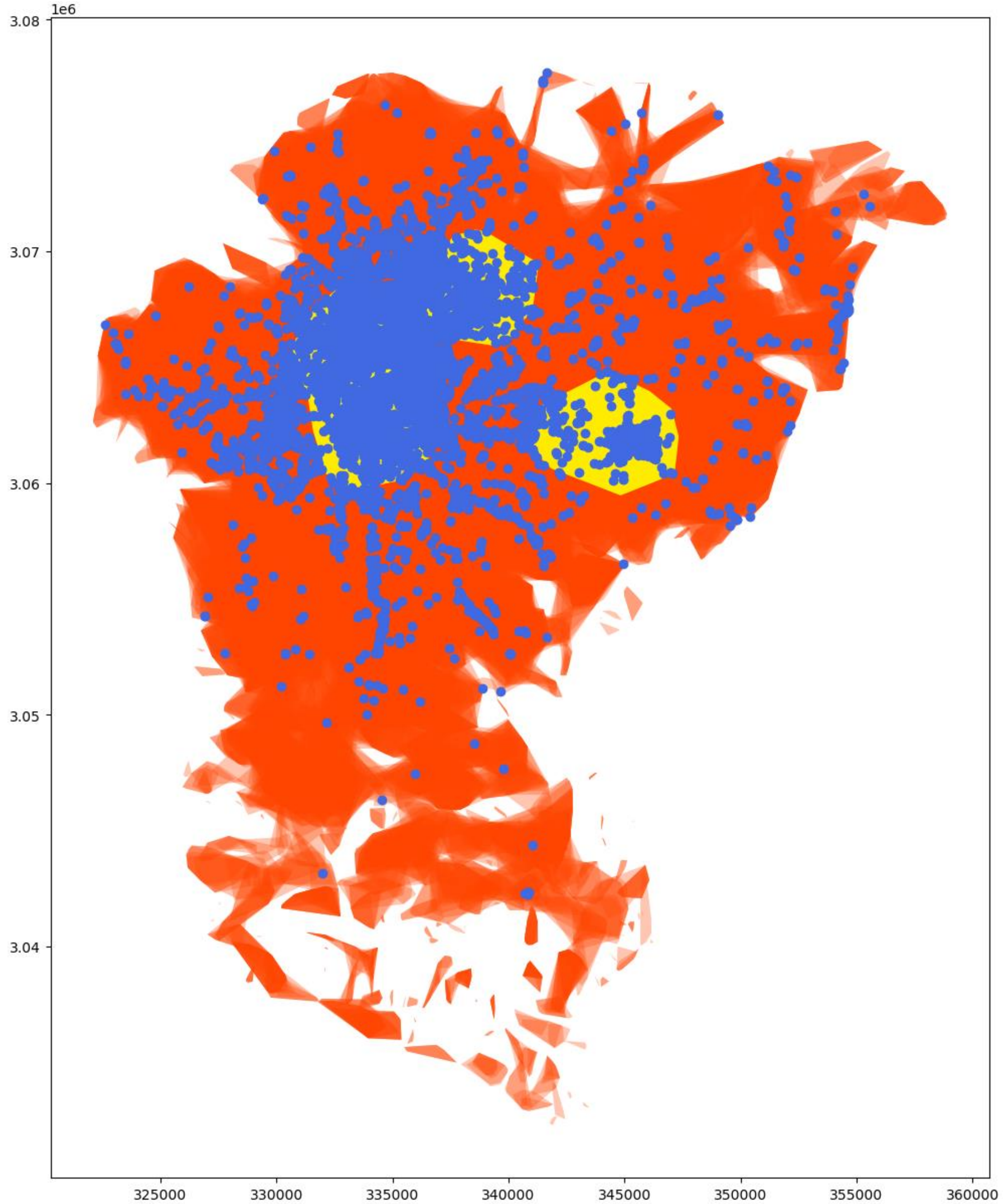


In [12]:

```
fig, ax = plt.subplots(figsize=(15, 15))
ax.set_aspect('equal')
s2.plot(ax=ax, color='orangered', alpha=0.3)
s1.plot(ax=ax, color='yellow', alpha=0.9)
gd_demand.plot(ax=ax, color='royalblue')
```

Out[12]:

```
<AxesSubplot:>
```



In [13]:

```
coverage1 = Coverage.from_geodataframes(gd_demand, s1, "osm_id",
"fid", demand_name="demand")
coverage2 = Coverage.from_geodataframes(gd_demand, s2, "osm_id",
"id", demand_name="demand")
```

In [14]:

```
problem = Problem.lscp([coverage1,coverage2])
```

In [15]:

```
pulp.listSolvers(onlyAvailable=True)
solver = pulp.getSolver('GLPK_CMD')
```

In [16]:

```
problem.solve(solver)
```

Out[16]:

```
<allagash.problem.Problem at 0x1df120b3af0>
```

In [17]:

```
selected_locations = s1.query(f"fid in ({[float(i) for i in
problem.selected_supply(coverage1)]})")
selected_locations2 = s2.query(f"id in ({[float(i) for i in
problem.selected_supply(coverage2)]})")
```

In [18]:

```
f"id in ({[float(i) for i in problem.selected_supply(coverage2)]})"
```

Out[18]:

```
'id in ([100.0, 1007.0, 1015.0, 1020.0, 1021.0, 1032.0, 1036.0, 1053.
0, 1070.0, 1090.0, 1115.0, 1144.0, 1147.0, 1150.0, 117.0, 1216.0, 122
5.0, 1238.0, 1280.0, 1285.0, 1293.0, 1301.0, 1305.0, 1333.0, 1339.0,
1387.0, 1402.0, 1407.0, 1411.0, 1491.0, 1538.0, 1645.0, 1664.0, 1772.
0, 1791.0, 1838.0, 1852.0, 1865.0, 1877.0, 1898.0, 1905.0, 1914.0, 19
57.0, 30.0, 325.0, 507.0, 554.0, 582.0, 732.0, 740.0, 76.0, 801.0, 80
2.0, 812.0, 894.0, 920.0])'
```

In [19]:

```
selected_locations2
```

Out[19]:

	id	type	start	area	perimeter	geometry	centroid
29	30	lines	343292.728034, 3063083.53949	2.335685e+07	17604.211155	POLYGON ((342960.739 3060346.429, 342822.406 3...	POINT (343227.594 3063094.736)
74	76	lines	339752.677646, 3058353.74452	1.876052e+07	16335.530447	POLYGON ((339483.619 3056232.217, 338381.497 3...	POINT (339751.155 3058613.546)
98	100	lines	329926.443228, 3059743.98759	1.256702e+07	13491.547750	POLYGON ((330852.031 3057369.088, 330460.260 3...	POINT (330224.974 3060030.947)
115	117	lines	340485.476171, 3048728.8049	4.319388e+06	8323.219387	POLYGON ((339859.129 3047252.660, 338082.516 3...	POINT (339624.261 3048391.939)
323	325	lines	324085.172316, 3064824.36588	1.829365e+07	16284.843041	POLYGON ((325694.483 3062421.441, 322513.848 3...	POINT (324658.671 3064647.516)

	id	type	start	area	perimeter	geometry	centroid
503	507	lines	330115.494931, 3064502.94839	2.628297e+07	18820.598233	POLYGON ((330326.093 3062110.216, 329732.231 3...	POINT (330210.921 3064647.222)
550	554	lines	332882.24226, 3050837.5802	1.504070e+07	14469.179630	POLYGON ((331688.813 3048772.848, 331100.705 3...	POINT (333159.148 3050936.055)
578	582	lines	339959.18911, 3051772.68239	7.885007e+06	10962.564576	POLYGON ((339506.018 3050733.274, 338479.213 3...	POINT (339893.629 3053021.215)
727	732	lines	335170.556722, 3072182.06047	1.572501e+07	15240.332836	POLYGON ((333836.972 3069580.523, 333790.824 3...	POINT (335570.240 3072162.919)
735	740	lines	340636.249105, 3069402.47595	2.119191e+07	16887.582221	POLYGON ((340252.346 3066605.053, 339493.324 3...	POINT (340592.559 3069477.982)
796	801	lines	330268.080089, 3072615.94021	9.808431e+06	11479.492668	POLYGON ((331166.682 3070763.867, 330358.961 3...	POINT (330968.463 3072597.615)
797	802	lines	338797.429973, 3074101.00867	1.221177e+07	13491.041432	POLYGON ((337271.759 3071249.131, 337243.409 3...	POINT (338622.255 3073435.811)
806	812	lines	345878.108315, 3071256.66158	9.066120e+06	11332.464963	POLYGON ((345252.985 3068822.481, 343688.806 3...	POINT (345327.242 3070726.888)
888	894	lines	351811.848338, 3071759.21352	8.883183e+06	11892.619841	POLYGON ((351795.870 3069371.575,	POINT (351758.966 3071896.735)

	id	type	start	area	perimeter	geometry	centroid
						351048.575 3...	
914	920	lines	328353.76048, 3066622.54305	1.207731e+07	13659.242870	POLYGON ((330555.682 3065064.520, 327607.974 3...	POINT (328541.014 3066901.985)
1001	1007	lines	327681.805495, 3053846.2354	4.612391e+06	8291.194198	POLYGON ((328505.561 3052470.100, 327476.436 3...	POINT (328111.216 3053796.716)
1009	1015	lines	332532.277525, 3042204.72475	2.139801e+06	6208.084969	POLYGON ((332762.678 3041296.759, 331495.616 3...	POINT (332087.427 3042590.735)
1014	1020	lines	342007.176319, 3043464.91126	4.610187e+06	8501.632709	POLYGON ((342880.108 3042050.556, 341921.606 3...	POINT (342234.880 3043574.571)
1015	1021	lines	333856.624673, 3074666.10904	1.218974e+07	13414.083095	POLYGON ((333509.420 3071785.775, 333199.408 3...	POINT (333684.077 3074270.622)
1026	1032	lines	328469.587932, 3062374.45888	1.660702e+07	15073.239192	POLYGON ((326888.939 3059987.219, 325867.929 3...	POINT (328273.742 3062346.155)
1030	1036	lines	333295.776144, 3068740.90147	2.262822e+07	17742.322091	POLYGON ((333173.917 3066161.124, 332622.167 3...	POINT (333199.719 3068972.818)
1047	1053	lines	347210.955968, 3074920.82562	3.712409e+06	9905.489521	POLYGON ((345684.312 3073093.358, 345679.216 3...	POINT (347299.920 3074701.596)

	id	type	start	area	perimeter	geometry	centroid
1064	1070	lines	334999.407415, 3047476.70637	5.931938e+06	10887.197211	POLYGON ((334623.809 3046104.368, 334617.091 3...	POINT (334966.870 3047140.098)
1084	1090	lines	337459.747434, 3062072.69504	2.791250e+07	20034.812086	POLYGON ((337895.131 3059574.647, 334750.929 3...	POINT (337689.240 3062354.786)
1109	1115	lines	340801.96697, 3042405.27987	6.421628e+06	10974.332902	POLYGON ((342928.687 3041482.469, 340753.449 3...	POINT (340736.298 3042542.272)
1138	1144	lines	341947.340436, 3058988.75753	1.192027e+07	12717.571148	POLYGON ((342022.859 3057342.954, 341954.417 3...	POINT (341653.450 3059425.334)
1141	1147	lines	325235.679622, 3066645.57102	1.177503e+07	12522.463447	POLYGON ((325201.959 3063885.666, 325013.697 3...	POINT (325457.475 3065797.452)
1144	1150	lines	355355.207962, 3072788.41916	5.081031e+06	9095.974489	POLYGON ((355734.463 3071420.862, 355613.764 3...	POINT (355220.530 3072371.418)
1210	1216	lines	331911.361009, 3067895.1895	2.224364e+07	17344.352575	POLYGON ((330552.041 3064683.022, 330315.980 3...	POINT (332046.843 3067602.137)
1219	1225	lines	330416.250564, 3052920.4293	1.390785e+07	14171.859263	POLYGON ((330824.760 3050909.504, 328672.722 3...	POINT (330553.523 3053127.229)
1232	1238	lines	345823.271207, 3075382.057	4.383346e+05	4690.354334	POLYGON ((345849.626 3074214.305,	POINT (345834.028 3075379.919)

	id	type	start	area	perimeter	geometry	centroid
						345814.473 3...	
1273	1280	lines	340900.809034, 3054028.09141	6.844328e+06	10159.359609	POLYGON ((340006.083 3051597.526, 338516.035 3...	POINT (340177.402 3053513.474)
1278	1285	lines	348692.760565, 3068499.25028	1.820824e+07	16311.729384	POLYGON ((346606.956 3066493.959, 346385.432 3...	POINT (348477.777 3068510.442)
1286	1293	lines	343308.889751, 3056916.69513	4.361009e+06	8183.091993	POLYGON ((343326.825 3055014.842, 342965.811 3...	POINT (343448.148 3056329.231)
1294	1301	lines	353934.311059, 3068256.09335	6.621511e+06	10666.910936	POLYGON ((354243.719 3066311.870, 353718.765 3...	POINT (353640.264 3068264.964)
1298	1305	lines	343478.47458, 3067383.17957	1.648057e+07	15267.123230	POLYGON ((344034.040 3065350.659, 341613.486 3...	POINT (343591.941 3067427.263)
1326	1333	lines	350160.388934, 3060290.00708	1.271212e+07	13048.265395	POLYGON ((350293.777 3058492.256, 348620.516 3...	POINT (349668.600 3060637.657)
1332	1339	lines	348846.036035, 3057954.58916	3.898879e+06	7852.190020	POLYGON ((348299.060 3056695.088, 347838.345 3...	POINT (348721.671 3058280.907)
1380	1387	lines	337776.822183, 3051989.2198	9.029213e+06	11824.879291	POLYGON ((336193.891 3050213.265, 336056.398 3...	POINT (337006.038 3051961.040)

	id	type	start	area	perimeter	geometry	centroid
1395	1402	lines	328716.548298, 3055446.33817	2.079511e+07	17153.199961	POLYGON ((329996.553 3052635.745, 329402.354 3...	POINT (328934.928 3055591.743)
1400	1407	lines	333607.50417, 3061176.83039	2.592103e+07	18776.061784	POLYGON ((334076.752 3058307.577, 332756.868 3...	POINT (333962.771 3061331.296)
1404	1411	lines	345937.23205, 3060937.08781	2.398836e+07	18508.259614	POLYGON ((346004.710 3058140.634, 345980.118 3...	POINT (345767.759 3060976.003)
1484	1491	lines	350656.291039, 3064190.20161	1.114003e+07	12619.972776	POLYGON ((351948.270 3062021.474, 349571.549 3...	POINT (350296.956 3063619.925)
1530	1538	lines	353045.84909, 3065813.23171	8.216255e+06	12443.286580	POLYGON ((354168.524 3064738.471, 349942.605 3...	POINT (352787.974 3066208.511)
1637	1645	lines	348061.907432, 3065587.27496	1.321543e+07	13954.694737	POLYGON ((346802.244 3063062.701, 346797.949 3...	POINT (347957.850 3065112.052)
1656	1664	lines	336984.739613, 3056748.49	2.195552e+07	18030.678559	POLYGON ((338466.983 3053829.710, 337086.794 3...	POINT (336961.460 3056716.477)
1764	1772	lines	337492.876233, 3068588.02105	2.095166e+07	16994.700896	POLYGON ((336382.275 3065312.802, 336023.667 3...	POINT (337464.739 3068455.508)
1783	1791	lines	334801.384461, 3066075.17116	2.062643e+07	16606.112640	POLYGON ((334137.635 3063002.336,	POINT (334904.453 3065895.372)

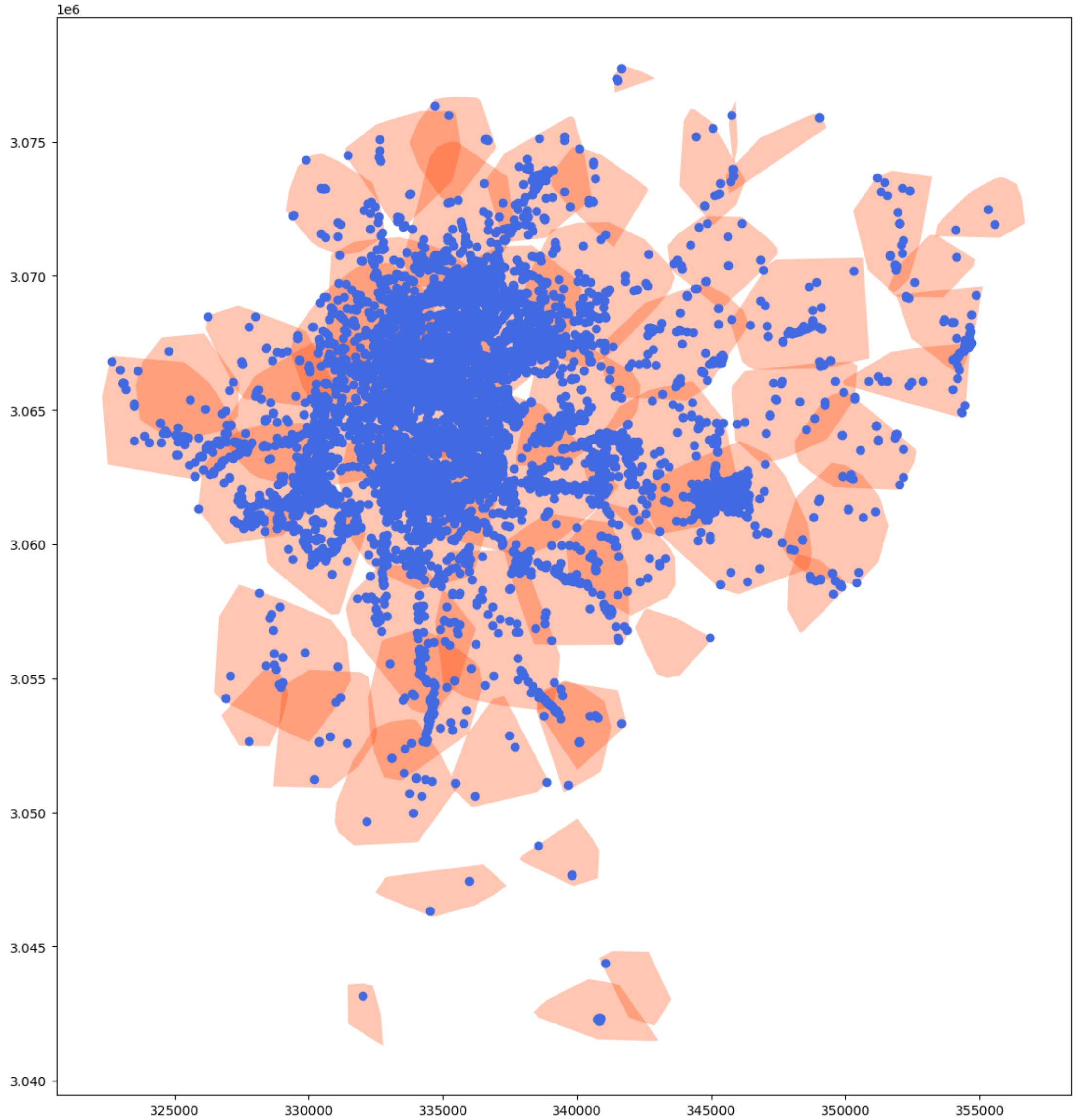
	id	type	start	area	perimeter	geometry	centroid
						334081.258 3...	
1830	1838	lines	335795.501134, 3074737.47413	8.490311e+06	10968.710986	POLYGON ((335435.974 3072727.758, 334918.732 3...	POINT (335357.516 3074907.807)
1844	1852	lines	340758.105003, 3073386.92467	7.512449e+06	10763.000758	POLYGON ((341359.226 3071074.514, 340500.193 3...	POINT (340786.741 3073128.826)
1857	1865	lines	333910.821753, 3056454.52107	1.747828e+07	15707.873680	POLYGON ((334543.640 3053693.528, 334127.447 3...	POINT (333829.324 3056674.946)
1869	1877	lines	344694.563401, 3074043.90143	6.551423e+06	10420.853817	POLYGON ((345081.745 3071898.436, 345076.566 3...	POINT (344889.022 3073993.213)
1890	1898	lines	340094.747548, 3064811.06657	1.423661e+07	14464.008738	POLYGON ((338895.308 3062911.456, 337753.481 3...	POINT (339916.848 3065131.623)
1897	1905	lines	353500.484374, 3070123.31558	4.837874e+06	8593.461872	POLYGON ((353639.570 3069195.071, 351897.430 3...	POINT (353175.160 3070218.767)
1906	1914	lines	333848.640239, 3054048.89265	1.730553e+07	15669.449727	POLYGON ((333361.292 3051189.266, 332798.576 3...	POINT (334145.298 3054154.409)
1949	1957	lines	341746.714182, 3077790.66062	8.371904e+05	4036.842953	POLYGON ((341399.875 3076834.394, 341329.033 3...	POINT (341942.568 3077354.963)

In [20]:

```
fig, ax = plt.subplots(figsize=(15, 15))
ax.set_aspect('equal')
selected_locations2.plot(ax=ax, color='orangered', alpha=0.3)
selected_locations.plot(ax=ax, color='yellow', alpha=0.9)
gd_demand.plot(ax=ax, color='royalblue')
```

Out[20]:

```
<AxesSubplot:>
```



In [21]:

```
selected_locations
```

Out[21]:

fid	Id	Name	type	start	area	perimeter	geometry	centroid

In [22]:

```
selected_locations2
```

Out[22]:

	id	type	start	area	perimeter	geometry	centroid
29	30	lines	343292.728034, 3063083.53949	2.335685e+07	17604.211155	POLYGON ((342960.739 3060346.429, 342822.406 3...	POINT (343227.594 3063094.736)
74	76	lines	339752.677646, 3058353.74452	1.876052e+07	16335.530447	POLYGON ((339483.619 3056232.217, 338381.497 3...	POINT (339751.155 3058613.546)
98	100	lines	329926.443228, 3059743.98759	1.256702e+07	13491.547750	POLYGON ((330852.031 3057369.088, 330460.260 3...	POINT (330224.974 3060030.947)
115	117	lines	340485.476171, 3048728.8049	4.319388e+06	8323.219387	POLYGON ((339859.129 3047252.660, 338082.516 3...	POINT (339624.261 3048391.939)
323	325	lines	324085.172316, 3064824.36588	1.829365e+07	16284.843041	POLYGON ((325694.483 3062421.441, 322513.848 3...	POINT (324658.671 3064647.516)
503	507	lines	330115.494931, 3064502.94839	2.628297e+07	18820.598233	POLYGON ((330326.093 3062110.216, 329732.231 3...	POINT (330210.921 3064647.222)
550	554	lines	332882.24226, 3050837.5802	1.504070e+07	14469.179630	POLYGON ((331688.813 3048772.848, 331100.705 3...	POINT (333159.148 3050936.055)
578	582	lines	339959.18911, 3051772.68239	7.885007e+06	10962.564576	POLYGON ((339506.018 3050733.274, 338479.213 3...	POINT (339893.629 3053021.215)
727	732	lines	335170.556722, 3072182.06047	1.572501e+07	15240.332836	POLYGON ((333836.972 3069580.523,	POINT (335570.240 3072162.919)

	id	type	start	area	perimeter	geometry	centroid
						333790.824 3...	
735	740	lines	340636.249105, 3069402.47595	2.119191e+07	16887.582221	POLYGON ((340252.346 3066605.053, 339493.324 3...	POINT (340592.559 3069477.982)
796	801	lines	330268.080089, 3072615.94021	9.808431e+06	11479.492668	POLYGON ((331166.682 3070763.867, 330358.961 3...	POINT (330968.463 3072597.615)
797	802	lines	338797.429973, 3074101.00867	1.221177e+07	13491.041432	POLYGON ((337271.759 3071249.131, 337243.409 3...	POINT (338622.255 3073435.811)
806	812	lines	345878.108315, 3071256.66158	9.066120e+06	11332.464963	POLYGON ((345252.985 3068822.481, 343688.806 3...	POINT (345327.242 3070726.888)
888	894	lines	351811.848338, 3071759.21352	8.883183e+06	11892.619841	POLYGON ((351795.870 3069371.575, 351048.575 3...	POINT (351758.966 3071896.735)
914	920	lines	328353.76048, 3066622.54305	1.207731e+07	13659.242870	POLYGON ((330555.682 3065064.520, 327607.974 3...	POINT (328541.014 3066901.985)
1001	1007	lines	327681.805495, 3053846.2354	4.612391e+06	8291.194198	POLYGON ((328505.561 3052470.100, 327476.436 3...	POINT (328111.216 3053796.716)
1009	1015	lines	332532.277525, 3042204.72475	2.139801e+06	6208.084969	POLYGON ((332762.678 3041296.759, 331495.616 3...	POINT (332087.427 3042590.735)

	id	type	start	area	perimeter	geometry	centroid
1014	1020	lines	342007.176319, 3043464.91126	4.610187e+06	8501.632709	POLYGON ((342880.108 3042050.556, 341921.606 3...	POINT (342234.880 3043574.571)
1015	1021	lines	333856.624673, 3074666.10904	1.218974e+07	13414.083095	POLYGON ((333509.420 3071785.775, 333199.408 3...	POINT (333684.077 3074270.622)
1026	1032	lines	328469.587932, 3062374.45888	1.660702e+07	15073.239192	POLYGON ((326888.939 3059987.219, 325867.929 3...	POINT (328273.742 3062346.155)
1030	1036	lines	333295.776144, 3068740.90147	2.262822e+07	17742.322091	POLYGON ((333173.917 3066161.124, 332622.167 3...	POINT (333199.719 3068972.818)
1047	1053	lines	347210.955968, 3074920.82562	3.712409e+06	9905.489521	POLYGON ((345684.312 3073093.358, 345679.216 3...	POINT (347299.920 3074701.596)
1064	1070	lines	334999.407415, 3047476.70637	5.931938e+06	10887.197211	POLYGON ((334623.809 3046104.368, 334617.091 3...	POINT (334966.870 3047140.098)
1084	1090	lines	337459.747434, 3062072.69504	2.791250e+07	20034.812086	POLYGON ((337895.131 3059574.647, 334750.929 3...	POINT (337689.240 3062354.786)
1109	1115	lines	340801.96697, 3042405.27987	6.421628e+06	10974.332902	POLYGON ((342928.687 3041482.469, 340753.449 3...	POINT (340736.298 3042542.272)
1138	1144	lines	341947.340436, 3058988.75753	1.192027e+07	12717.571148	POLYGON ((342022.859 3057342.954,	POINT (341653.450 3059425.334)

	id	type	start	area	perimeter	geometry	centroid
						341954.417 3...	
1141	1147	lines	325235.679622, 3066645.57102	1.177503e+07	12522.463447	POLYGON ((325201.959 3063885.666, 325013.697 3...	POINT (325457.475 3065797.452)
1144	1150	lines	355355.207962, 3072788.41916	5.081031e+06	9095.974489	POLYGON ((355734.463 3071420.862, 355613.764 3...	POINT (355220.530 3072371.418)
1210	1216	lines	331911.361009, 3067895.1895	2.224364e+07	17344.352575	POLYGON ((330552.041 3064683.022, 330315.980 3...	POINT (332046.843 3067602.137)
1219	1225	lines	330416.250564, 3052920.4293	1.390785e+07	14171.859263	POLYGON ((330824.760 3050909.504, 328672.722 3...	POINT (330553.523 3053127.229)
1232	1238	lines	345823.271207, 3075382.057	4.383346e+05	4690.354334	POLYGON ((345849.626 3074214.305, 345814.473 3...	POINT (345834.028 3075379.919)
1273	1280	lines	340900.809034, 3054028.09141	6.844328e+06	10159.359609	POLYGON ((340006.083 3051597.526, 338516.035 3...	POINT (340177.402 3053513.474)
1278	1285	lines	348692.760565, 3068499.25028	1.820824e+07	16311.729384	POLYGON ((346606.956 3066493.959, 346385.432 3...	POINT (348477.777 3068510.442)
1286	1293	lines	343308.889751, 3056916.69513	4.361009e+06	8183.091993	POLYGON ((343326.825 3055014.842, 342965.811 3...	POINT (343448.148 3056329.231)

	id	type	start	area	perimeter	geometry	centroid
1294	1301	lines	353934.311059, 3068256.09335	6.621511e+06	10666.910936	POLYGON ((354243.719 3066311.870, 353718.765 3...	POINT (353640.264 3068264.964)
1298	1305	lines	343478.47458, 3067383.17957	1.648057e+07	15267.123230	POLYGON ((344034.040 3065350.659, 341613.486 3...	POINT (343591.941 3067427.263)
1326	1333	lines	350160.388934, 3060290.00708	1.271212e+07	13048.265395	POLYGON ((350293.777 3058492.256, 348620.516 3...	POINT (349668.600 3060637.657)
1332	1339	lines	348846.036035, 3057954.58916	3.898879e+06	7852.190020	POLYGON ((348299.060 3056695.088, 347838.345 3...	POINT (348721.671 3058280.907)
1380	1387	lines	337776.822183, 3051989.2198	9.029213e+06	11824.879291	POLYGON ((336193.891 3050213.265, 336056.398 3...	POINT (337006.038 3051961.040)
1395	1402	lines	328716.548298, 3055446.33817	2.079511e+07	17153.199961	POLYGON ((329996.553 3052635.745, 329402.354 3...	POINT (328934.928 3055591.743)
1400	1407	lines	333607.50417, 3061176.83039	2.592103e+07	18776.061784	POLYGON ((334076.752 3058307.577, 332756.868 3...	POINT (333962.771 3061331.296)
1404	1411	lines	345937.23205, 3060937.08781	2.398836e+07	18508.259614	POLYGON ((346004.710 3058140.634, 345980.118 3...	POINT (345767.759 3060976.003)
1484	1491	lines	350656.291039, 3064190.20161	1.114003e+07	12619.972776	POLYGON ((351948.270 3062021.474,	POINT (350296.956 3063619.925)

	id	type	start	area	perimeter	geometry	centroid
						349571.549 3...	
1530	1538	lines	353045.84909, 3065813.23171	8.216255e+06	12443.286580	POLYGON ((354168.524 3064738.471, 349942.605 3...	POINT (352787.974 3066208.511)
1637	1645	lines	348061.907432, 3065587.27496	1.321543e+07	13954.694737	POLYGON ((346802.244 3063062.701, 346797.949 3...	POINT (347957.850 3065112.052)
1656	1664	lines	336984.739613, 3056748.49	2.195552e+07	18030.678559	POLYGON ((338466.983 3053829.710, 337086.794 3...	POINT (336961.460 3056716.477)
1764	1772	lines	337492.876233, 3068588.02105	2.095166e+07	16994.700896	POLYGON ((336382.275 3065312.802, 336023.667 3...	POINT (337464.739 3068455.508)
1783	1791	lines	334801.384461, 3066075.17116	2.062643e+07	16606.112640	POLYGON ((334137.635 3063002.336, 334081.258 3...	POINT (334904.453 3065895.372)
1830	1838	lines	335795.501134, 3074737.47413	8.490311e+06	10968.710986	POLYGON ((335435.974 3072727.758, 334918.732 3...	POINT (335357.516 3074907.807)
1844	1852	lines	340758.105003, 3073386.92467	7.512449e+06	10763.000758	POLYGON ((341359.226 3071074.514, 340500.193 3...	POINT (340786.741 3073128.826)
1857	1865	lines	333910.821753, 3056454.52107	1.747828e+07	15707.873680	POLYGON ((334543.640 3053693.528, 334127.447 3...	POINT (333829.324 3056674.946)

	id	type	start	area	perimeter	geometry	centroid
1869	1877	lines	344694.563401, 3074043.90143	6.551423e+06	10420.853817	POLYGON ((345081.745 3071898.436, 345076.566 3...	POINT (344889.022 3073993.213)
1890	1898	lines	340094.747548, 3064811.06657	1.423661e+07	14464.008738	POLYGON ((338895.308 3062911.456, 337753.481 3...	POINT (339916.848 3065131.623)
1897	1905	lines	353500.484374, 3070123.31558	4.837874e+06	8593.461872	POLYGON ((353639.570 3069195.071, 351897.430 3...	POINT (353175.160 3070218.767)
1906	1914	lines	333848.640239, 3054048.89265	1.730553e+07	15669.449727	POLYGON ((333361.292 3051189.266, 332798.576 3...	POINT (334145.298 3054154.409)
1949	1957	lines	341746.714182, 3077790.66062	8.371904e+05	4036.842953	POLYGON ((341399.875 3076834.394, 341329.033 3...	POINT (341942.568 3077354.963)

In [23]:

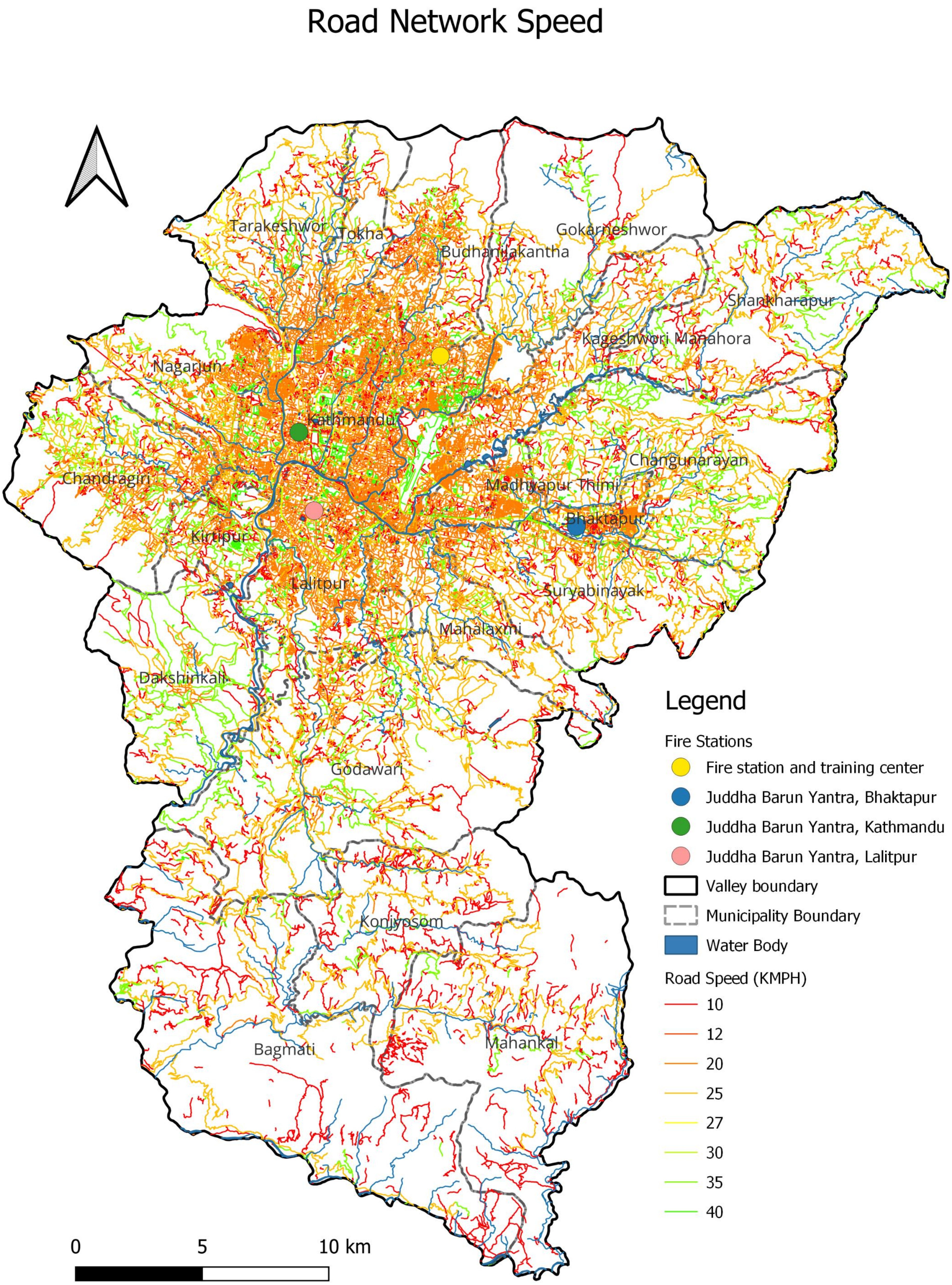
```
selected_locations.to_csv(path_to_data+'selected_locations_5plus_1.cs
v')
```

In [24]:

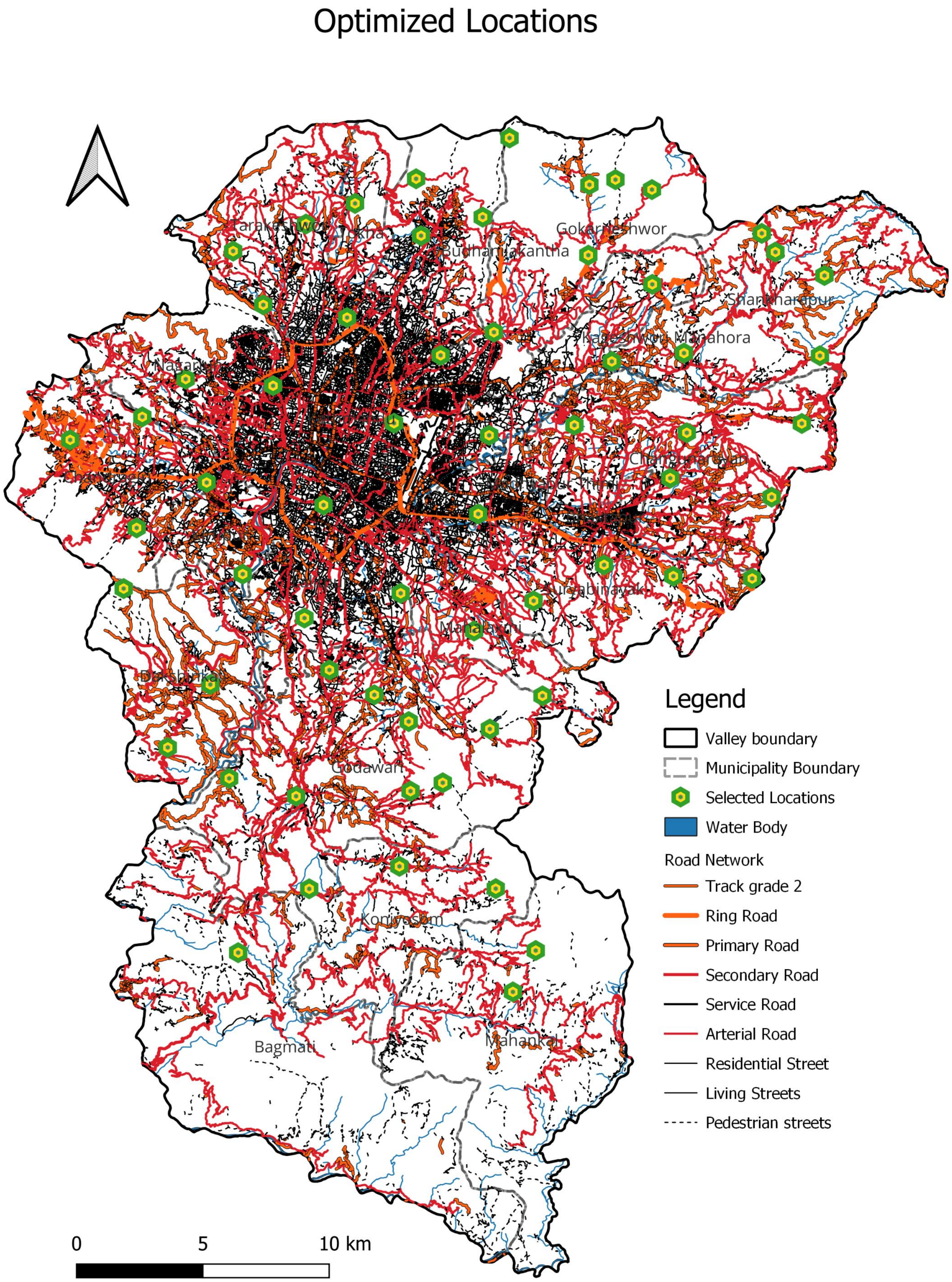
```
selected_locations2.to_csv(path_to_data+'selected_locations_5plus_2.c
sv')
```

In [ ]:

APPENDIX C: Road Speed Map Implemented for Thesis



APPENDIX D: Optimized Fire Station Location Map



APPENDIX E: Photographs

Juddha Barun Yantra, Lalitpur

Juddha Barun Yantra, Lalitpur

Road Traffic Condition

Road Traffic Condition

Road Traffic Condition

Road Traffic Condition

Road Traffic Condition

Juddha Barun Yantra Office, Lalitpur


Kathmandu Metropolitan Office


Road Traffic Condition


Road Traffic Condition


Juddha Barun Yantra Office, Kathmandu


Juddha Barun Yantra, Kathmandu

Juddha Barun Yantra, Kathmandu

Juddha Barun Yantra, Kathmandu


Road Traffic Condition


Road Traffic Condition


Road Traffic Condition


Road Traffic Condition


Road Traffic Condition


Road Traffic Condition


Road Traffic Condition


Juddha Barun Yantra, Kathmandu


Road Traffic Condition

Road Traffic Condition

Juddha Barun Yantra Office, Bhaktapur

Juddha Barun Yantra, Bhaktapur

Road Traffic Condition

Road Traffic Condition

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