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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GRADUATE STUDIES

CORRELATING LAND-USE CHARACTERISTICS AND PARKING DEMAND CONDITIONS: A CASE STUDY IN YEKA SUB CITY, ADDIS ABABA-ETHIOPIA

By

Dawit Berhanu

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Civil and Environmental Engineering

(Road and Transport Engineering Stream)

Advisor

Dr. Yonas Minalu

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DECLARATION

This MSc thesis entitled with "CORRELATING LAND-USE CHARACTERISTICS AND PARKING DEMAND CONDITIONS: A CASE STUDY IN YEKA SUB CITY, ADDIS ABABA-ETHIOPIA" is my unique work. This thesis is a one-of-a-kind piece of work that has never been presented at any university and is not being submitted concurrently for any other degree. Furthermore, all sources of material included in the thesis have been appropriately acknowledged, guaranteeing that the work is both unique and correctly credited.

Dawit Berhanu (GSR/5825/14)		October, 2024
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i

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AACRA..Addis Ababa City Roads Authority

AACRTB ....Addis Ababa City Roads and Transport Bureau

AASHTO ....American Association of State Highway and Transportation Officials

AHP..Analytical Hierarchy Process

CI..Consistency Index

CR ....Consistency Ratio

DEM…………………………………Digital Elevation Model

ERA...Ethiopian Roads Authority

ESRI…………………………………Environmental System Research Institute

GIS ....Geographic Information System

HCM ....Highway Capacity Manual

ITDP..Institute of Transportation and Development Policy

KM ....Kilo Meter

km^2………………………………… Square Kilo meter

m^2………………………………… ..Square meter

M ....Meter

MCDM...Multi-criteria decision-making

OWA ………………………………..Ordered Weighted Averaging

RI………………………………… …Random Index

TAC………………………………… Travel Absorption Centers

TPMO………………………………Transport Programs Management Office

W…………………………………... Criteria Weights

ABSTRACT

The increasing car ownership in Addis Ababa is causing increased parking issues, leading to traffic and impacts. Current parking lots are high in traffic and population density but cannot meet city needs due to their location and capacity. A more effective parking system is needed, requiring a thorough examination of existing conditions and analysis of suitable locations for new parking lots. This study investigates parking conditions and land use characteristics in Yeka sub city, Addis Ababa, focusing on on-street parking areas and available off street parking. It assesses the city's current parking issue in terms of available supply and required demand in terms of land use.

A Multi-Criteria Decision Analysis (MCDA) approach is used to solve the parking location selection analysis problem. The weightage of criteria used in the analysis is estimated, and potential parking solutions or site selections for new parking areas are identified using a combination of GIS & Analytic Hierarchy Process (AHP) techniques, identifying primary & sub-criteria, with a focus on travel absorption centers (land use), parking, and transportation as the primary criteria for selecting parking lots. The combination of GIS and AHP provides an efficient and optimal strategy for site selection & locating suitable parking locations. The AHP approach, when applied to criteria, established relative weights, whilst GIS enabled spatial analysis to discover ideal parking spaces. The MCDA results indicate that the most suitable parking lot.

The study identifies accessibility to main roads as the criterion carrying the greatest weight (0.6472), while accessibility to church and mosque facilities (0.0205). The study area, primarily in the south-west of the sub city, has high suitability for public parking, with 0.924 square kilometers (1.057%) being extremely suitable. The remaining areas are suitable, moderately suitable, less suitable, and unsuitable covers 6.972, 9.52, 1.507, and 80.945 percent of the study area. To summarize, the integration of GIS with sophisticated aggregation and suitability analysis methodologies has a high potential to integrate and evaluate several geographical data sets at the same time, particularly in site selection studies. The study identified the suitable area for parking having 1.057% being extremely suitable with different suitability ranges. The study is a critical resource for sustainable urban management and decision-making, offering insights into future urban planning and identifying ideal parking lot sites.

Keywords: - *Parking, Land use, Multi-Criteria Decision Analysis (MCDA), Analytic Hierarchy Process (AHP), GIS, suitable parking location, Yeka sub city.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Global urbanization has been steadily increasing, with the urban population projected to reach 68% by the middle of the twenty-first century (Kundu 2020). This trend is particularly evident in Asia and Africa, where cities are quickly expanding (Kundu 2020). The trend of urbanization is driven by a shift in human activity to urban areas and is expected to continue, particularly in emerging countries (He 2013). Parking demand in cities is impacted by urbanization rates, land type, and use (Muška, 2006). Parking is a vital part of the transportation system. It is the act of halting, disengaging, and abandoning a vehicle unattended. Cities in developing countries, such as Ethiopia, face issues with parking supply.

Due to a lack to plan and relevance in master plans, the parking problem has been evident as a result of the rapid increase in car ownership, which has been matched by an increase in demand for vehicles that can be stopped in suitable parking places (Abdulkareem et al., 2021). This has an impact on the city's physical development, the growth of shopping centers, the distance between dwellings and centers of activity, the increase in vehicle ownership or use, and the generation of traffic on the road, all of which are affected by an imbalance in the provision of urban infrastructure and facilities (Riri Fausari et al., 2019). Microsimulation models are proposed as a method for sensible urban parking management (Makarova, 2022). However, China's increasing motorization has resulted in an imbalance between parking supply and demand, prompting a shift in urban parking management (Wang, 2013). The constructed environment and parking accessibility have a significant impact on vehicle ownership and use. Transit-oriented development of cities and parking limits are proposed as viable sustainable transportation alternatives (Yin, 2018).

One of the transportation issues is the need for parking in the city center, which is growing (Riri Fausari et al., 2019). Parking in Addis Ababa is crucial; the majority of parking occurs on the street, which jams main traffic arteries. It is currently a big issue in some sub-cities of the city of Addis Ababa, and it appears to be an underappreciated aspect of transportation development. Markets, stores, churches, mosques, workplaces, schools, and other activity areas usually generate significant parking demand, increasing the sub-city's parking issues (Abu, 2019).

The growing number of automobiles in transportation has resulted in about significant improvements, including more travel flexibility and economic prosperity. However, these cars have also caused environmental problems such as pollution, noise, and increased traffic accidents, necessitating immediate action. These difficulties have prompted the need for immediate remedies to protect humans and animals on the road (Biyik et al., 2019). Vehicles have generated economic problems in cities due to traffic congestion, offering a challenge to city planners in accommodating the growing number of vehicles through road development and parking space creation. Parking is particularly important as most people favor owning a private vehicle, which is deeply ingrained in everyday life (Guo, 2013; Kent, 2013; Biyik et al., 2019). Consequently, finding a parking space in crowded towns and cities is a challenging task that adds to climate change by wasting time and using needless fuel (Polycarpou, 2013; Tayade, 2016; Biyik et al., 2019). Parking is a key issue that has been discussed in both climate change mitigation conversations and political forums (Biyik et al., 2019).

A method has been presented to address parking shortages by using a shared parking lot model. This concept would make optimal use of temporary residential parking spots (Shao, 2016). However, many people, including those who do not own a car, are unwilling to give up parking provisions for autos. This is mostly due to the perceived value of parking in terms of sustainability and urban design (Stubbs, 2002). Various urban stakeholders who shoulder some of the cost of poorly managed parking spots stand to gain from smart parking systems. For instance, it's anticipated that these systems would lessen traffic accidents, or crashes brought on by drivers' inattentiveness when vying for parking spots or occupying ones that already exist (Biyik et al., 2019). This study report assesses the impact of parking efficiency and difficulties on the transport system in Addis Ababa. The current parking system is inadequate and has operational issues, particularly for street parking. As a result, it has led to poor road utilization, safety issues, and traffic congestion. Parking is a key issue in local transportation planning.

1.2 Statement of the Problem

Parking is a major concern in Addis Ababa, with a high occupancy rate and few off-street parking options (Abu, 2019). This problem is worsened by the city's lack of parking spots, which causes congestion on major transportation routes (Alkheder, 2016). As a result, traffic congestion plays a key role in road accidents, emphasizing the need for improved road infrastructure and traffic flow management (Berhanu, 2004). The development of smart parking schemes is also delayed, with client-related considerations being the most important (Woldeyohannes, 2020). These studies highlight the crucial need for comprehensive solutions to Addis Ababa's parking related to land use demand in the area and transit congestion issues. Currently, there are numerous issues in Addis Abeba that are primarily concerned with a lack of parking space, such as road congestion resulting from a shortage among on-street parking capacity and vehicle count, environmental emissions caused by the search for parking space, and drivers sitting idle while waiting for parking.

Figure 1. 1 On-street parking problem in Addis Ababa.

Source: Own (from my site investigation)

On-street parking is viewed as critical since it reduces land use and provides convenient access to destinations. However, it should be prohibited (Hongwei Guo et al. 2012) due to its impact on roadway resources such as automotive lanes, bike lanes, and walkways. Entering and leaving parking spots are examples of parking movements that can slow down traffic and lower the capacity of nearby transportation lanes. Furthermore, on-street parking is associated with an increase in traffic accidents. The Addis Ababa Transport Policy has recognized parking as a significant infrastructural issue in the city. Unauthorized parking is a serious issue since it limits traffic routes, causing traffic congestion and increased travel costs. In most parts of the city, especially in the vicinity of marketplaces, shops, mosques, churches, and businesses, there is little space for off-street parking (Abu, 2019). This study intends to solve the issue by looking at parking patterns in the city, identifying difficulties and opportunities for authorities to minimize road traffic congestion by allocating parking areas based on demand suitability of land use in the area, improve parking efficiency by considering the existing and proposed parking area, and examine constraints in applying parking management approaches.

Parking demand in Addis Ababa is a major challenge, particularly in high-traffic areas such as market centers, enterprises, and offices (Abu, 2019). The city's rapid development and population growth have led to increased car ownership, aggravating the situation (Voukas, 2012). The current public transportation system, which is dominated by Anbessa buses and Minibus cabs, cannot meet the increasing demand for transportation (Fenta, 2014). The scenario in Addis Ababa is similar to that of Abu Dhabi, where a dearth of available parking spots has led in the creation of a paid parking system (Alkheder, 2016). These studies highlight the need for improved parking management along the allocation of new facility and public transit services in Addis Ababa. The number of automobiles and available parking spots in cities and metropolitan areas are not in balance when it comes to parking demand. Parking problems are becoming more and more important in cities and metropolitan areas, and they are one of the most often discussed topics by experts and the general public alike.

The main causes of the Addis Ababa parking issue are inaccurate space requirements estimations and poor land use planning (Ibrahim, 2017). High demand for parking is exacerbated by activities like market centers, shops, and offices, leading to full use of available capacity (Abu, 2019). This mismatch worsens with land use type, affecting traffic volumes and parking demand (Mužka, 2006). The lack of a parking system in Addis Ababa leads to traffic congestion, accidents, and environmental pollution. Despite its potential to improve urban mobility, parking is often overlooked in urban planning, necessitating improved solutions at management, planning, and design levels.

This study aims to improve the implementation strategy of a modern parking system in Addis Ababa by identifying challenges and problems that prevent its successful implementation. The city's rapid economic and social changes have led to an increasing need for parking, especially in the city center, which serves as a hub for travel. The study identifies the lack of an effective system for defining and distributing parking areas, as well as the negative effects of random and illegal parking, which reduces roadway capacity and leads to overtaking on sidewalks, roads, and land uses.

1.3 Objective of the Study

1.3.1 General Objective

In general, the goal of this thesis is to correlate land-use features with parking issues in Yeka sub City of Addis Ababa.

1.3.2 Specific Objective

The specific objectives of this thesis work are the following

i. To assess the existing parking performance and land use characteristics of the Yeka sub City of Addis Ababa.

ii. Appropriate site selection of parking lots using Geographic Information System (GIS)-supported Multi-Criteria Decision Analysis (MCDA) method.

iii. Analyzing the future parking requirements based on parking demand suitability in selecting areas with interrelation to land use and provide recommendations based on land use characteristics.

1.4 Research Question

The best results for this suggested thesis might be obtained by the following investigation questions are going to be addressed:

1. What are the existing parking demand and land use characteristics in Addis Ababa city?
2. How to select appropriate site for parking lot using GIS-MCDA?
3. What requirements are needed for parking based on parking demand suitability in selecting areas with interrelation to land use and solutions to address the land use problem in Addis Ababa?

1.5 Significance of the Study

This research project aims to provide an up-to-date overview of present standards in on-street parking services and off-street parking control, with a focus on congestion and municipal authorities. The data will help researchers learn more about parking and its impact on the city, potentially leading to the development of countermeasures to alleviate mobility issues. Furthermore, it will entice investors to invest in parking creation. The study's findings will also provide significant input for future research to improve the study's conception and methodology.

The goal is to improve both the standard of life within neighborhoods and the effectiveness of the transportation system.

The purpose of this study is to assess the current parking network and land utilization in Addis Ababa, with a focus on demand and the likelihood of modernization. The findings will give a thorough examination of the benefits and drawbacks of current parking and land utilization schemes. The study serves as a foundation for ongoing research in these areas and will offer critical resources for future projects. The benefits of this research include providing solutions to city's most problematic parking lots, improving the efficient use of modern parking capacity, and reducing traffic congestion through improved parking supply. The city will also obtain its particular demand for parking rates, which are going to be used in upcoming parking structure design as the nation creates an accepted parking demand rate handbook.

1.6 Scope of the research

While parking raises a number of issues in and of itself, the planned study focuses exclusively on the impact of on-street issues on the road. The study will assess the negative effects of unconditional parking on the roadside, as well as the existing conditions of insufficient modern parking in Addis Ababa, and factors contributing to the city's lack of car use, as well as route choice measures, particularly on driver cars for parking, and potential solutions. The geographical scope of the study will be limited to Yeka sub-city of Addis Ababa, which has a diverse variety of vehicle user activities, and from this study region, the recently implemented huge modern parking lots and land.

1.7 Limitations of the Study

The investigation faced limitations due to time and data constraints, resulting in surveys conducted in Addis Ababa, a representative area. Secondary data from plan and development commissions and other city government agencies was difficult to access and organize. The study also examined city master plan records, but the data quality was poor and required extensive cleaning. This study's conclusions are limited to Yeka sub-city land use characteristics which might be vary from other sub cities demand and supply trend. Comparative studies in other sub cities are needed to generalize the findings. It only evaluated parking suitability demands based on land use characteristics then allocating spaces for this specific area, leaving room for further research. The study's limitations highlight the need for more comprehensive studies in other sub cities of the city centers which will require highlighted.

1.8 Organizations of the Thesis

The thesis is divided into five chapters and includes a reference section. The initial chapter is an introduction which discusses the backdrop, problem statement, research objectives and inquiries, importance of the study, the extent of the research, study limitations, and thesis summary. The second chapter discusses the theoretical structure and reviews recent studies. Chapter three delves into the research technique in depth, including information overview and sources, before going through Chapter four, that covers the results and comments. The final chapter, Chapter 5, ends the investigation and makes suggestions. Additionally, references to supporting documents used to finish the thesis work are supplied in accordance with referencing standards.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Parking for cars is a significant issue in both municipal and strategic planning. To develop a firm parking regulation, it is necessary to thoroughly investigate parking behavior and characteristics. A number of studies on parking have been done in recent years, such as prediction of parking buildup profiles from survey information by the clustering technique, which claims that parking supply was a successful way of controlling ownership and utilization, however a severe lack of parking may drive away business and other activities (Janak et al., 2019).

As the number of cars increases quickly, there is an increasing demand for parking spaces. To reduce traffic congestion and make the best use of a parking lot, cars should be parked close together (Sumathi, 2013). The number of automobiles is continually increasing, making obtaining a free parking spot a significant challenge. Because of the increasing number of vehicles, drivers must scour the streets and parking lots for available parking spaces. As a result, there are worries about traffic congestion, time consumption, fuel waste, and air quality degradation caused by fine dust emissions in residential and shopping districts (Yugesh, 2019).

Parking is the process of stopping, disengaging, and leaving a vehicle empty. Parking along one or the other side of a road is frequently permitted, albeit with limits. Some buildings provide parking facilities for their users. Parking spots are designed and used according to standards established by countries and municipalities (Lay, 1992). Parking is vital for car-based travel. Cars are normally immobile for 95 percent of the day (Paul 2013). The availability and cost of parking encourage and subsidize dependence on automobiles (Hagman, 2006). Car parking consumes a significant amount of urban area, particularly in North America, accounting for up to half of many town centers (Donald Shoup 1997).

2.2 Parking facilities

The concept of parking facilities is multidimensional, with numerous aspects impacting its design and usage. Parking facilities in transportation infrastructure require caution from both automobiles and pedestrians. Slower speeds in parking lots can create a false sense of security (Okan, 2022). Martosenjoyo (2020) emphasizes the complexities of public parking places, which can easily turn private due to limited access. The level of service approach for determining parking efficiency is introduced by Yu (1973), where the flow/capacity ratio and availability are crucial factors. Bolger (1992) discusses park-and-ride facilities, emphasizing the importance of location requirements, accessibility issues, and parking slot allocation. Kanafani (1972) proposes a methodology for arranging parking facilities that takes into account the distribution of parking potential as well as land costs. These studies all highlight the importance of accessibility, efficiency, and location when defining and building parking facilities.

2.2.1 Types of Parking Facilities

Parking is a vital component of roadway and highway systems. Parking supply affects driving demand by altering the fundamental cost structure associated with mode selection decisions. It also affects auto utilization by altering the price of ownership. These two features combine to make parking administration a vital and efficient traffic control tool (Weinberger, 2009).

Parking options include both public and private parked (www.britishparking.co.uk). Such facilities might be on-street parking or off-street parking, which is placed in a parking lot or garage. The distinction between public and private parking spaces is a complex one with important consequences for urban planning and management. Martosenjoyo (2020) emphasizes the blurring of this distinction, with public parking places frequently considered as private by certain groups. This emphasizes the necessity for clear regulations and enforcement. Hackman (1969) offers a historical perspective on the parking sector, emphasizing the importance of private enterprise in supplying public parking. Shao (2016) proposes an approach for utilizing private parking spaces that has the potential to alleviate urban parking shortages, while Scheiner (2020) suggests that neglected private parking might serve as an alternative to illegal parking on the streets as well as thinks about a variety of regulatory efforts to address the issue.

Public parking is a crucial facility for urban residents, managed by local authorities, and accessible to all. It aids high mobility activities. Allocating public parking is a complex issue, with bottom-up approaches being more efficient but often hindered by political processes (Epstein, 2002). GIS can help choose the best locations for parking, considering factors like efficiency and land availability (Karimi, 2007). Smart city technologies, like intelligent parking assistant (IPA) design, can enhance public parking management. Private parking, owned by a private entity, can be shared to alleviate parking issues in large cities due to lack of public facilities. Customers who share parking spaces can benefit from free or fee payment options. However, privacy can be compromised when customers share their parking spots, potentially leading to identity theft. Existing private parking sharing programs often ignore or fail to address privacy concerns, or assume the presence of a trustworthy third party when privacy is a concern (Wang, 2020).

The table below depicts the different kinds of parking structures and their role in a reliable parking system. Some of these groups cross over: parking lots could be free, expensive but limited to one place, or commercial. Parking structures that are regulated and priced to prioritize higher-value routes (such as delivery and customers above commuters and homeowners) and serve many destinations have a greater chance to be utilized successfully (Todd Litman, 2018).

Table 2. 1 Types of parking facilities (Todd Litman, 2018).

Type	Images	Costs and Density	Role
On-Street (or Curb) Designated parking spaces located within a road right-of-way, usually in the curb lane.		Moderate construction costs and high density (relatively little land used per space) because they require no driveway.	Convenient to use, and can serve multiple destinations. On-street parking should be managed for maximum efficiency.
Surface Parking A parking lot directly on the ground (either paved or unpaved).		Low to moderate construction costs. Low density (they require lots of land per space, including driveways and circulation lanes.	Inefficient if they serve a single destination. Should be minimized and managed for efficiency.
Structured or Underground Any multi-story parking structure (often called a *parking garage*, *parkade* or *ramp*), including parking facilities within or under a building.		High construction costs but relatively low land costs and high densities.	Supports compact development but must be efficiently managed to justify their high construction costs.
Priced (or Metered) Any parking facility where motorists are charged directly for use, including on-street metered parking, and off-street lots where motorists pay by the hour, day, week, month or year.		Varies. Can be applied to any type of parking structure.	Pricing, particularly congestion pricing (fees are higher at times and places with high demand) tends to encourage efficient use of parking facilities.
Commercial Parking A for-profit parking lot available to any motorist and serves multiple destinations.		Varies. Can be applied to any type of parking structure.	Tends to be efficient because it is priced and usually serves multiple destinations.

Parking spots vary based on their features and location. Car parking features and standards reflect this variance. The placement of car parks impacts investment and running costs, as well as the needed area and capacity. Parking facilities are frequently divided into two categories: on-street and off-street parking (Ahmad Shekib, 2022).

2.2.1.1 On-street parking

On-street parking is a method of parking cars along the side of an open road or street. Threshold parking refers to spots for vehicles that are available alongside roads. It is a frequent form of parking in cities and suburbs in which parking lots or specialized off-street parking places are restricted (Kadiyali, 1987). Parking is allowed on either side of the roadway. On-street parking spots are often determined by government entities. Unrestricted parking facilities provide unlimited and free parking. Restricted parking, either free or charged, during peak hours may limit parking possibilities (Yousif S., 1999; Ahmad Shekib, 2022). Street parking is a type of prevalent parking that is known for its land-saving effectiveness and ease for motorists by allowing people to park their vehicles near their intended destination (Verma, 2022).

Figure 2. 1 Example of on-street car parking

To increase parking structure productivity, on-street parking has been separated into three categories. This grouping relies on the angle at which vehicles are parked in relation to the road layout (Ahmad Shekib, 2022).

1. **Parallel parking**

Owners of vehicles park their vehicles parallel to the road's length on the wayside. In the case of a collision, broad street entry and departure techniques are more pleasant than angled parking, but they take up the most space with the fewest automobiles. (Yousif S., 1999)

2. Perpendicular parking

Vehicles are being parked 90 degrees from the road by drivers. Perpendicular parking spaces, which are at a 90-degree angle to the curb, are one of the most prevalent types of parking. These places can be approached from the left or right, although if you're in a parking lot, it may be easier to enter spaces on your left because they usually allow more space to turn in comfortably. When trucks are loading and unloading merchandise in trade zones, the parking approach works very well (TSE, 1992).

3. Angle parking

The car are parked at an angle across the street. Increasing the angle decreases mobility when entering and leaving the street. The cars are parked at angles of 30, 45, and 60 degrees to the road axis. To avoid causing damage to neighboring parked autos, drivers should exercise caution when opening the door. It is suggested that one park at 45 degrees (TSE, 1992; Ahmad Shekib, 2022).

Types of on-street parking and their standards (Addis Ababa Norms and Standards, 2002).

a) Parallel parking 2.5 x 5.9 m per car P No. $\frac{L}{5.9}$

b) 30^0 angle parking 5 x 2.5 m P No. = $\frac{L-1.25}{5}$

c) 45^0 angle parking 5 x 2.5 m P No = $\frac{L-1.77}{3.54}$

d) 60^0 angle parking 5 x 2.5 m = P No = $\frac{L-2.16}{2.89}$ 90^0 angle parking 5 x 2.5 m = P No = $\frac{L}{2.5}$

L = Length of Kerb

P No = Number of parking spaces

2.2.1.2 Off-street parking

Off-street parking refers to parking spots for automobiles in an enclosed parking lot or garage. Parking lots can be held by municipalities, government agencies, or private individuals. Off-street parking refers to parking your vehicle anywhere other than on the street. These are typically parking areas such as garages and lots. It can be both indoors and outside. It also covers private property, garages, and driveways. Off-street parking is now the preferred method for storing large numbers of vehicles. Off-street parking options with significant vehicle capacity include multistory, surface, subterranean, and mechanized parking lots (Ahmad Shekib, 2022).

Figure 2. 2 Example of Off-street car parking

Types of Off-Street Parking

- Single-level garages.
- Multilevel garages.
- Underground garages.
- Automated parking garages – this involves driving your vehicle on the parking system, and the system automatically moving your car to an available space.

2.2.2 Parking Space and Dimensions

Nowadays, every town have a significant lack of parking spaces. The amount of cars continues to rise, not only in metropolitan areas and megalopolis, but additionally in tiny cities throughout the country, yet there are not enough parking spots. The speed of issue resolution is significantly lower than the rate of development in citizen mobility (Mikušová, 2020). Many advanced cities have the difficulty of regulating traffic flow optimally while keeping an acceptable number of parking spaces. Creating an adequate raster of the transit system, limited by historic and present-day structures and locations, is an extremely tough task. Similarly, supplying an adequate quantity of open parking space at peak hours in cities is challenging. Even when enough parking capacities are available, both the input and output stations of parking lots and building infrastructures regularly grind to a halt because of a mismatch among their capabilities and the needs of traffic at any given time (Krpan 2017).

A parking space is any covered or open place, whether enclosed or not, that is big enough to accommodate cars. Parking spots require a driveway serving them that allows cars to enter and exit and connects them to a roadway or alley. According to CMDA guidelines, a car parking place must be at least 2.5 m wide and 5 m long. Parking spots for trucks need to be at least 4.57m wide and 9.14-12.2m long (www.parking.net).

Table 2. 2 Building type and parking requirement standards

Building type	Parking requirement
Flats in rental apartments and condominium housing	1 parking/flat
Offices	1 parking/every 40 m^2 floor space
Supermarkets, Department stores, trade fares etc.	1 parking/every 60 m^2 floor space
Primary and secondary schools	1 parking/2 class rooms
Universities	1 parking/every 5 employees
Hospitals	1 parking/every 40 m^2 floor space
Museums and libraries	1 parking/every 40 m^2 floor space
Hotels and motels	1 parking/every 5 beds
Theatres and Cinemas	1 parking/every 10 sitting spaces
Stadium	1 parking/every 10 spectator
Restaurants, bars, coffee houses, pastries etc.	1 parking/every 10 sitting spaces

Sources: Addis Ababa Norms and Standards, 2002.

On-street parking spots are normally allocated areas alongside the sides of roads for automobiles to park. These areas are designated with lines of paint or signage stating parking regulations such as time constraints, authorization demands, or payment instructions. Off-street parking is divided into allocated parking places that are labeled and placed in lines or sections. Painted paths, numbers, or other indications can be used to clearly designate places. This improves space use and enables for more effective car parking and retrieval (www.parking.net).

2.2.3 Parking Facility Costs

One key benefit of parking administration is the ability to reduce facility costs. Parking expenses are sometimes disguised in rental agreements, taxes, and retail products, making it hard for individuals to determine the full cost and potential savings from improved oversight (Todd Litman, 2018). The several sorts of parking costs are addressed here (Litman, 2009).

- **Land costs:** land requirements for parking spaces vary based on their kind and size. Off-street parking necessitates driveways as well as entry lanes. Landscaping normally contributes 10-15% to the parking area size.
- **Construction prices** may increase due to poor drainage, hilly or irregular lots, significant landscaping, or the addition of restrooms and elevators. The real expenses are frequently far higher. Underground parking (for example, in a building's basement) is frequently twice the cost per spot as outside structured parking.
- **Costs for operations and maintenance** include cleaning, lighting, repairs, safety, landscaping, snow removal, access control (e.g., entry gates), fee collection (for paid parking), enforcement, coverage, labor, and administration. Parking lots require regular cleaning and repaving. Parking facilities usually last 20-40 years without needing substantial repairs or replacement.
- **Transaction costs:** refer to continuing expenditures associated with regulations and prices, such as equipment, attendants, space, administration, and enforcement.
- **Total Parking Cost:** Numerous studies have estimated the number of parking spaces in a typical community. Because there are fewer access roads, on-street parking requires less land than off-street parking. However, it may incur significant potential costs when it takes up roadway space for highways or walkways. The Parking Cost, Costing, and Revenue Calculator can calculate expenses related to certain scenarios.

2.2.4 Benefits of parking facility

Research has consistently demonstrated that effective parking pricing and administration can result in a variety of benefits. Study emphasize the possibility of reducing transportation congestion, air pollution, and carbon emissions, as well as increasing money for public services (Shoup, 2023; Litman, 2010). Parking lots allow easy access to structures such as offices, retail establishments, restaurants, schools, and hospitals. Parking places may be found within or outside the structure itself. If there isn't enough room inside the structure, it makes logical to install parking outside.

1. Reduces influence on historic sites and buildings through reduced footprints and discrete access.
2. Improves personal safety at night.
3. Reduces accidents and vehicle damage.

4. Reduces theft and Improves safety for walkers and cyclists
5. Reduces noise, pollutants, acoustic and vibrational affects.
6. Offers choices like storage chambers or provision for riders' bike storage.
7. Ensures accessibility for all users, including the disabled & parents with children.
8. Offers convenience with intelligent software for scheduled car retrieval and reduced waiting times.
9. Saves users' time from having to drive into a parking lot to find an area to park, and walk out.

2.3 Definition of Parking Demand and Supply

Parking Demand: Parking Demand refers to the quantity of parking that will be used at a given time, location, and price. It is an important aspect in determining parking issues and solutions. Demand for parking is influenced by a facility's nature, location, and design as well as by how it stacks up against other choices in the area. The most accessible and prominent locations are in most demand.

Parking demands could be classified in numerous ways, affecting parking management possibilities and requirements (Todd Litman, 2018):

- Short-term parking (under one hour) includes deliveries and most errand trips.
- Medium-term parking (one to four hours) includes meals, shopping, service trips (e.g. plumbers and electricians), commuters, and guests.
- Long-term parking includes commuting, residents, as well as certain service trips.

Parking supply: Parking supply is defined as the quantity of legal space available for parking. Parking Supply refers to the availability of parking spaces. Parking is a significant urban land use. The ideal situation parking supply can be described as the amount of money that motorists would spend if all costs were covered immediately and they had convenient parking and means of transportation.

2.4 Parking management

Parking management entails rules and activities designed to maximize the use of parking assets through multiple initiatives and policies (Barter 2014; Todd Litman, 2018). Parking management may substantially decrease the total amount of required parking spaces, which has advantages in terms of economy, society, and the environment. More effective leadership is frequently a useful answer to parking problems. It covers measures for making greater utilization of existing facilities, increasing service quality, and enhancing facility design. Parking management tools are new technology that assist individuals, businesses, and organizations in managing their parking spaces. The main aim behind such structures is to increase the overall effectiveness of parking facilities. Managing car parks is a difficult undertaking for businesses and organizations since there are so many moving variables, such as traffic and space availability. It is time-consuming, labor-intensive, and inefficient. Using a parking management system can assist a business decrease its parking administrative overhead while also reducing the impact of their parking spot on the surrounding community (Todd Litman, 2018).

2.4.1 Principles of Parking Management

Parking management can improve user alternatives such as travel (walking, cycling, ride-sharing, public transportation, car-sharing), pricing (per hour, daily, or monthly costs), and ways to pay (money, invoices, credit cards, payments via the internet, etc.). These five basic themes can help drive parking management strategy (Todd Litman, 2018).

1. Consumer choice. Users should have enough parking and transportation choices.
2. User information. Motorists should grasp their parking and transportation options.
3. Share. Parking lots ought to accommodate a variety of users and locations.
4. Efficient utilization. Parking lots ought to be developed and managed to ensure that spaces are used on a regular basis.
5. Flexibility. Parking strategies should accommodate uncertainty and change.
6. Prioritization. Most valuable areas should be prioritized for higher-value utilization.
7. Prices. As far as possible, users ought to pay for parking immediately.
8. Peak management. Special efforts must be undertaken to meet the high demand.
9. Quality vs. quantity. Quality for parking structures, including visual appeal, security, access, and user data, is as important as quantity.
10. Comprehensive analysis. Parking design should take into account all applicable costs and benefits.

2.4.2 Benefits of Parking Management

- Reduce facility costs: reduces the expenses for governments, corporations, developers, and consumers.
- To improve service quality, consider expanding consumer alternatives, reducing congestion, enhancing customer data, and creating more appealing facilities.
- Parking management improves choosing the location and design flexibility, allowing designers, builders, and planners to better address parking needs.
- Some management approaches generate cash for parking facilities, transit upgrades, and other vital efforts.
- Effective parking administration saves land and protects environmentally friendly, historic, and cultural values.
- Effective parking management encourages efficient commuting, lowering traffic congestion, costs, contamination, use of energy, and accidents.
- Effective parking management supports Smart Growth by promoting equitable and effective land use, aligning with development objectives.
- Parking management enhances walkability by encouraging grouped building and proximity to sidewalks and streets.
- Parking management encourages transit-oriented development and transit use.
- Reduced storm water management expenses, water pollution, and heat island effect: parking management can save pavement area and improve architectural characteristics.
- Supports equity aims: effective management solutions may decrease the requirement for subsidies, expand non-driver travel options, and make transportation more affordable for low-income households.
- Increased livability in communities: effective parking management can enhance community design by decreasing paved areas, promoting walkability, and allowing for more flexible layouts.

2.4.3 Parking Management in Rapidly Developing Cities

In many cities throughout the world, increased use of personal vehicles has led to traffic congestion, pollution, and economic loss. Nairobi and Addis Ababa are no exceptions. Parking rules in these cities are beneficial to drivers, but they have proven ineffective in traffic management because they encourage the use of private cars and worsen congestion. To improve current rules, it is critical to understand how parking regulations can help to create an effective integrated transportation system (africa.itdp.org). The Parking Handbook for Chinese Municipalities (Weinberger et al. 2013) presents global strategies to oversee urban parking that are consistent with long-term goals. It suggests a number of eight strategies:

1. Establish centralized management for parking activities.
2. Establish minimal performance standards for parking management.
3. Use appropriate technologies for invoicing and data gathering.
4. Consider lowering or eliminating parking minimums and implementing limits or quotas.
5. Differentiate land utilization and off-street parking regulations and put in shared parking.
6. Charge off-street parking depending on market costs.
7. Enhance enforcement using electronic technology and physical design.
8. Provide clear information on parking supplies to maximize their effectiveness.

2.5 Parking costs

Parking pricing, often known as user pay or meter parking, is a direct price that cars must pay to utilize a parking space. This enables parking lots to recoup costs and manage demand. This could be used as part of a parking administration approach (to reduce parking issues), a transit management method (to reduce traffic issues), to cover parking expenses (so that parking facilities are funded through users rather than subsidized), or to produce revenue for any cause (for example, funding local transportation initiatives or the center improvements). It is widely used to achieve several goals (Shoup, 2013).

Effective parking pricing has many advantages, such as more turnover and thus better customer comfort, lower parking facility expenses, less traffic issues, and higher profits. Parking fee implementation guidelines are provided in this study. Examples of effective parking pricing systems are provided, along with information on common roadblocks and objections and the costs and advantages of parking charging. It is optimal to incorporate parking price into an integrated parking management scheme. The benefits of effective parking charging are growing according to current trends. Appropriate regulations and tactics can be used to address valid concerns about parking price (Richard and John, 2007).

2.6 Effects of parking on urban traffic

On-street parking affects road capacity primarily in two ways. First, it reduces the width of the carriageway by bordering the traffic channel. Vehicles are compelled to migrate into this narrower channel, resulting in a slower total stream pace. Second, repeated parking and un parking movements generate complex situations, resulting in traffic congestion on major metropolitan roadways. These two implications of on-street parking lead to urban road capacity reduction (Spilopoulou, 2012).

Off-street parking refers to parking your vehicle anyplace other than upon the street. These are usually parking structures, like garages and lots. It may take place both indoors and outside. Private homes, garages, and driveways are also included. Sadly, paid street parking is commonplace. It is going to cost you a few bucks, and you must complete your assignment within a certain time range. That can be very uncomfortable and irritating when you have nowhere to go and need to pay the meter; thus, parking off-street spares you money and is environmentally friendly since ramps are avoided. A decrease in the number of vehicles driving about an area in search of a parking spot can improve local air quality while saving time on the road; a plan may also have social, community safety, housing, or planning policy benefits (Chaniotakis, 2015).

Parking causes congestion, accidents, pollution, and obstructs firefighting efforts, among other things (Shoup, 2006).

2.7 Parking Site Selection

Choosing a parking lot is crucial for drivers heading to restaurants, malls, or business centers. The primary goal of parking lot selection is to identify the most appropriate parking lots that match the necessary conditions as indicated by numerous criteria (Rong, JinZhou, 2017). Previously, site selection was done using traditional methods that relied almost entirely on considerations such as land price and accessibility to market locations, resulting in wasteful utilization of existing parking capability. Traditional data processing methods can be time-consuming and may not always produce anticipated outcomes (Shahabi et al., 2011). Finding an appropriate location for parking lots would enhance efficiency and save overall building costs. To address this issue, new technologies must be developed that can examine multiple parameters in parking site selection at the same time and offer unambiguous results.

Several research have employed aggregation approaches to pick parking locations, including boolean logic, heuristic, and weighted linear combination (Kazazi Darani and al., 2018; J. Niaraki & Malczewski, 2015b; Aliniai et al., 2015; Farzanmanesh et al., 2010). A geographic information system (GIS) provides valuable analytical tools for geographical research and planning. Overlay approaches frequently use Analytic Hierarchy Process (AHP), Boolean logic, weighted linear combination (WLC), ordered weighted averaging (OWA), and fuzzy logic. Boolean algorithms equalize every factor from zero to one, yielding the final map. WLC offers more flexibility than the Boolean method. According to Ishizaka and Nemery (2013), this technique allows for compensation for specific circumstances.

2.7.1 GIS Technology

GIS-based methods are useful for arranging, handling, quantifying, visualizing, and assessing transportation data. GIS is a successful instrument for geographical support of decisions because it can capture, store, query, analyze, display, and generate geographic data. GIS is commonly regarded as an exciting emerging tool for choice evaluation and information management. This groundbreaking technique categorizes databases and provides information in geographically relevant formats. GIS provides users with site-specific data and presents data in an understandable style.

GIS can also work alongside additional choice-support approaches, such as multiple-criteria decision making. Combining these approaches with GIS technology enhances the effectiveness and efficacy of geographic evaluation for parking lot choice (Rong, JinZhou, 2017). In recent years, GIS has become increasingly popular as a tool for traffic planners and engineers to tackle complicated transportation difficulties. It has a substantial impact on planning and decision-making. These tools can display spatial data, query certain traits or features, and create fresh information sets from current sources. A. Nazarboland and B. Izadi (2014) provide an example of using GIS for overseeing parking facilities.

2.7.1.1 Measured Benefit of using GIS in Managing Parking Facilities

Predicting future parking demands is difficult due to factors such as expanding individual vehicle ownership, population growth, growth in commercial space, and increasing retail locations. Present parking capacity, the reason for travel, parking time, and proximity to walking trails are all important factors in projecting prospective parking (J. Wang & G. Sung, 2010). However, the usage of GIS technologies yields the following benefit: Using GIS technologies ensures precise and effective outcomes for this complex procedure, taking into account all elements.

- Using a GIS allows for organized and exact data storage for individual parking spaces. Simple searches reveal several parking options in a city. GIS is a great tool for organizing and visualizing parking lot features based on location.
- Another advantage of GIS is the ability to readily update map layers. Study found that digital systems make it easier to update information when adding new spaces or changing existing ones (R. Farzanmanesh et al., 2010).
- GIS can visualize and analyze parking (organized and unstructured, on-site or off-site) in real-time, reducing campus congestion and increasing customer satisfaction (J. O. Olusina and Desalu T, 2014).

2.7.1.2 Geographic Data Models

In the GIS environment, two data models are employed to depict and visualize the real world: vector and raster. The vector data model represents two-dimensional objects in geographical coordinates using points, lines, and polygons. Point entities restrict the geographical scope of a phenomenon, whereas line entities identify the geographical scope of phenomena using sets of XY coordinates. Polygons are uniform representations of two-dimensional spaces such as plots, structures, and land use (Burrough et al., 2015).

The raster data model is represented by a grid of identically sized cells (pixels). This model, often known as grid models, is classified into two categories: thematic data and picture data. Thematic data values typically represent measurable quantities or classifications of specific objects, whereas image data values, such as satellite and scanned images, depict the quantity of emitted or reflected energy in a color range of 0 to 255. For the actual world to be accurately represented and seen in a GIS system, both models are necessary (Sánchez-Lozano et al., 2013).

2.7.1.3 Geographic Analysis Techniques

Geographic analysis is an important method for obtaining and analyzing information from data. It entails employing mathematical models to look for solutions via various methods. A wide range of tools are available in GIS applications, from simple overlay and buffer analysis to complex regression and surface analysis. The geographic problem has to be well described and stated in steps and substeps in order to be correctly analyzed data (Kahraman and Ünsal, 2014).

Geographic analyst tools enable users to perform numerous geographic operations on GIS data, extracting new information and generating interesting maps. They can provide answers to specific questions such as determining the most profitable market location, pollution levels, and population density (Giridhar et al. 2012). Geographic analysis makes use of points, lines, and polygons to better comprehend geographical phenomena. Plant species distribution is depicted by points, road and field boundaries are shown by lines, and health zones, province and district borders, and natural regions like vegetation and lands are represented by polygons. However, the situation may change depending on the study's magnitude. Overall, spatial analysis is an effective approach for producing detailed and useful maps (McCoy and Johnston, 2001).

Kernel density

Density quantifies the distribution or concentration of point and line values across a surface within a search region. Two methods exist for determining density: kernel density estimation and simple density estimation. To calculate simple density, add up all of the fallen lines and points in the field, then divide the result by the size of the field. Density kernel computation is comparable, with the exception that points and lines around the center of raster cells are considered more heavily, resulting in a smoother surface. This geographic analysis technique works with point and line feature data sets, producing a smoother and more interpretable outcome for raster data types. This method is beneficial for smoothing out multivariate distributions and abnormalities in data that is scarce, allowing for classification and interpretation of such data (McCoy and Johnston, 2001).

Euclidean distance

The Euclidean distance tool is the most often utilized instrument for distance analysis. The primary objective here is to calculate the straight-line distance between each cell and the nearest source. A school, a forest stand, a road, or a well can be the source of the object of interest that has been identified. From each cell center to the center of the source cell, the Euclidean distance is calculated, which is preferable to use in software. Raster or feature class data can be used as the input source data. When dealing with raster input source data, the correct values must be present in the source cells and NoData values should be present in the other cells. If the input source data is a feature class, the source locations are internally converted to a raster before the analysis is completed. The distance between the center of the source cell and the centers of the surrounding cells is measured by the Euclidean distance. Applications for Euclidean distance are numerous and span a wide range of domains, including shoreline determination, flood zone detection, and highway distances to particular locations. In the event of an emergency helicopter trip, the nearest hospital is also located using the Euclidean distance tool. Alternatively, this instrument can be used for building an appropriate map, for data indicating how far it is from a specific object is required (ESRI ArcGIS; Kahraman and Ünsal, 2014).

The Euclidean distance techniques use the straight-line distance to describe the link between each cell and a source or collection of sources. Three Euclidean techniques are available.

- Euclidean Distance measures the distance between the nearest origin and every raster cell. Use the following instance: how close is it from the closest town?
- Euclidean Direction describes the direction each cell takes to reach the nearest source. Example of usage: Which direction where is the next town located?
- Euclidean Allocation assigns cells to a source based on their closest proximity. Use the following example: Which city is the closest?

Spatial inquiries are crucial in transportation operations, which rely heavily upon road network distance measures. However, the significant computing cost of calculating road network connectivity may limit rapid query processing. Euclidean distance-based solutions have a lower computational cost than road network distance. A study evaluated how well it performed of a Euclidean distance-based strategy for addressing Group closest neighbor queries, which might be used in transportation applications. The study discovered that Euclidean distance can achieve high accuracy in solving the associated query type, contradicting the notion that road network distance is the only dependable option (Hua, 2018).

2.7.2 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP), a MCDM approach, was used to identify and rank criteria for parking lot site selection. AHP's appeal originates from its capacity to effectively manage multiple criteria, use both quantitative and qualitative information, and be easy to understand (T. Alkan and S.S. Durduran, 2021). Furthermore, using AHP does not require sophisticated mathematics. Furthermore, pair-wise comparison ensures unquestionable judgments and calculations. The process involves three key steps: problem decomposition, pair-wise comparison, and prioritization. The AHP technique requires creating a hierarchy structure that divides the problem into goals, criteria, and sub-criteria. The AHP approach relies heavily on creating a hierarchical framework (Ahmad Shekib, 2022).

Myers and Alpert proposed the AHP approach in 1968, and Saaty developed it in 1977. The AHP technique assesses both qualitative and quantitative factors based on expert opinions in decision-making challenges. The stages for applying the AHP approach are as follows (Saaty, 2008).

AHP technique and GIS technologies provide excellent methods for selecting acceptable parking locations (T. Alkan, and S.S. Durduran, 2021). This study employed the AHP approach to identify appropriate parking locations. The AHP approach relies on pairwise comparison matrices. The criteria are evaluated to determine their relative relevance. The AHP approach involves establishing a hierarchical structure initially. The purpose, key criteria, sub-criteria, and alternatives are defined. This study focuses on two primary criteria: land use and transportation. Land use sub-criteria include proximity to shopping malls, health facilities, social and cultural amenities, educational facilities, public services, and markets. Transportation sub-criteria include proximity to key roads, tram stops, and parking areas.

To determine the criteria weights, an AHP-based survey will be developed, and expert feedback will be collected. The human mind uses a complicated classification system known as a hierarchy to organize material from research or our personal ideas. It enables us to forecast decisions by understanding the complexities of events and dispersing their impacts. Decision-making is affected by various factors instead of being isolated. Hierarchies are essential for the network of impact (Ahmad Shekib, 2022).

To determine whether or not the decision is consistent, the CR of the n items is evaluated in this section. The pairwise comparison may be updated if the CR is below the necessary level (Lee 2007). The (CR) is computed using the formula below:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \dots\dots\dots\dots\dots\dots\dots (1)$$

Where; CI is a consistency index &

RI is a random index that is obtained for a number of variables (n) using the table below (Kumar, 2013).

2.7.3 Weighted averaging in order

One creative and useful way to assess several criteria is to use ordered weighted averaging (OWA). Researchers have used OWA for many studies, including land-use suitability, urban water management, natural resource management, and landfill site selection (Zhang et al. 2012; Malczewski, 2006; Rahman et al., 2012; Jelokhani-Niaraki & Malczewski, 2015). Aliniai & Bakhtiari Lak (2015) employed OWA as an aggregation method for parking site selection, while prior studies used many methodologies.

OWA is a combination strategy similar to WLC, but it uses two sets of weights. The OWA technique, unlike Boolean logic, allows for a variety of dangerous scenarios between the conjunction (AND) and union (OR) operators (Malczewski 1999).

2.7.4 Boolean logic

Index overlays and Boolean logic (based on zero/one digits) can combine many data layers. Because discovering best places for public parking site selection. When influenced by numerous factors, this problem can be classified as a spatial multicriteria decision analysis (SMCDA) (Malczewski, 1999).Using professional opinions, the Weightings for Overlay index approach was evaluated. According to Brown (1990), data is weighted using zero/one digits and logical operators such as AND, OR, XOR, and NOT. The model's fundamental shortcoming is that all criteria are weighted equally, despite its simplicity.

In the Boolean model, the AND operator of information layers indicates an environment that meets both conditions, while the OR operator specifies environments that meet at least one condition. Finally, the NOT operator eliminates all possible conditions. This research utilized the Boolean AND operator. (Mohammad Ali, 2019).

2.8 Accessibility

Accessibility is the ability to reach desired items, offerings, activities, and locations.
Accessibility encompasses all costs of journey, including time, cash, convenience, and safety (Muška, 2006). Accessibility is affected by the following:

- Mobility refers to the physical movement of people through numerous forms of transportation, including walking, cycling, public transport, and driving.
- Land use: the geographical distribution of activities and destinations.
- Road network design, including links between roads and pathways.
- Other factors include information, price, comfort, and security.

Accessibility is a crucial factor in determining a location's accessibility, as it affects various aspects such as travel time, cost, and user demographics. It can influence trip destinations, travel modes, household expenditures, and opportunities for study, labor, and relaxation. Accessibility can also impact financial operations, property valuations, and economic development in a location. It can be viewed from multiple angles, including location, user type, and activity. When rating accessibility, it is essential to specify a specific point of view, such as whether a building is accessible for physically disabled people, public transport, or pedestrians, or if it is suitable for specific users (Muška, 2006).

Land use considerations, such as density, activity concentration, mix, and road network links, impact area accessibility. Accessible land use lowers physical travel for products, services, and activities.

2.9 Parking Regulation

Parking regulations prioritize the use of parking facilities by limiting who can park where, when, and for how long (Todd Litman, 2018). Improved Enforcement and Control requires rational, effective, and courteous enforcement of parking restrictions and pricing. Parking evasion is a common practice among law-abiding individuals, leading to reduced effectiveness of parking restrictions. Regulations frequently include unwarranted exemptions (Manville and Jonathan Williams 2011). Parking management activities are expanding, and enforcement activities must be perceived as efficient, thoughtful, and just. To be effective, the enforcement procedure must be viewed as swift, thoughtful, and equitable. To reduce the need for citations, provide appropriate user information and options. Exemptions from parking restrictions and fines, such as "First Time Free," can help solve difficulties like illiteracy, a shortage of parking metre denomination, or late meetings. Prioritise parking enforcement in places where violations cause the most problems, such as arterials and downtown streets.

Parking enforcement officials should get proper training and clear standards for enforcing parking restrictions. Offering brochures, maps, general directions, and tourist information, they should be kind, thoughtful, and helpful. It is important to have frequent audits and explicitly limit parking privileges. Parking management agreements must be upheld with developers and facility managers, since failure may result in fines or bonds being imposed by the local government. There are three processes to creating parking laws (Todd Litman, 2018).

First, giving parking facilities priority usage. Here's a typical example:

1. Delivery and service trucks.
2. Vehicles used by the ones with disabilities.
3. Transportation and sharing a ride cars.
4. Customers, tourists, and visitors.
5. Employees & Residents.
6. Long-term vehicle storage.

Second, choose appropriate regulations that encourage higher-priority activities. The chart below summarizes typical parking rules and preferred activities.

Third, decide how the regulations will be expressed and enforced. Use signs, curb paint, diagrams, and pamphlets to clearly indicate parking facilities for different kinds of users and penalties for offenders.

2.10 Evaluation of parking demand and Analysis of future parking requirement

2.10.1 Evaluation of parking demand

At the tactical level of planning, it is critical to evaluate existing parking facilities in order to produce a quality of service that will enable better future planning and operation. To assess the current performance of the parking system, three methodologies have been differentiated. These include ones based on infrastructure, vision, and mass sensing (Enriquez et al. 2017). Yu (1973) investigated different parking characteristics that are significant in assessing parking service levels and measuring individual parking efficiency.

2.10.2 Analysis of future parking requirement

Parking regulations specify how many parking spaces developers must include when creating new complexes. Parking regulations, which are a national standard for planning and construction rules, are changing. A type of land use limitation known as parking standards requires the builder of any new building to provide a particular amount of parking spots. Parking regulations can be minimum or maximum; nonetheless, parking minimums are frequently found in zoning codes throughout the United States, with only a few exceptions. This is because the primary goal of US parking laws is to ensure that each construction project provides sufficient parking to meet the projected need for building entry (Abdulkareem, 2021).

2.11 Parking surveys

Parking surveys have long been employed in transportation planning to address issues such as parking supply/demand, use, and turnover. As demand for travel models get more advanced, parking surveys are now employed to give extra data for the modeling process. Parking generation surveys, for example, can help to enhance travel model calibration by determining and combining the demand and supply of car journeys from and to parking facilities in specified traffic analysis zones (TAZs). Parking pricing studies may additionally offer a more nuanced knowledge of the price flexibility of parking prices, which have a significant impact on mode choice and, thus, travel patterns (Tierney et al., 1994).

Parking surveys used to enhance the travel modeling procedure are reminiscent of workplace or institution surveys in that trip-makers are typically polled at the conclusion of their excursion. The goal of gathering this data is to understand the quantity, kind, and geographical distribution of journeys to a certain institution inside the travel model. Work and institution surveys are more widespread, and in many circumstances, they may be more useful than parking surveys for capturing travel behavior data. Parking surveys may be skewed if they primarily collect information regarding automobiles (Tierney et al., 1994).

2.12 Land-use characteristics

Land use implies how people make use of land. It depicts financial and social events (e.g., related to agriculture, residential, manufacturing, mining, and leisure uses) that occur in a specific location. Public and private properties frequently serve different objectives. Parking problems in cities arise from a conflict among supply and demand for parking. Land use generates demand for parking, whereas availability of parking facilities determines supply. Such an imbalance frequently causes congestion difficulties. Parking is also affected by land use, as the technique and frequency of land use influence traffic volumes, modal split, and demand for parking in the area. Urban transportation must be sustainable. This necessitates, among other things, the careful planning of appropriate transport facilities (Muška, 2006).

Parking facilities are inseparable components of transportation infrastructure, therefore their location and provision can be a significant factor in increasing land use accessibility for specific travel modes in accordance with urban transport sustainability (Muška, 2006). Urban utilization is commonly characterized as land use at the ground level. This is often what appears on maps. It is important to keep in mind that land usage can change both vertically and horizontally. For example, an apartment block could be built on top of a shopping complex. This vertical variation is especially visible within the Central Economic District.

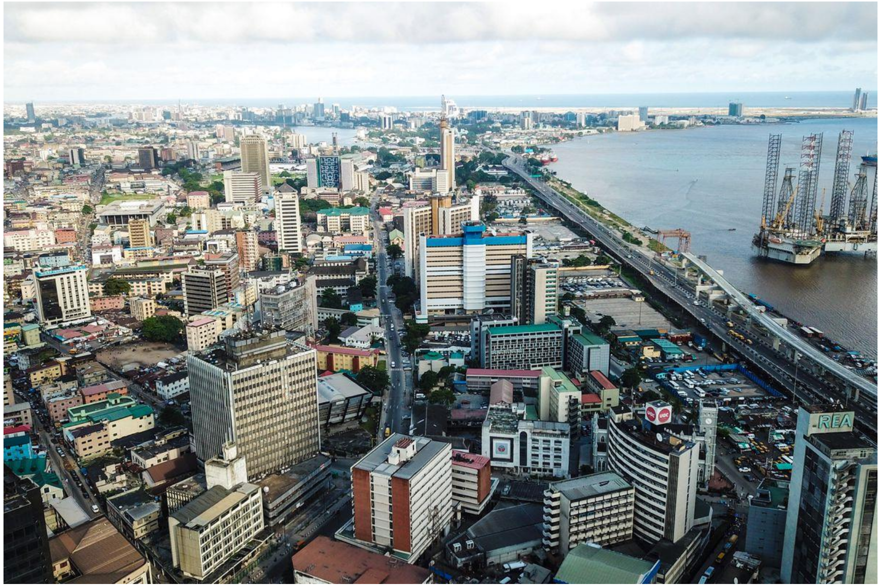

Figure 2. 3 Example of Urban land use

The primary urban land uses are residential, manufacturing, economic and management, infrastructure (including transportation), as well as open space (including scheduled open space such as parks and derelict space).

2.13 Car parking research

Car parking research has looked into a variety of creative solutions to the difficulties of urban traffic congestion and limited space. Banerjee (2011) presented a real-time automobile parking system that employs image processing to count parked cars and identify open spaces. Sumathi (2013) designed an energy-efficient automated car parking system that allocates each car a unique slot, saving parking time and maximizing space consumption. Yugesh (2019) described a connected car-based parking location service system that employs a mobile sensing unit to detect available parking spaces and a mobile application to guide drivers. Jakle (2004) gave a historical perspective on the impact of cars at rest, focusing on the transformation of urban infrastructure caused by the expansion of parking lots and garages. These studies collectively underscore the importance of efficient and sustainable car parking solutions in urban environments.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 The Study Area

For this research, the Yeka sub-city of Addis Ababa was selected as the case study area. The quality, amount, distribution, and readability of the data in the research region were determined to be appropriate for the experimental investigation. Yeka is one of the sub-city in Addis Ababa, Ethiopia, that is located in the city's northeast. It shares boundaries with Gullele, Arada, Kirkos, Lemikura, Bole, and Oromia, with coordinates 9"01'30.73" N and 38"48'27.55" E. The sub-city covers 85.98 km² and contains four road grading types: asphalt, cobblestone, gravel, and earthen, with varying topography. According to the Central Statistical Agency of Ethiopia, the population of Yeka is projected to be 488,537 in 2022. The vast majority of the population is female. The area is mostly covered in Eucalyptus, auriferous, and acacia trees, with limited access to public open spaces. Addis Ababa's vehicular population leads to traffic jams, pollution, illegal parking, and spillover in off-street spaces. Popular destinations include residential areas, shopping malls, commercial centers, transportation hubs, Hospitals, public libraries, and office-business zones. High demand for parking is observed throughout the day, with open-air, ground-floor, paid, automatic tower parking lots and conveniently located near major urban roads. Figure following depicts the geographic location of the case study region using solid black arrow.

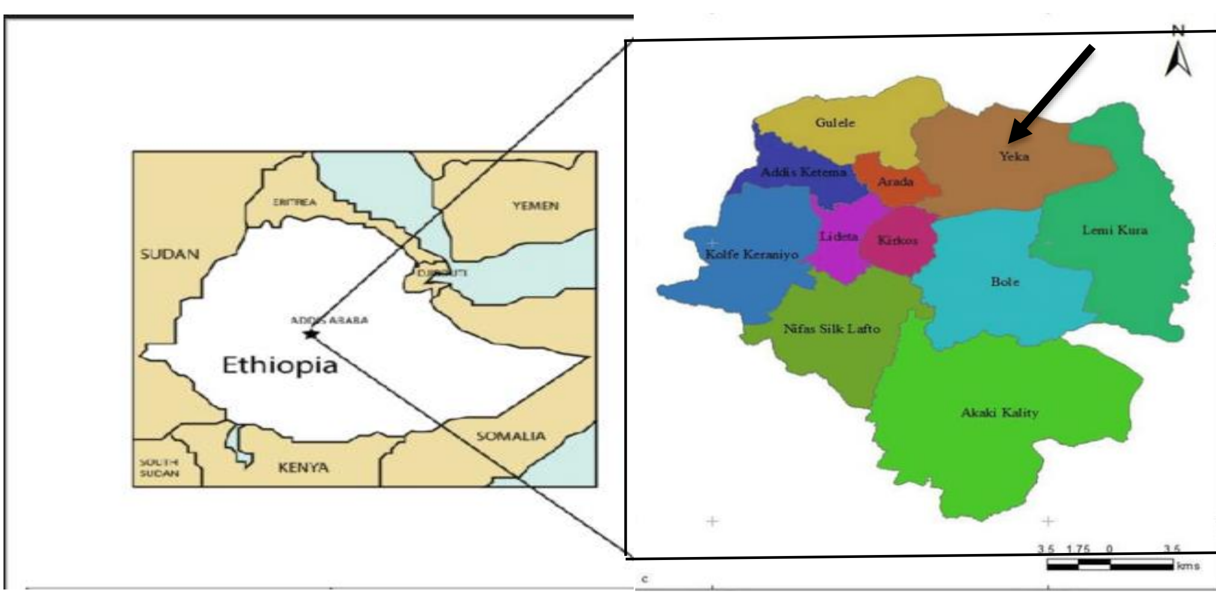

Figure 3. 1 Map showing the study area

Yeka sub city is selected due to currently under development, high concentration of residential area, bordering many sub cities and regional state, high concentrations of traffic attractions like bus stations and taxi stands, different markets and malls at different locations and major roads. The Yeka sub-city has experienced substantial urbanization and transportation infrastructure development in recent years. Notable in the area are various government office investments, railway system investments, road investments, highway investments, and access to the rural highway. These factors make the sub-city a desirable location, but they also result in a lack of some sub-city services, parking lots being one of them.

3.2 Study design

The methods used in this research will encompass office and field level investigation of the subject area, as well as the following data gathering and analysis methodologies and techniques. The technique of the study will also necessitate the use of various materials and procedures in order to achieve the state objectives. The study focuses on evaluation of land use characteristic and parking conditions. In so doing the principal focus based on the existing parking condition in the city and generating model for demand. However the paper limited itself to suggesting recommendations that can make this land use characteristic and parking conditions functionally and effective.

The methodology involves three stages: data collection, analysis, and weighting. After gathering data, it is sent into ArcGIS software, which creates basic maps and then does geographic analysis, rasterization, and scoring. The consistency ratio is computed and the weight of the data is determined by the application of the AHP approach. The data is then overlaid to determine suitable parking places. Criteria affecting physical, legal, and geographical suitability are determined, and the MCDM method is implemented by dividing criteria into sub-criteria and weighting data at each level. All criteria were classified into major categories based on literature reviews, and data availability. Transportation, parking, and travel absorption center criteria were taken into account. To show the hierarchy of criteria and sub-criteria used to choose parking places, the criteria were divided into sub-criteria based on their respective features.

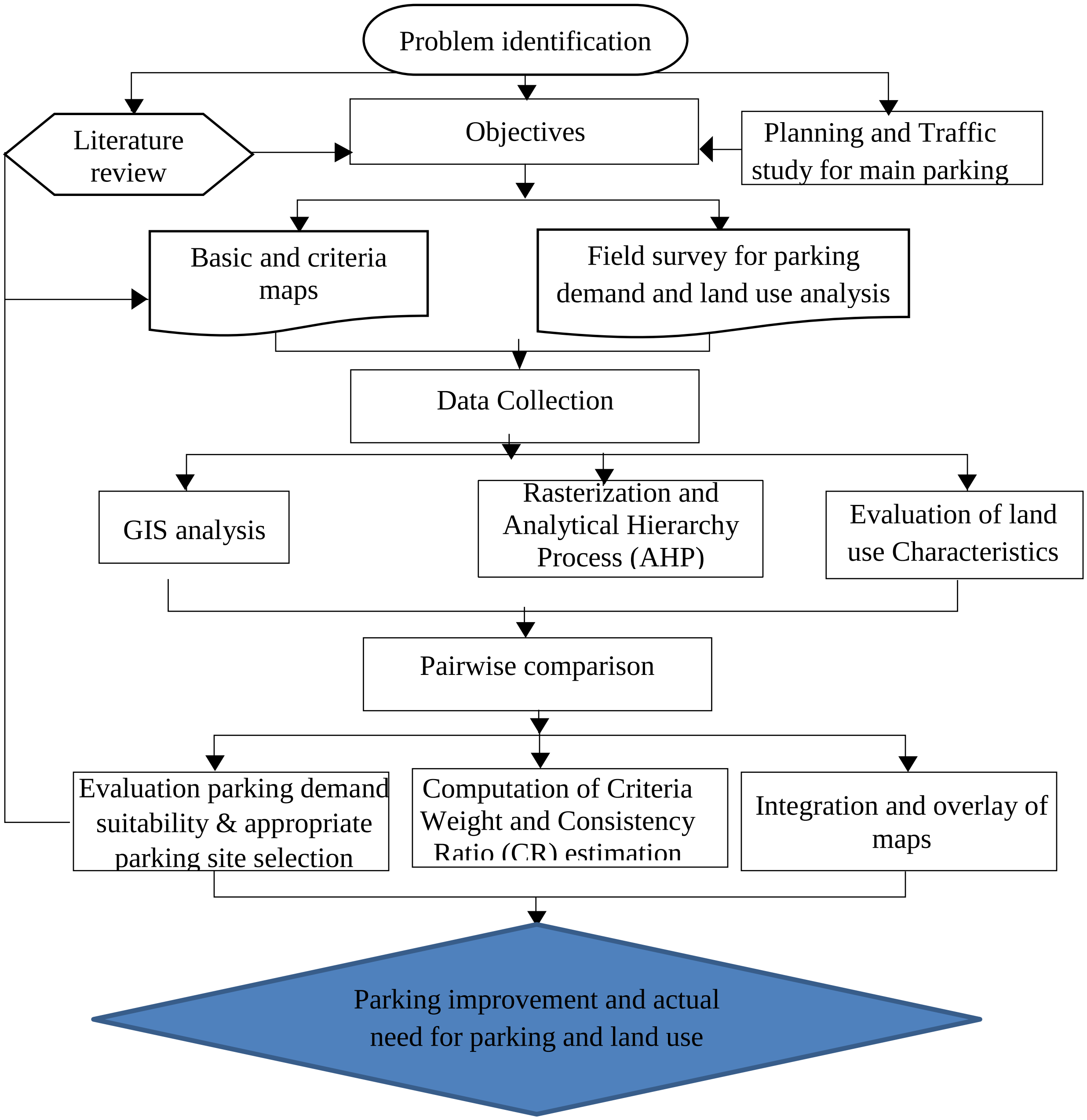

Figure 3. 2 Conceptual frame work

Source: Organized by the author (March 2024)

3.3 Data analysis Tools and Software's

Google earth (Google LLC, 2018), Arch GIS and ArcMap (ESRI, 2021), and the Microsoft Excel (Microsoft Corp., 2016) software's was used in this study. The last two used for data processing and analysis purposes.

3.4 Data Collection Technique and Source

3.4.1 Data Collection

To determine the city's land use characteristics, the study acquired data from the Addis Ababa municipal design and development commission. The data needed to conduct the study is gathered through the field surveys, such as identifying specific areas of land use provisions and collecting data of present parking spaces for each land use criteria of the study area, which coordinates are recorded using a computer from Google Earth, and required data, such as guidelines, standards, and other policy tools documents, are collected from Addis Ababa highway and transport Bureau, transportation policy offices, and Addis Ababa city plan and development.

3.4.2 Data Sources

To achieve the study's objectives, primary and secondary data from the study area are collected exclusively for this study.

1. **Primary data collections:** During the use of the Multi-criterion Decision-Making approach, primary data were gathered from the various road users using methods such as real site surveys and data of weight at the level of criterion and sub-criteria. Data on transportation criteria, parking criteria, and travel absorption centers will be acquired while taking literature studies, guidelines, and data availability into consideration.

It was necessary to collect both geographic and non-geographic data for the investigation in great detail. The Addis Ababa Municipality provided the study's geographic data, while the Addis Ababa Transportation Master Plan's transport evaluation survey provided the study's non-geographic data.

Here is a summary of the data that were gathered for this research topic;

- Building information, such as its location, (may include residential and workplace, education facilities, health facilities, cultural facilities, sport facilities, public institution, green space and shopping malls location data/coordinates)
- Road network datasets (highways, bus stations, main roads and train stations coordinates),
- Datasets of land use.
- The capacity of the current parking facilities (current parking location information, slope, land cost, vehicle ownership and traffic volume in the study area)

- Candidate parking facilities.
- The Addis Ababa Transportation Master Plan study on parking practices includes information on ratios of automobiles used, cars left on the road during the day, and the number of visits by vehicle based on kind of function.
- Demographic information such as employment, population density, and automobile ownership at the neighborhood level.

Field survey

A field survey entails going into the field (in the designated sector) and conducting a detailed survey of data pertaining to parking capacity in current parking facilities. Data was collected through a field survey for two types of parking: on-street and off-street parking.

- On-street parking data gathering: all parking-related information was noted, including the dimensions of roadways sections, the number of long-term equipment (driveways, bus stops, etc.), the details given by regulatory signs (including strict parking prohibitions at all times), and the accessibility of parking by type (general population, private, cautious, paid, free, funded, etc.).
- Collected data on off-street parking areas, types, and regulations, resulting in less fluctuation compared to on-street parking.

2. **Secondary data collections:** Secondary data were acquired through the AACRA, Yeka Sub-city, ERA, Addis Abeba Planning and Development Commission, & Addis Abeba City Government's Road and Transportation Bureau. The data gathering procedures that will be utilized to assess problem validity and views of the City are outlined. Analyzing data on each issue yields a set of suggestions that can satisfy a wide range of stakeholders, such as the City, downtown business owners, consumers, office workers, residents, faculty, and staff, for the time being or until conditions change sufficiently to warrant a new approach.

This thesis relied on data from three sources: a literature study, an online and printed parking survey, and field observations. During the site exploration phase, just a few intercept surveys were completed. These involve asking persons who are getting out or reaching given parked car a limited number of questions in order to determine why they were parking there, whether or not the parking bay/location satisfied their needs, and their general perception of street parking. Time limitations limit the total amount of intercept studies done.

3.5 Method of data analysis

Following the gathering of research data, analysis and interpretation process take place. The analysis of the information gathered from various sources sorted into representative categories in order to produce logical results. When dealing with qualitative analysis based on evidence gathered from various sources, an effort made to carefully analyze and interpret the information so that it may be used in in addition to quantitative data.

3.5.1 Descriptive analysis

To gain complete understanding of existing parking condition in relation to land use, the study used descriptive analysis to describe the conditions of facilities used for parking space. Facility observations in field related to land use are crucial to know the general land use characteristics and parking demand and supply of the specific area. General facility information regarding specific land use are identified whether they are isolated parking space from the facility/ not. The facilities in this land use category provide which specific services are selected for specific analysis of the parking demand. Parking survey information done in all the chosen facilities that are examined in relation to land use considering peak parking demand with their respective time & day.

3.5.2 Assessing parking demand and allocating parking spaces requirements

The goal of this study is to create a technique for correlating land use features in terms of parking demand and assigning parking sites in the Yeka sub-city. Two techniques are used: the first integrates the AHP with the GIS, and the second applies map algebra to demand-suitability analysis in a GIS setting.

3.5.3 Parking Demand by Integrating GIS with AHP

Urbanization is a result of technological progress, increasing the number of cars and creating a parking dilemma in industrialized areas. Efficient parking reduces traffic congestion by increasing roadway width and vehicle movement. However, inappropriate parking spot placement is crucial for traffic management, since poor decisions can result in inefficient traffic management, economic loss, and environmental deterioration. Modern urban transportation and traffic management systems depend on precise parking space allocation (Hosseinlou 2012a). In areas where there are commercial, residential, or business operations, parking spots are usually necessary. Providing adequate parking spaces to meet parking demand in such regions may enhance marginal parking (Levy, 2015).

Parking demand is affected by a variety of factors, rendering standard solutions ineffective. A complete plan combining GIS and AHP is necessary. The MCDM technique uses GIS to create a map of parking demand based on transportation, parking, and trip absorption centers. Literature reviews and data provision are used to select the best parking places. A GIS database with effective criteria is established, and a pixel-based site selection model is developed using AHP, an MCDM. MCDM is an approach for determining the optimal option based on a number of factors such as location, cost, safety, and availability. It has a long history, with Benjamin Franklin's moral algebra research acting as its foundation. MCDM offers a formal framework for handling multiple factors and generating preferences between options (Taherdoost and Madanchian, 2023). It finds applications in urban planning (Amari et al., 2023), business, sustainable environmental practices, and healthcare solutions. Various MCDM methodologies include the AHP, TOPSIS, and VIKOR. AHP organizes criteria hierarchically, TOPSIS ranks alternatives based on distance from the ideal answer, and VIKOR handles conflicting criteria. MCDM enables more informed decisions by considering multiple aspects simultaneously (Taherdoost and Madanchian, 2023).

GIS generates location queries from a variety of data sources. It converts a variety of information formats into raster layers via geographic interpolation and vector-to-raster translation. High parking needs are identified, and weight values for the criterion and sub-criteria are determined. Geographic coordinates are commonly used to determine the precise position of an object. Additionally, GIS may translate census or electronic data into a map-like format, resulting in multiple layers of conceptual information. The GIS-AHP method facilitates the analysis of tough situations and provides decision-makers with enough information. This thesis focuses on the GIS-AHP technique for developing parking lots in the Yeka sub-city.

According to Ibraheem (2016) and Kumar (2008), the AHP approach consists of three steps: creating the pairwise comparison matrix, calculating the criteria weights, and assessing the consistency ratio. A necessary parking map was created after the weights of the criteria were determined and the findings were combined with a GIS methodology to determine parking demand. The weighted combination of the category maps was multiplied by their weight in the raster calculation tool to create a parking area suitability map. The classified layer data of the transportation sub criteria was first incorporated into the raster calculator tool and multiplied by their weightage, parking sub criteria, and TAC sub criteria, respectively, due to the fact that the data was separated into three categories (transportation criteria, parking criteria, and TAC). A parking area suitability map was then produced by combining the three main criteria into the raster calculation tool and multiplying by their weights.

The distance from transportation facilities is crucial for passengers, employees, and users to reach their destination from a parking spot with minimum walking distance. To determine the maximum acceptable distance, Euclidean distance is used to create a distance layer and classify it into different ranges. This technique is preferred in spatial analysis of raster or feature class data. To plan and analyze parking suitability, a pre-planned study area is needed, and distance ranges are evaluated based on proximity to the road and required walking distance after parking. The raster-analyzed data is re-classified into ranges for planning the parking area using Euclidean distance. Network analysts' suitable parking location are used to determine the optimum locations of parking areas. A demand map is created using raster-based map algebra and the AHP method is used to evaluate the weight of criteria and sub-criteria. The closest distance layers are determined using Euclidean distance technique, depending on the study area and raster analysis.

Each number on the objective scale, which ranges from 1 to 9, indicates the relative importance of one criterion over another in the pairwise comparison (Saaty, 1980; Taherdoost, 2017). In the study region, trip absorption centers, parking criteria, and transport criteria were the main determinants of parking spots. Using the AHP method, the weights of the criteria and sub-criteria were determined. The study should construct a pairwise comparison matrix in order to ascertain the weight of the criterion. Each of the columns that were divided into the matrix was added up to create the normalized pairwise comparison matrix. The average of the components was then determined for each row in the normalized matrix. The results demonstrate the significance of the criteria. Thus, the criteria weight and criteria weight percentage for the research regions were established, as well as the normalized Pairwise comparison matrix for each criterion. The essential requirements must also be integrated in order to get the intended outcome. The ultimate outcome obtained by superimposing the primary criterion on top of the pairwise comparison matrix of criteria with their weights.
The followings are the basic steps in an AHP (analytic hierarchy process) model development:

1. Identify the problem, set the objective and identify the criteria that will affect the measure.
2. Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

3. Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.
4. For each comparison matrix, there performs the calculation of eigen values, consistency index and ratio, and weights for each criteria, sub criteria and alternatives to identify priority rating. To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared.

Procedures for GIS-AHP integration, to obtain the overlay map of each criteria and for the parking suitability map in the study area

1. First add overall reclassified raster data of all the criteria listed in one Arc GIS (Transportation, parking and TAC criteria) with their respective sub-criteria
2. Then, check the source coordinates by going through the properties and make it common that means if its different spatial resolutions and coordinate system for each criteria, since they should have the same spatial resolution and coordinate system
3. Next, they should resample to the same coordinate system and spatial and then in output cell size the desired raster data should be reclassified finally
4. Then, to do Weighted Overlay for each criteria the study add each criteria with their respective sub-criteria and with their percentage criteria weight value for each to obtain overlaid map of each criteria.

The weights of the criteria and sub-criteria were calculated using the AHP approach. As stated above, using the AHP method, the study do a pairwise comparison of linked items to determine their weight of criteria (Transportation, parking and TAC criteria) and their sub-criteria. To obtain the Transportation, Parking and TAC overlay map, multiply the categorized layer data by their appropriate weights in the raster calculator tool to produce the overlay map of each criteria.

Weighted overlay:

$$w = \sum_{i=0}^{n} (x_i * w_i)$$

Where; w is the weighted overlay, n is the number of decision criteria, x_i is the particular normalized criterion, and w_i is the respective weight of criterion. The cell/pixel values of the raster layers are multiplied by their weight/percentage influence obtained by AHP analysis, and the results are added together to create the flood susceptibility output raster map.

To achieve the desired result, the key criteria must also be combined. The pairwise comparison matrix of criteria with their weights and the final result achieved by overlaying the primary criterion. The procedures outlined above were used to establish the weights of criteria, and the findings were combined with a GIS approach to determine parking demand, resulting in the creation of a required parking map. The classed maps were then combined into the raster calculation tool and multiplied by their weightage to create a parking area suitability map. Because the data was divided into three categories (transportation criteria, parking criteria, and TAC), the classified layer data of transportation sub criteria were first integrated into the raster calculator tool and multiplied by their weightage, parking sub criteria, and TAC sub criteria, respectively. The three major criteria were then merged into the raster calculation tool and multiplied by their weightage, resulting in the creation of a parking area suitability map.

Then the study assesses the CR of the n items to determine whether the decision is consistent. According to Lee (2007), if the CR falls below the required threshold, the pairwise comparison could be modified. The following formula determines the (CR):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \dots \dots \dots \dots \dots \dots \dots (1)$$

Where; CI is a consistency index and

RI is a random index that can be obtained from the Table for a number of variables (n) (Golden and Wang, 1990). (Kumar, 2013).

$$\mathrm{CI} = \frac{\lambda \mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \dots \dots \dots \dots \dots .. (2)$$

Where; n is the number of factors or criteria used in the study.

λ_{max} is the largest eigenvalue of the comparison pair matrix.

$$\lambda \mathrm{max} = \frac{(WSV/CW)_{total}}{n}$$

The idea behind the CR is that if $CR \leq 0.10$, the ratio indicates that the paired comparisons are consistent; if $CR > 0.10$, the ratio values are inconsistent and necessitate reevaluating the pairwise comparison matrix; if $CR = 0.10$, the ratio confirms consistency in pairwise comparisons (Al Garni, 2017). Consequently, the consistency index and random index are used to calculate the consistency ratio for each of the study areas' criteria.

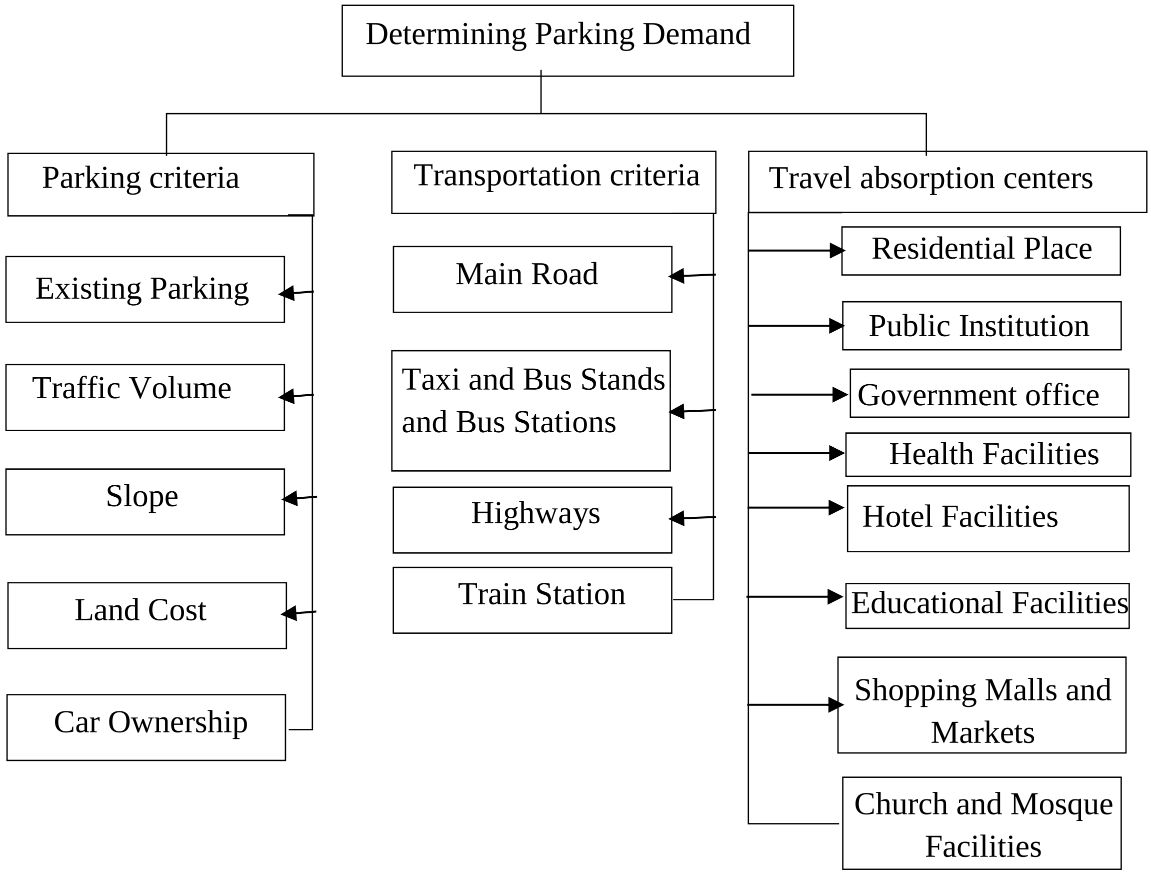

Figure 3. 3 Criteria and sub-criteria hierarchy.

The methodology involves three stages: data collection, analysis, and weighting. Data is collected and processed using ArcGIS software for basic maps, followed by geographic analysis, rasterization, and scoring. The consistency ratio is computed and the weight of the data is determined using the AHP approach. The data is then used to determine suitable demand parking places. Physical, legal, and geographical suitability criteria are determined, and the MCDM method is applied by dividing criteria into sub-criteria and weighting data at each level. Criteria for transportation, parking, and travel absorption centers are considered.

In order to evaluate the walking distance to parking spots based on transportation parameters and Travel Absorption Centers (TAC), the study used ArcGIS spatial analytic approaches. The data was graded and scored using a reclassifying tool, with the smallest distance having the highest scores. The study aimed to improve parking accessibility and user experience by calculating the weights of criteria and sub-criteria using the AHP approach. The resulting map was then merged into a raster calculation tool.

Analysis Procedure

ESRI ArcGIS software was used in all stages of the analysis procedure. This tool was chosen for the study because it can analyze both raster and vector data formats. It can handle geographic data, generate geodatabases, conduct geographic visualization, editing, modification, and reporting, in addition to standard GIS analytical tools. Figure below depicts ArcGIS spatial analyst tools. All adopted data were categorized and entered into the geographic geodatabase after taking into account the heads of the criterion. The Adindan_UTM_Zone_37N coordinate system was used to georeference and register all of the approved data in order to ensure that the research area was preserved and that no distortion happened throughout the analysis, which might provide unreliable findings. With the exception of the area's slope, which was produced in raster format from the digital elevation model (DEM), all data were supplied in vector format.

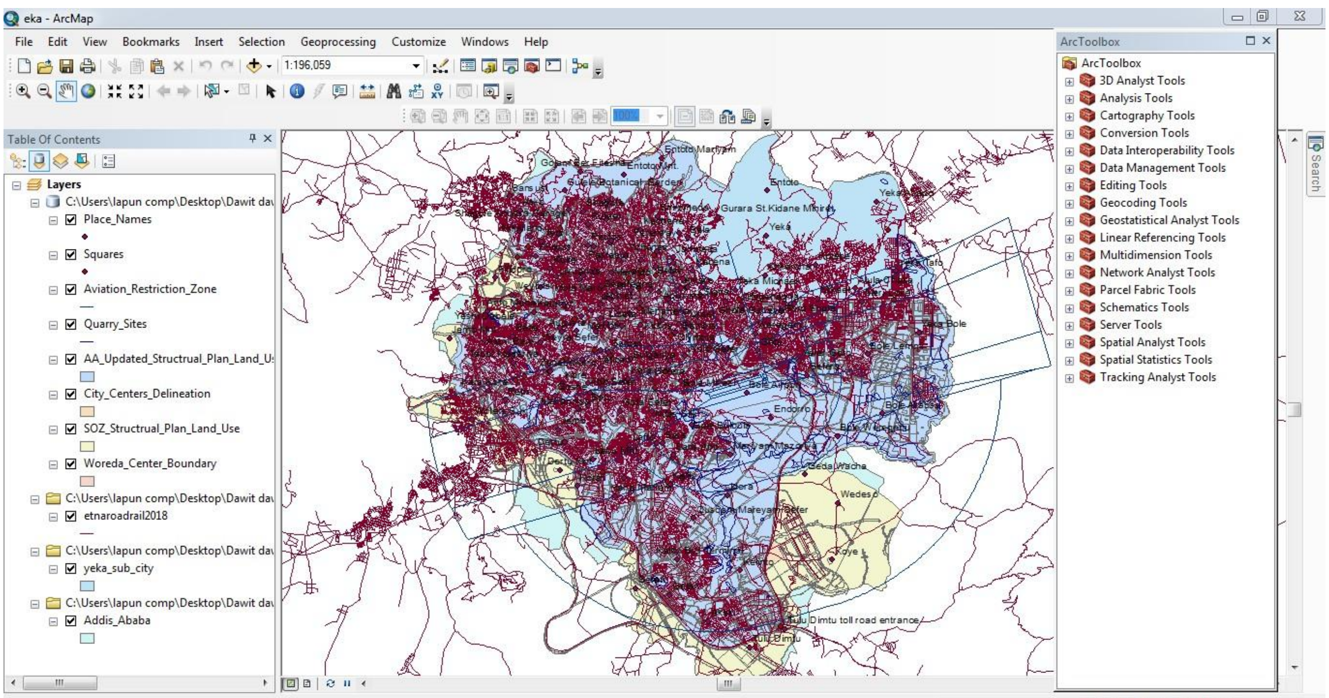

Figure 3. 4 ArcMap screen and spatial analysis Arc Toolboxes.

The ArcGIS software's ArcMap was used to represent and analyze data. "ArcMap is the primary application used in ArcGIS and is used to perform a wide range of common GIS tasks as well as specialized, user-specific tasks" (Web April 7, 2019). This program or interface is what we used to pull data out of the geodatabase and get it ready for geographic analysis (see Figure 3.4 above).

3.5.4 Demand-Supply analysis

In this method uses map algebra in a GIS setting to analyze parking demand-supply suitability map in parking location allocation. It uses a pixel-based approach to determine fixed demands, transforming geographical data into point geometry. The study transforms parking demand suitability into raster datasets, identifying high-demand pixels. The network analyst's location allocation analysis tool is tested to assign parking spaces based on parking demand. Geographic data, encompassing information about a specific location, is increasingly used in urban planning, disaster management, & transportation planning. Advancements in technology & communication methods enable the integration of various data sets, including fixed and variable transport infrastructure. Geographic information technologies manage these datasets, enabling the development of decision support tools and policies. They aid in selecting transportation infrastructure and facility locations, such as public transportation lines & logistic distribution hubs.

The method balances parking demand and supply using spatial analysis and map algebra functions. Urban congestion, irregular buildings, and population growth hinder transportation planning. A unique strategy uses GIS tools for optimal parking spaces selection. A modeling strategy is used for car park demand research, followed by network analyst techniques for site selection. Network analysts use location-allocation techniques to fulfill parking demand.

Analysis of Parking Demand Suitability

To give a realistic picture of the actual world in a virtual context, parking demand has to be treated as an abstraction. This entails figuring out how people behave when parking in different locations and at different times. It is not possible to determine specific parking demand because of the intricacy of the activities involved and how they interact with land use functions. The geographic distribution of fixed demand weights is determined by gathering data sets for various land uses based on parking demand suitability maps in order to simulate parking demand in a GIS system. Point vector geometry can be used to digitally describe a structure defining parking demand and supply in a shared Projected Coordinate System. Local governments lack a database to calculate parking demand for constructing units based on real supply.

Parking demand-supply analysis requires advanced data analysis and generalization skills. A raster-based technique uses the smallest pixels to calculate parking demand and availability. Parking demand, functional parking, on-street parking, and subterranean facilities for distinct buildings are all represented by point geometry. Parking demand can be estimated using raster-based computations and map algebra approaches. Red pixels show an increase in parking supply, whereas blue pixels show a rise in parking demand. This approach helps to identify areas with high and low parking demand (IBB, 2014). The problem of determining parking demand in GIS is addressed using geographic analytics steps within the modeling scope, this makes sense in the following way (IBB, 2016);

Identifying the issue: Simple sub-steps have been used to examine the situation, such as a geographic study of parking demand appropriateness for use in allocating parking locations.

Determining the data: A geographic database including raster or vector geometry and associated data was created by assigning and combining the available datasets.

Choosing a method: The issue was resolved by employing suitable geographic analytics methods created in an application-process-driven software environment, including the ArcGIS Toolbox tools.

Processing the data: The selected analytic tools were used for the process steps, and the outcomes were created in accordance with that.

Analyzing the result: Based on their statistical analysis and significance level, the findings were published.

CHAPTER FOUR

4. DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 Parking Demand-Supply analysis using ArcGIS

Geographic data is location-related information that is managed via the use of technology and communications capabilities. It can be used to manage both fixed and variable transportation infrastructure, allowing for the creation of decision-support tools and policies. Geographic information technology support urban planning, disaster management, and transportation planning by allowing for site selection analysis and data design. They help to determine public transportation routes, logistic distribution points, and parking lot placements. This technique balances parking supply and demand using geographical analysis and map algebra functions. To address traffic planning difficulties caused by increased vehicle numbers, irregular building, and population expansion, an innovative approach utilizing GIS techniques is devised. Car park demand analysis is carried out utilizing modeling and network analyzer techniques to ensure appropriate parking sites.

In this study, walking distances to parking facilities are calculated using ArcGIS spatial analytic tools based on travel absorption centers (TAC), parking criteria, and transit criteria. All the information was supplied in vector format, except for the slope, which came from a raster digital elevation model (DEM). All layers were converted to raster format for the final layer. The rasterized maps were scored using a reclassifying program, with five values assigned to each. The distance used to score parking criteria, transportation criteria and TAC was determined by accessibility to parking spots, with the shortest distance receiving the highest scores. The greatest slope values had the lowest scoring values. The study's goal is to improve user experience by lowering walking distance and boosting automobile parking near parking lots.

4.1.1 Parking Criteria

A variety of studies have looked into parking requirements, with a focus on smart city initiatives, tactical preparation, local setting up, and transit-oriented developments. The Multiple Criteria Based Parking Space Reservation (MCPR) algorithm allocates parking spots in a fair and user-friendly manner (Rehena, 2018). This criterion considers the following factors: current parking, land expenses, quantity of traffic, slope, and car ownership.

4.1.1.1 Existing Parking

The issue of existing parking options is complex and influenced by various factors. A more effective system is needed to recommend specific parking spots to eliminate unnecessary lineups (Imbar, 2014), especially in high-density locations. The current situation consists of commercial or government-operated parking lots with high traffic density and population density. Due to the increased number of vehicles, these lots cannot meet the city's parking needs due to their location and capacity. A more effective parking system is needed to address these issues.

The study calculated the walking distance from the existing parking data using the Euclidean distance approach. It produced a distance layer that extended up to 1 kilo meters, which it then divided into five intervals: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters. The maximum distance was set at high, while the minimum distance was set at low.

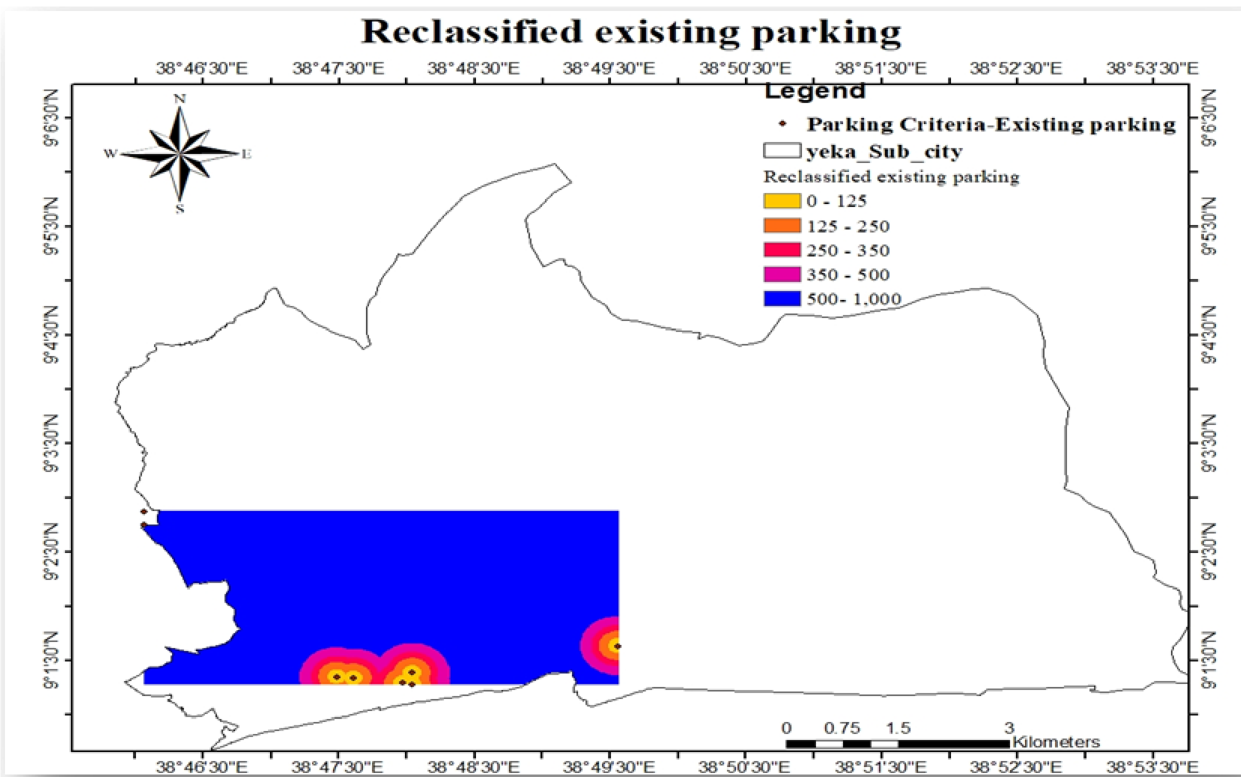

Figure 4. 1 Reclassified existing parking distance.

4.1.1.2 Slope

The DEM was utilized to compute slope data in the Yeka sub-city. The slope data influenced accessibility and the provision of new parking spaces. Therefore, the research must first locate sites with suitably level land before building a parking lot. The research area's maximum slope values, which ranged from 0 to 38.65 degrees, were obtained from the DEM. The slope values were then categorized as 0°–5°, 5°–10°, 10°–15°, 15°–25°, and >25° based on assessments of urban construction and land suitability (Zhang, 2013). As seen in figure 4.2, discrete integer values between 1 and 5 were assigned to the detected slope values. The values with the highest slope received the lowest scores (selection chance), which means, in order to build a parking lot, the study identified areas with reasonably flat ground.

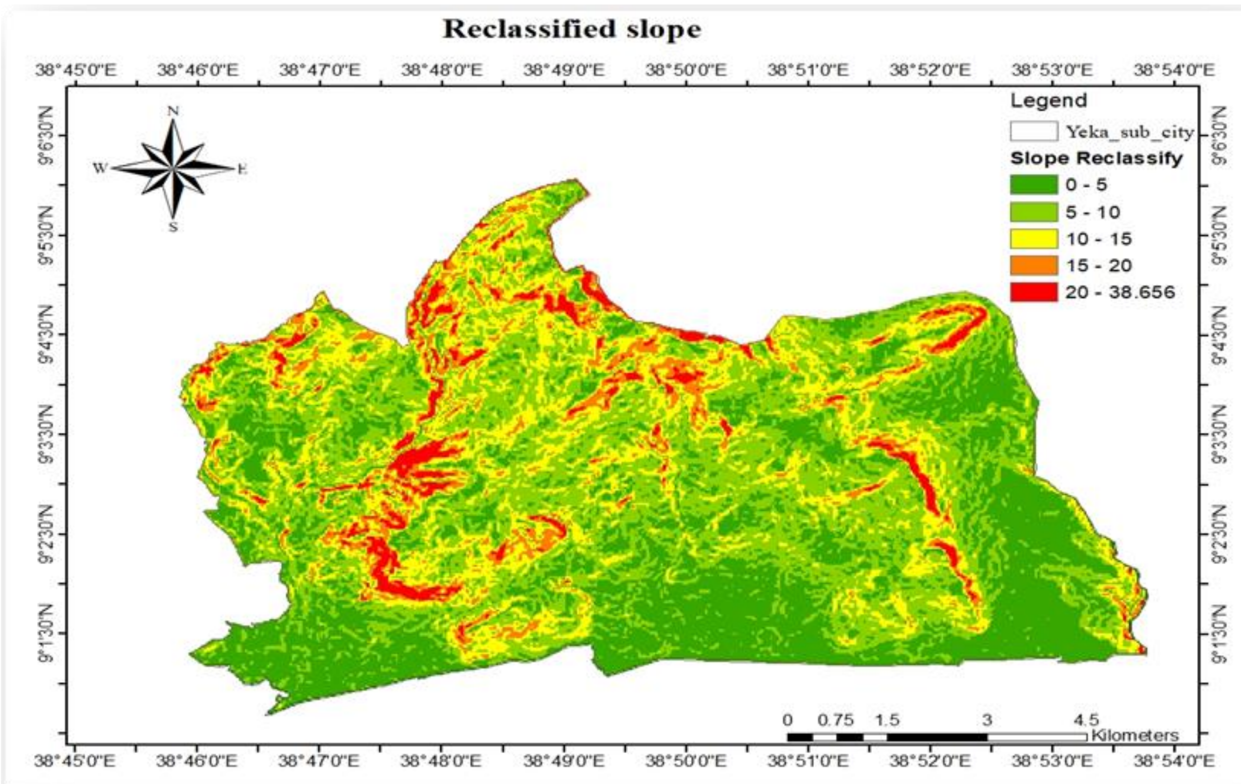

Figure 4. 2 Reclassified slope of the area.

4.1.1.3 Traffic Volume

Traffic volume data is gathered from Remote Traffic Microwave Sensors (RTMS) installed on major roadways or manually, which consumes time. RTMS uses microwave frequencies to identify cars and provides information on the speed, duration, average speed, and total volume for each lane. Vehicles per hour is a common unit of measurement for traffic volume (Coifman, 2006). Parking demand increases in areas with high vehicle mobility and traffic volume. However, using the line density technique to cover the entire study area is difficult, so the study uses general assumptions and considerations. Larger projects areas, with higher numbers of additional trips, may have a broader impact on the surrounding transportation network across a longer distance from the development site. As a result, a larger study area will be explored based on land use. A larger study area may also be appropriate for developments located within an already crowded transportation network. This type of study needs consultants to check the study area with the Road Traffic Management Agency (TMA) before beginning the study which is big fruit work. So general assumptions and considerations used:

1. Data used for traffic volume in the study area specified by TMA & Plan & Development Commission which assumed to consider & based on trip generation & attraction and background trips
2. Traffic growth projection by other planned developments based on land use and adjacent transportation plans & developments are included
3. The research area is determined by the development's size and position within the transportation network. A minor development's study area will be the immediate vicinity, whereas major developments will consider impacted roadways outside the immediate surroundings.
4. The existing transportation/traffic conditions in the development's neighborhood must be well recognized because they serve as the foundation for the impact analysis based on Addis Ababa’s TMA & Plan & Development Commission data (since traffic survey is a standard procedure for gathering basic information to aid analysis and comprehension of existing situations).
5. Surveys must cover pedestrian/cyclist movements in areas where there are or will be a high volume of pedestrians/cyclists. For Traffic Impact Assessments (TIA) situations that require calibration and validation of previous year models, surveys must include traffic queue lengths at intersections, travel durations along significant routes, and/or additional data specified by TMA is used.
6. Data specified by TMA & Plan & Development Commission used in the study, the traffic surveys data are often conducted at 15-minute intervals and classified by vehicle type to identify the pattern of traffic changes during peak hours.

4.1.1.4 Car Ownership

Car ownership in Ethiopia is increasing due to factors like earnings, economic expansion, diverse wants, and insufficient public transportation networks. Despite this, the country has a low motorization rate, with 1.2 million registered vehicles (Joseph, 2024). Motorbikes are the top type of vehicle registered by the Federal Transport Authority. As of the last fiscal year ending July 7, 2020, 1,200,110 vehicles were registered nationwide. This low motorisation rate is a common issue in African countries (Yonas, 2020). The study says that Addis Abeba has registered approximately 630,440 automobiles, while Oromia (204,026), Amhara (106,434), and SNNPR have registered 118,424 cars. The above four regions are ranked from first to fourth, respectively. According to the Ministry, the remaining areas rank 5th to 11th, with Tigray reporting 60,800 automobiles, Dire Dawa Administrative (24,510), Somali (19,579), Harari (10,728), Benishangul Gumuz (10,655), Afar (8,277), and Gambella registering 6,237 vehicles (Yonas, 2020). However, the study did not specify how many automobiles hadn't been recorded during the period but were scheduled to be registered.

The distribution or concentration of point and line values on a surface within a search region is measured by density. There are two methods for estimating density: simple density and kernel density estimation. In ArcGIS software, there are three approaches: simple (point) density, line density, and kernel density estimation. To compute simple density, sum all of the fallen lines and points in the field, then divide the result by the size of the field (McCoy and Johnston, 2001).

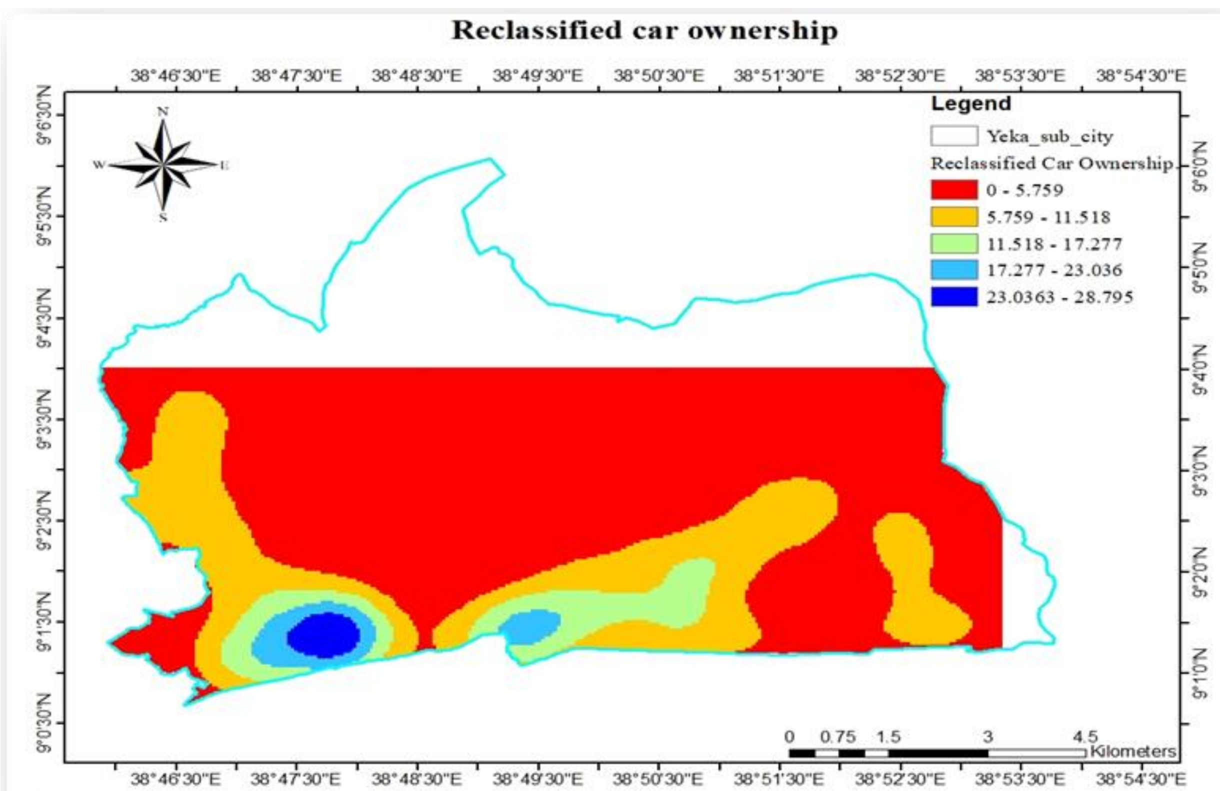

Figure 4. 3 Reclassified car ownership.

Kernel computation of density is similar, with the exception that points and lines around the center of raster cells more heavily, resulting in a smoother surface. This geographic analysis technique is beneficial for smoothing out multivariate distributions and abnormalities in scarce data (McCoy and Johnston, 2001).

The figure 4.3 above depicts the information that was transformed on car ownership using kernel density. The car ownership layer was built utilizing the kernel density method of estimation and car ownership ratio values. A score ranging from 1 to 5 was the result of the categorized raster format. The largest number (as seen in figure 4.3) denotes the highest percentage of car ownership.

4.1.1.5 Land Cost

Land price data demonstrates that regions with good transportation, proximity to enterprises, public amenities, retail malls, and new development have higher land values. Despite the high costs, parking demand is significant in these places, indicating that encouraging parking investment is critical owing to transportation problems and public interest.

Table 4. 1 Minimum urban land - lease prices in Addis Ababa (EIA, 2012).

No.	Zone	Grade of Lease Land	Minimum price (Birr /M^2)	Multipliers to determine prices by width of roads (meter)			
				No road	Less than 10	10 up to 20	Above 20
1	Central Business Zone	1	1686	1.2	1.5	1.7	1.9
		2	1535	1.2	1.5	1.7	1.9
		3	1323	1.2	1.5	1.7	1.9
		4	1085	1.2	1.5	1.7	1.9
		5	894	1.2	1.5	1.7	1.9
2	Transitional Business Zone	1	1035	1.2	1.3	1.4	1.5
		2	935	1.2	1.3	1.4	1.5
		3	809	1.2	1.3	1.4	1.5
		4	685	1.2	1.3	1.4	1.5
		5	555	1.2	1.3	1.4	1.5
3	Expansion Zone	1	355	1	1.2	1.3	1.4
		2	299	1	1.2	1.3	1.4
		3	217	1	1.2	1.3	1.4
		4	191	1	1.2	1.3	1.4

Source: Addis Ababa City Government land Administration and Building Permit in 2012.

According to the Federal Democratic Republic of Ethiopia constitution, land belongs to both the nation and the Ethiopian people. Urban and rural land can be purchased as a leasehold or rented out. Certain areas offer urban property for rent. Urban property can be leased at auction based on a city's master plan or criteria. An auction will establish the minimum price for urban land. Anyone with an urban land use license is awarded a leasehold title document. The minimal price of urban land is decided prior to possession through an auction or agreement (EIA, 2012). The Addis Abeba municipal authority has evaluated rent land and set beginning prices, as stated in table 4.1 above. The figure 4.4 below shows the resultant edition of land cost data by area. Land cost values were turned into raster data and graduated based on land lease prices. The generated raster format was classed and scored from 1 to 5.

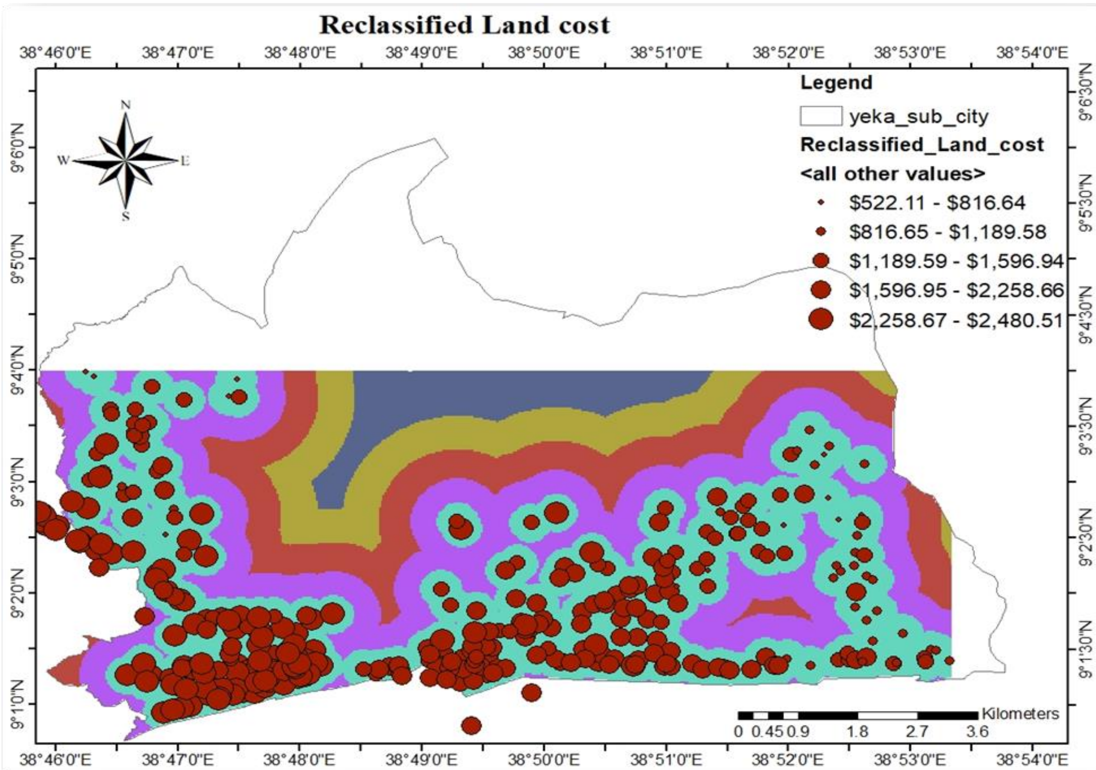

Figure 4. 4 Reclassified Land cost.

4.1.2 Transportation Criteria

Since transportation draws more travelers than other criteria, it is one of the most important elements for parking areas. The availability of parking is enhanced by choosing spots close to transit hubs, such as rail and bus stations, which draw large numbers of passengers. Another problematic factor is the distance from transportation. The minimal walking distance from a parking place to the destination for users, staff, and passengers should be considered while determining the distance.

The maximum walking distance for retail consumers and work parking varies widely, with measures ranging from 100 to 200 meters. Special activities can require distances up to 600 meters. Factors influencing walking distance include journey purpose, individual traits, and environmental conditions (Smith, 2008). Parking occupancy affects walking distances in residential areas, with a significant increase occurring when occupancy exceeds 85% (Vos, 2018). Car drivers' readiness to walk varies based on trip purpose, with shorter distances acceptable for weekly shopping and work and longer distances for non-weekly shopping (Timmermans, 2015). To reduce confounding factors, the driving sample was confined to individuals living within one kilometer of a park-and-ride facility, as they take public transportation (Walton, 2010). After a literature review, evaluation of current guides, and interviews with national regulations and standards, 1km was determined as the maximum permitted distance and this criterion takes into account the following factors: Arteries (Main Roads), Highway, Bus Station and Train Station.

4.1.2.1 Main Roads

Most trips into and out of metropolitan areas are frequently transported by arteries, with constant traffic flowing through the center of the city. Furthermore, key roadways function as transportation routes between central commercial districts, adjacent residential areas, and connecting metropolitan communities. The number of cars in the studied area increases in proportion to the geographical dispersion of arteries.

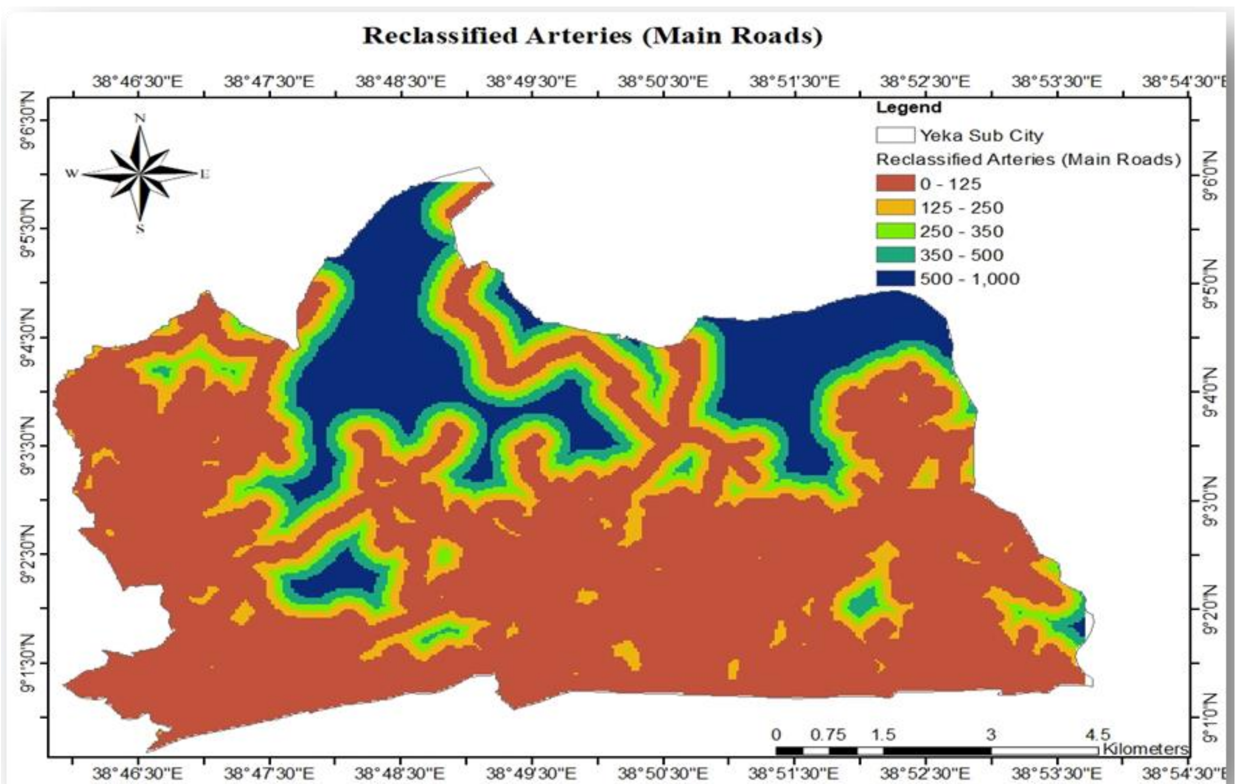

Figure 4. 5 Reclassified arteries distance.

The most important factor to consider is the walking distance between parking lots and arteries. The study calculated the walking distance using the Euclidean distance algorithm on artery data.

A distance of up to 1000 meters was constructed for the investigation. Subsequently, as seen in Figure, the study classed the distance into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters. Each range was given a discrete integer value between 1 and 5.

4.1.2.2 Highway

The main public road is a highway that connects cities, towns, and villages, playing a crucial role in a country's economic development. An efficient highway system makes travel simpler, safer, and quicker by lowering traffic, improving transportation systems, and cutting expenses. There is no highway facility in the sub city of the study area, but to determine the causal effect of highway network developments on suburban development of nearby land uses, and the study want to show the impacts of nearby highways that are close to Yeka sub city (highway infrastructure adjustments influence main roads) or use the sub city as a starting point (bus station) for a journey with a high traffic impact on the road and parking requirements.

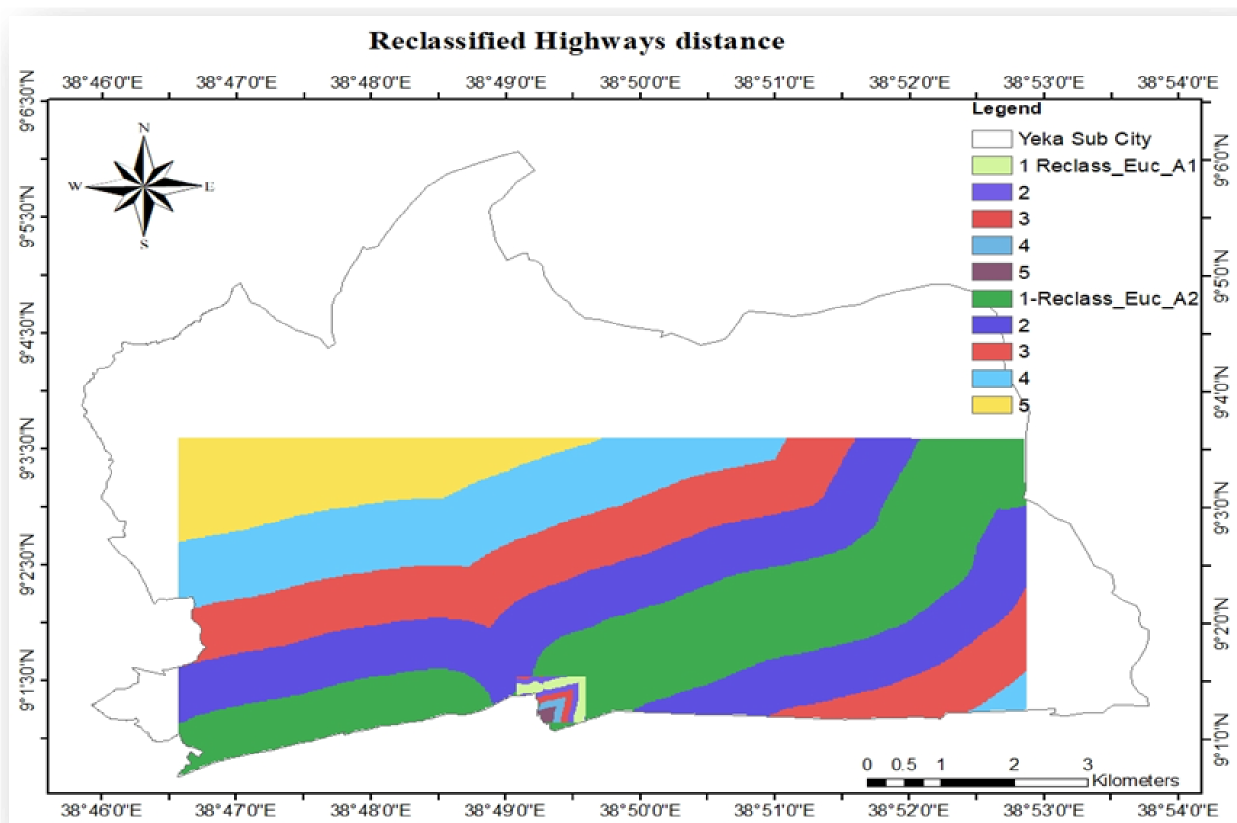

Figure 4. 6 Reclassified highways distance.

Because of the massive traffic flow near a highway, which causes masses on the road, locational pressure, prevents protests regarding potential adjustments of main roads, and may provide feedback for more equitable planning, which assists in ensuring that the infrastructure fits properly in its physical and social surroundings. So from this instance; the A2 highway of Addis Ababa-Dessie- Mekelle which mainly pass through the study area (whether it come from bus stations or from the southern part of the city) and A1 the Addis Ababa- Adama- Djibout which used the study area as initial point (Lamebert bus station) included to study the impact.

The walking distance was determined using the Euclidean distance technique using data from highways. According to Figure 4.6 above, the research established a highway distance of up to 1000 meters and divided it into 5 ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters. Each range was assigned a discrete integer value between 1 and 5.

4.1.2.3 Bus Stations

A bus station is an important transportation hub that provides a variety of purposes, including passenger waiting areas and services like sale of tickets and information about schedules (Kihl, 1989). It also contributes significantly to the social and economic growth of an area by providing amenities such as retail, parking, and rest spaces (guteris, 2016). As a result, the parking space should be close to the bus stations.

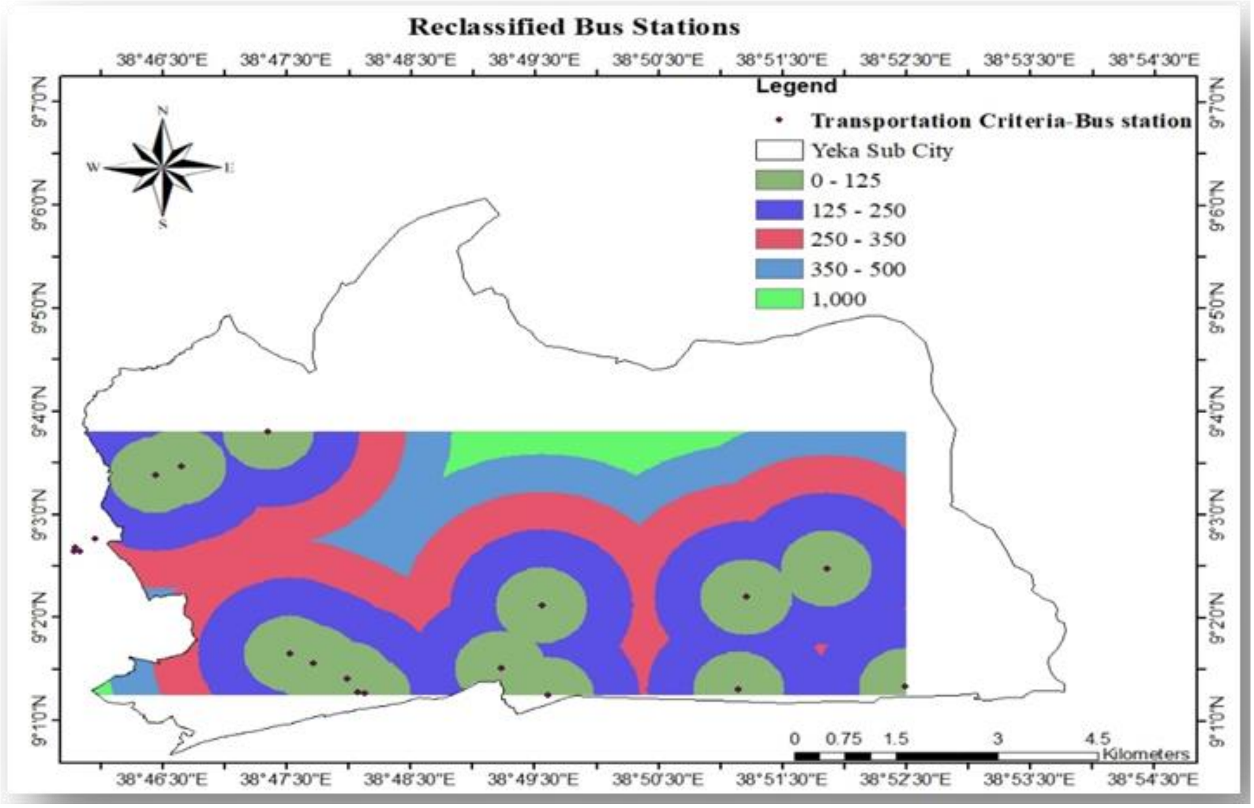

Figure 4. 7 Reclassified bus stations distance.

The study used the Euclidean distance algorithm to calculate walking distance based on data from bus terminals. As seen in Figure 4.7 above, the distance layer was separated into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters. Each range was given a discrete integer value between 1 and 5.

4.1.2.4 Train Stations

Railway stations have a single platform system for passengers to enter and exit trains, while some have two connected by footbridges. To reduce traffic congestion, they built an administration structure behind the main platform as well as a parking area near the station (https://en.wikipedia.org/wiki/Railway stations in Ethiopia, 2019).

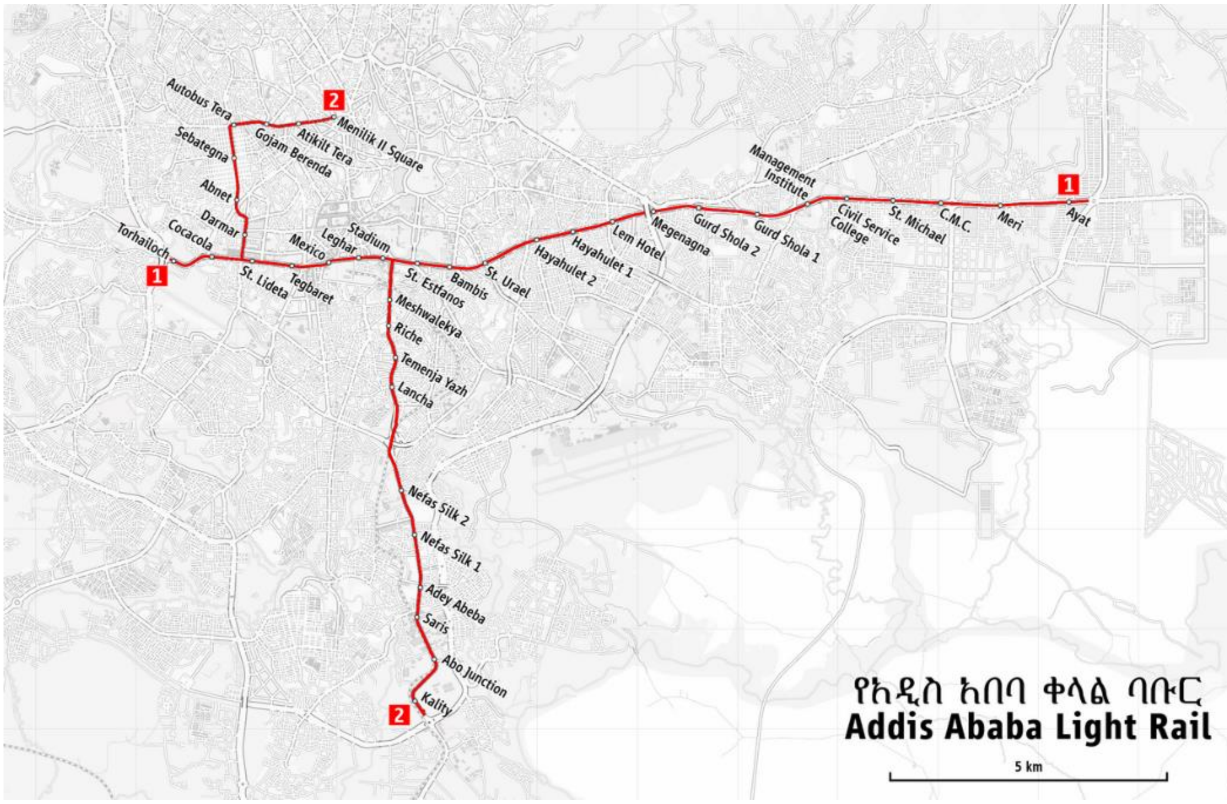

Figure 4. 8 System map of Addis Ababa Light Rail

Source: By Maximilian Dörrbecker (Chumwa)

The Addis Ababa Light Rail, the first light rail and rapid transit system in eastern and sub-Saharan Africa, debuted in September 2015 with a 17-kilometer line that connects the city center to industrial areas. The west-east route, which spans 31.6 kilometers, debuted in November 2015 and has two lines with 39 stations. The east-west train route connects Ayat Village with Torhailoch, while the north-south route passes through Menelik II Square, Merkato, Lideta, Legehar, Meskel Square, Gotera, and Kaliti. In January 2016, the rail transported an average of 113,500 people each day (https://en.wikipedia.org/wiki/Addis Ababa Light Rail, 2024).

According to our data, Yeka sub-city has 12 train stations in it or nears to it, including Hayahulet 2, Hayahulet 1, Lem Hotel Megenagna, Gurd Shola 2, Gurd Shola 1, Management Institute, Civil Service College, Saint Micheal Church, CMC, Meri, and Ayat 1. Walking lengths of zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters were created using the Euclidean distance approach. These walking lengths were then divided into ranges and given discrete integer values between 1 and 5, as shown in Figure 4.9 below.

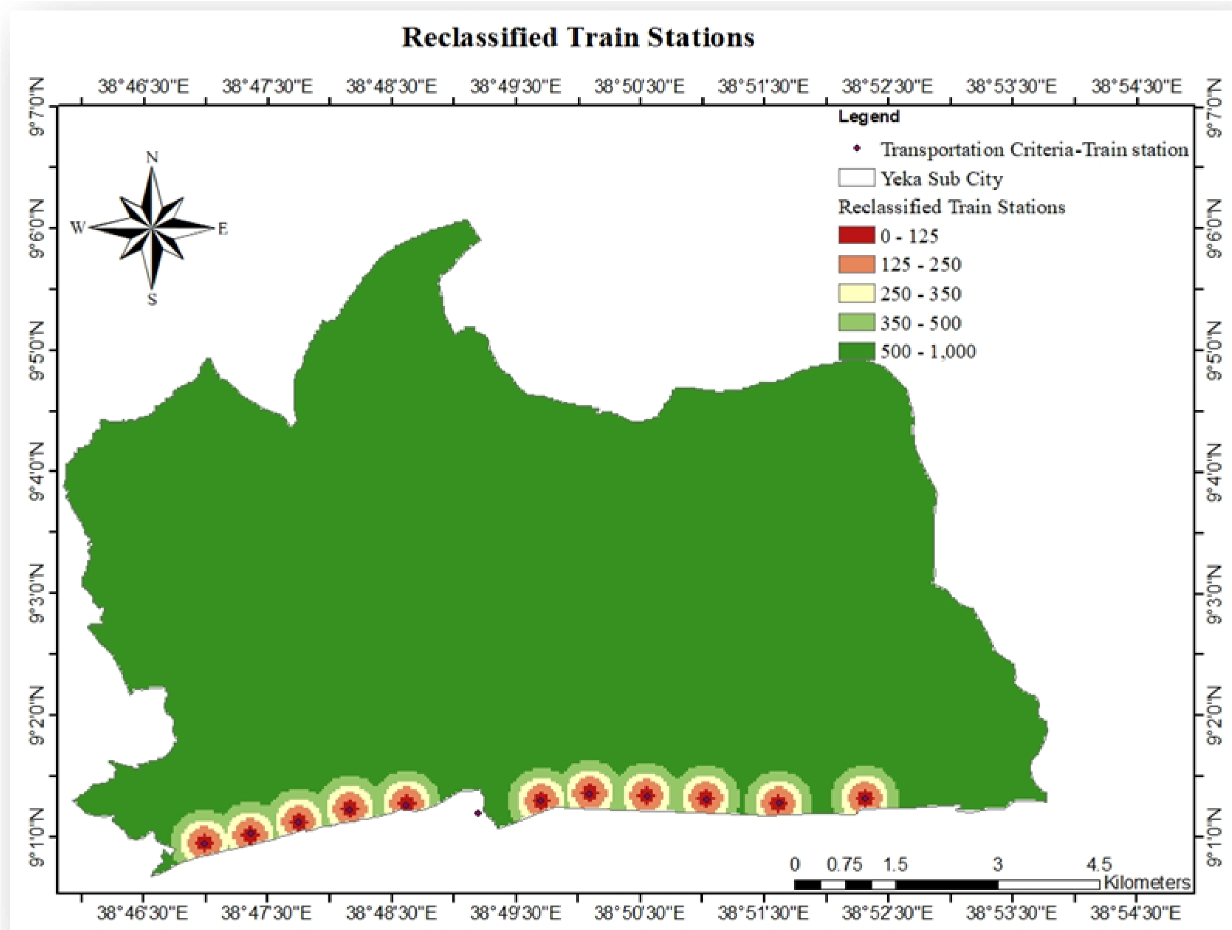

Figure 4. 9 Reclassified train stations distance.

4.1.3 Travel Absorption Centers

Because of the increased frequency of absorbing tourists, TAC is a crucial component in determining the demand for parking space. Another contentious topic is the distance from the TAC. The distance should be such that, from a parking place, travelers, staff, and clients may go to their destination with the least amount of walking distance.

There is a lack of unanimity, as evidenced by the numerous measures for what constitutes maximum walking distance, which ranges between 100 to 200 m for retail consumers and 360 and 460 m for work parking. Special activities can require walking distances of up to 600m. A variety of factors determine the appropriate walking distance for parking, including the purpose for the journey, individual traits, and conditions in the environment (Smith, 2008). Parking occupancy can affect walking distances in residential areas, with a considerable increase occurring only when occupancy surpasses 85% (Vos, 2018). Car drivers' readiness to walk varies according to trip purpose, with shorter distances acceptable for weekly shopping and work and longer distances for non-weekly shopping (Timmermans, 2015). Samples of both drivers and pedestrians are analyzed to better understand the elements that influence their choice to walk. To reduce confounding factors such as reliance on cars and trip distance, the driving sample was confined to individuals who lived within one kilometer of the park-and-ride facility. Because they take public transportation, these drivers are less reliant on their cars (Walton, 2010).

After performing a complete literature review and evaluation of current guides, as well as interviewing nations' regulations and standards, 1km was determined to be the maximum permitted distance and this criterion takes into account the following factors: residential places, public institution facilities, Government offices and other office Facilities, Health Facilities, Hotel Facilities, Educational Facilities, Shopping Malls and Market facilities and Church and Mosque Facilities.

4.1.3.1 Residential Place

The information is made up of polygons that show how many independent homes there are in the Yeka subcity. The use of private automobiles has increased as a result of urbanization and inadequate public transit. Traffic congestion is a result of residential neighborhoods' lack of parking, especially when there are brief stops on the road. Figure 4.10 below shows the processed version of residential layer data, with kernel density estimation applied to the independent buildings.

The final raster format has a score ranging from 1 to 5, where maximum numbers denote great density. The Euclidean distance method was utilized to compute walking distances from residential locations. A distance layer up to 1000 meters was generated for the study, and it was separated into five categories with discrete integer values ranging from 1 to 5: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters.

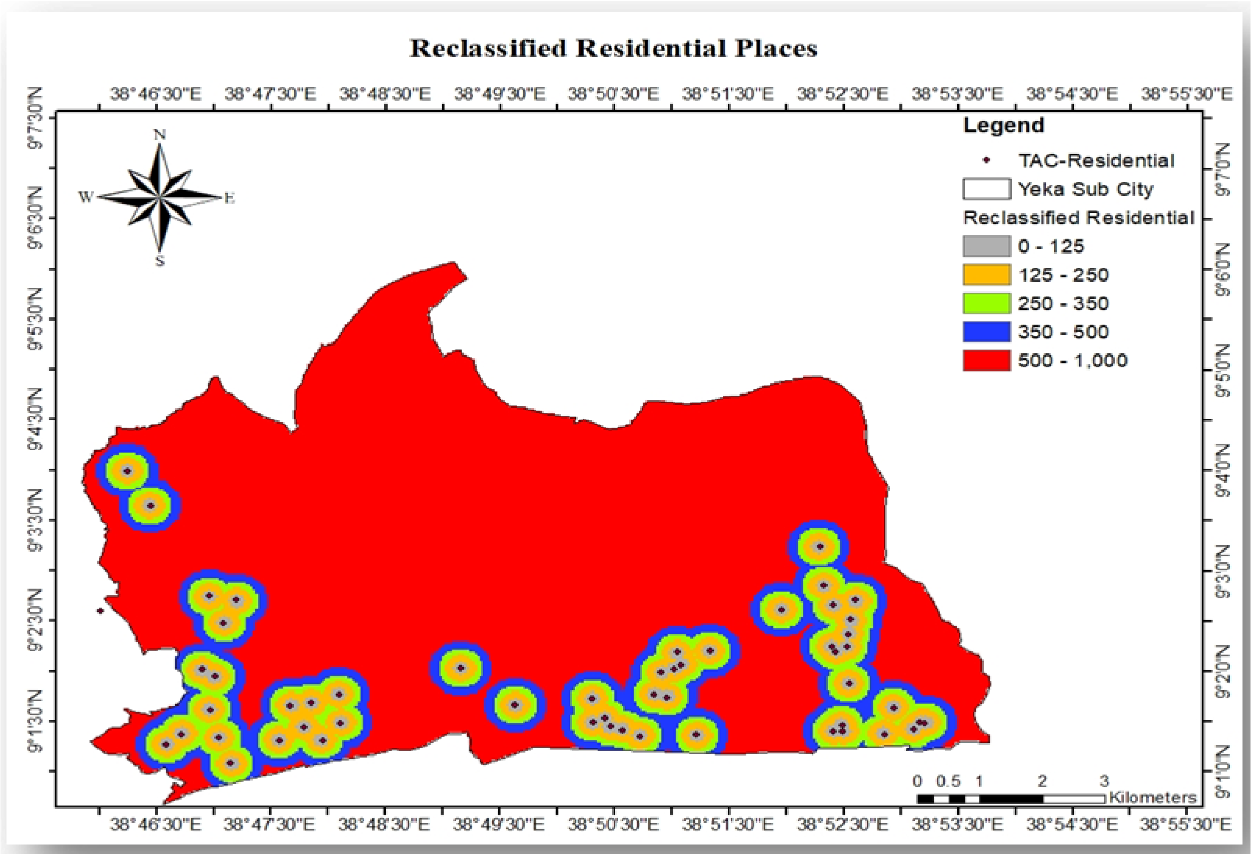

Figure 4. 10 Reclassified residential

4.1.3.2 Public Institution Facilities

Social Security offices, municipalities, district police departments, post offices, prisons, police stations, green spaces (parks, playgrounds, and public seating areas), and courthouses are among the public institutions for which data is available. These features attract a large number of individuals, particularly during the workweek. These facilities are often located near major thoroughfares and congested areas of the city; nonetheless, they are also popular tourist destinations. Theaters, movie theaters, libraries, performance and art centers, and art galleries are all included in the statistics on cultural facilities. These amenities attract a large number of people, particularly on weekends. Parking demand is driven by restricted public transportation and people's participation in various groups. Due to a scarcity of parking, employees and customers park their cars near the institutions, causing traffic congestion. Most of the facilities are found in Yeka's south, southeast, and south-west areas. These facilities are accessible throughout the day for a variety of activities.

Figure 4.11 displays the data analysis for facilities owned by public institutions. The walking distance from the public institution's facilities was calculated using the Euclidean distance technique. The study created a distance layer of up to 1000m and divided it into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters, each having a discrete integer value between 1 and 5.

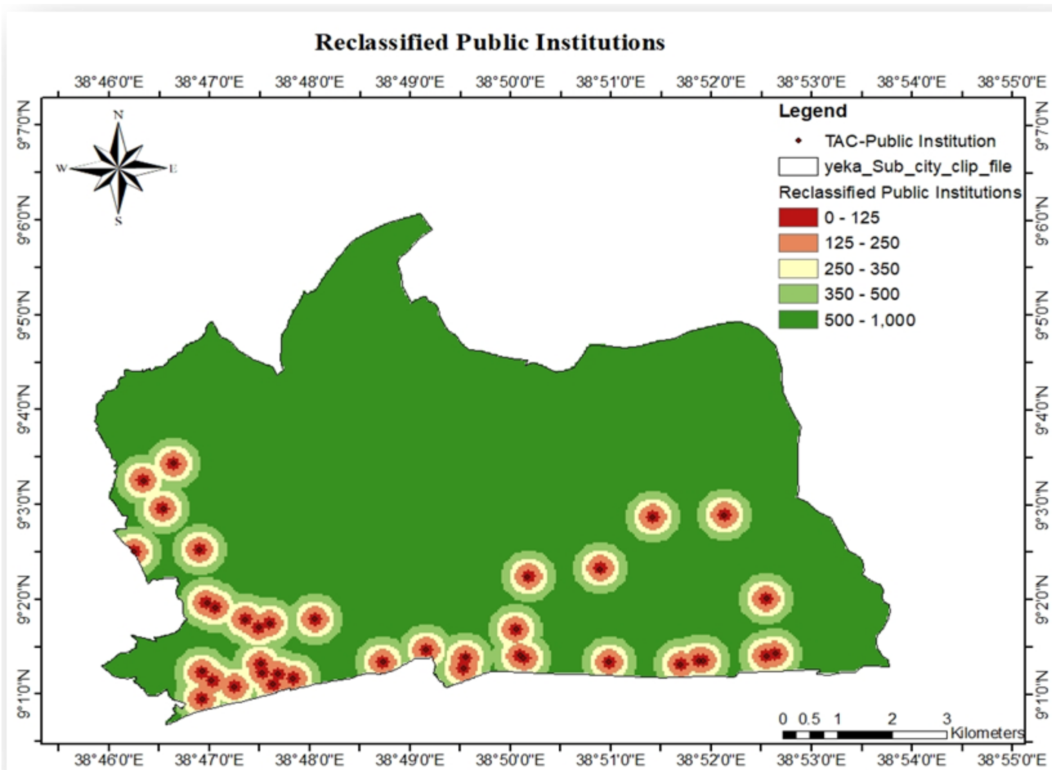

Figure 4. 11 Reclassified public institutions distance.

4.1.3.3 Government offices and other office Facilities

The Government Facilities Sector includes a wide range of facilities owned or leased by different government bodies, both domestically and internationally. These facilities might be public or sensitive, and are classified according to their primary role. Examples include agency headquarters, satellite offices, legislative chambers, as well as data and call centers. Government office buildings are intended to provide adaptable, technologically sophisticated working environments that are safe, healthy, comfortable, durable, visually beautiful, and easily accessible. They must meet the space and equipment requirements of administrative and management employees, who often inhabit certain portions of the building. Office buildings can be separated into parts for different occupants or dedicated to a single occupant, with each tenant having their own lobby area, conference rooms, individual or open-plan offices, bathrooms, cooking facilities, and staff rooms for lunch or breaks.

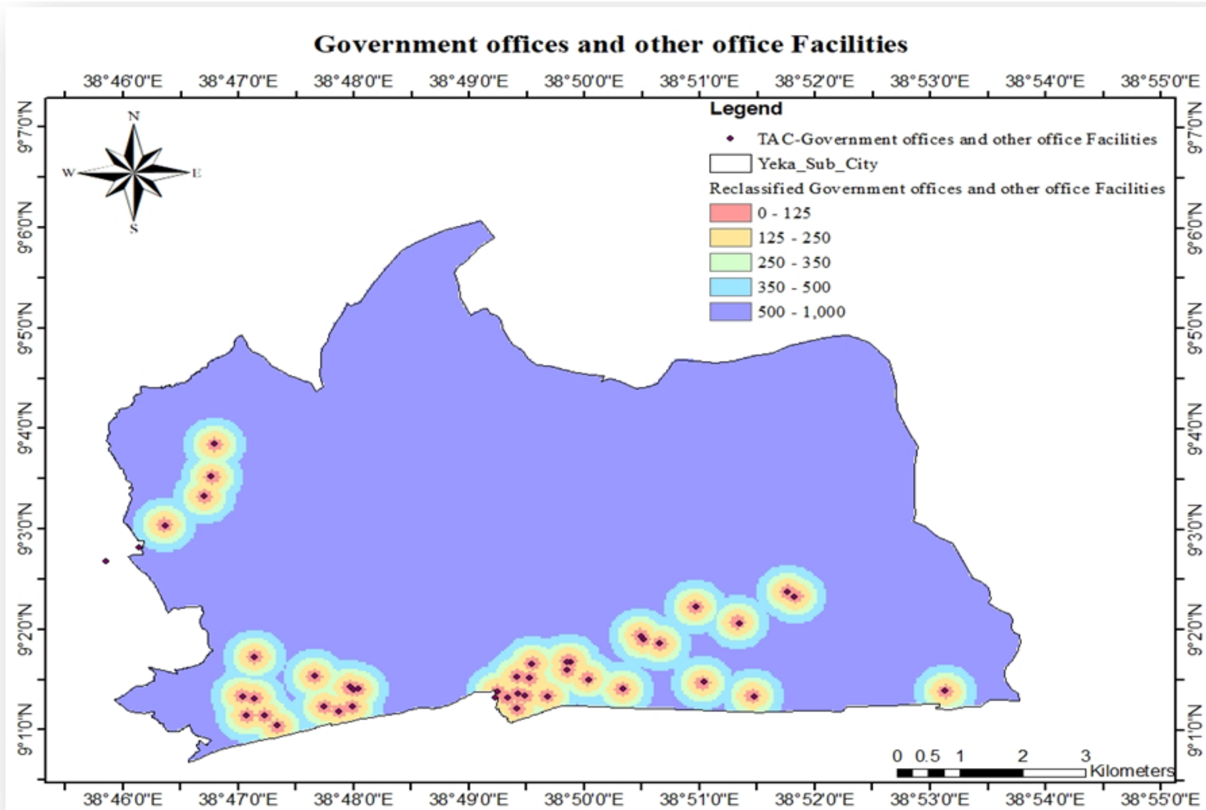

Figure 4. 12 Reclassified Government offices and other office Facilities distance.

The walking distance from the government offices and other office facilities was calculated using the Euclidean distance technique. The study created a distance layer of up to 1000m and divided it into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters, each having a discrete integer value between 1 and 5 as shown in figure 4.12.

4.1.3.4 Health Facilities

Health facilities are widely defined as any site where medical care is offered. They include healthcare providers, hospitals, pharmacies, neighborhood health centers, teaching and research hospitals, medical labs and research facilities, integrative clinics, and physical therapy. Services relating to health, emergency, and supplies should be easily accessible. Most health care institutions, such as hospitals, operate twenty-four hours every day, seven days a week and have employees, patients, and patient contacts. For these reasons, parking lots are required. Figure 4.13 illustrates the analyzed data for healthcare facilities. The walking distance from the healthcare facilities was calculated using the Euclidean distance technique. The study created a distance layer of up to 1000m and divided it into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters, each having a discrete integer value ranging from 1 to 5.

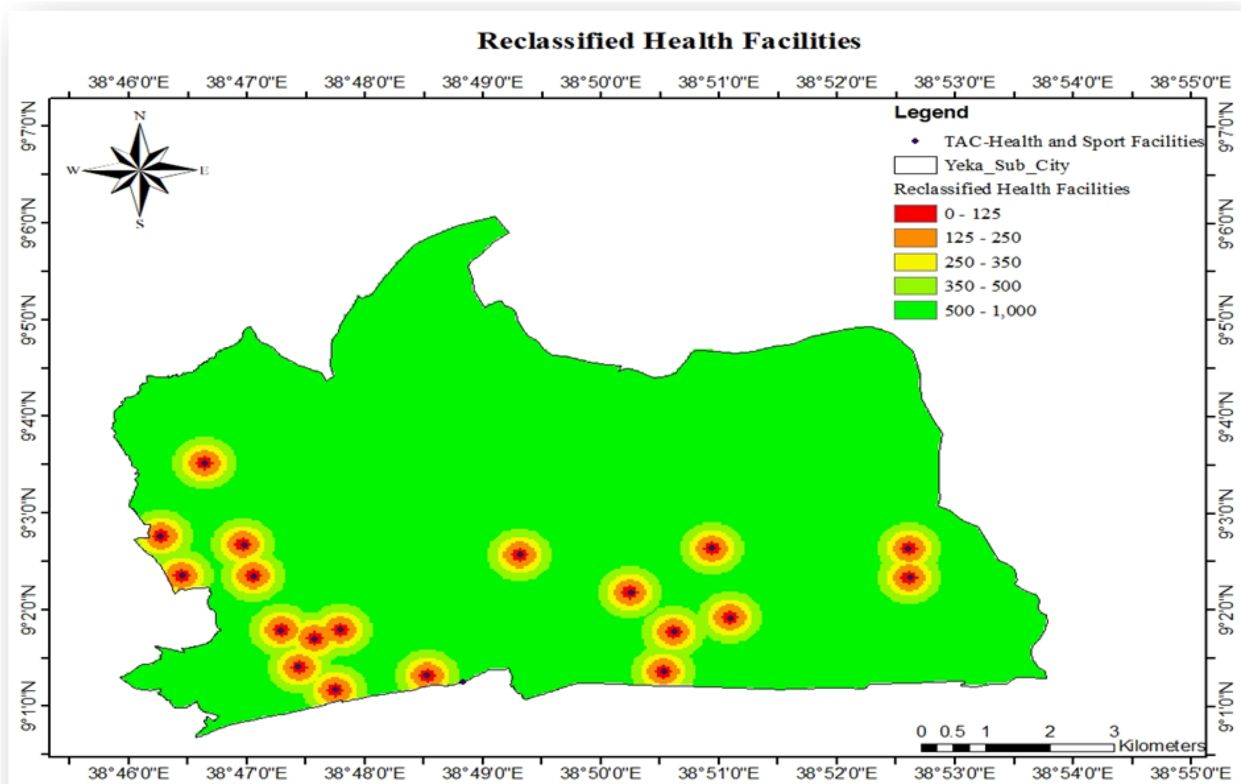

Figure 4. 13 Reclassified health facilities distance.

4.1.3.5 Hotel Facilities

Hotel facilities comprise not merely lodging and facilities but also amenities and entertainment venues including dining establishments, aquatic centers, tennis fields, spas, and meeting spaces. The hotel industry, a component of the tourism industry, focuses on meeting the needs of clients seeking overnight or longer-term lodging. The hotel industry is worldwide, ranging from simple bed-and-breakfasts to luxury resorts, and includes motels, inns, hostels, spas, holiday homes, and immediate apartment rentals. The sector generates huge economic activity, not only in the hotel industry, but also in related fields. The hotel industry is a major job provider worldwide, with possibilities ranging from beginning housekeeping to accounting, advertising, and hotel facility management (Martijn, 2024).

Walking distances from hotel facilities were calculated using the Euclidean distance technique. The study created a distance layer of up to 1000m and divided it into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters, each having a discrete integer value ranging from 1 to 5.

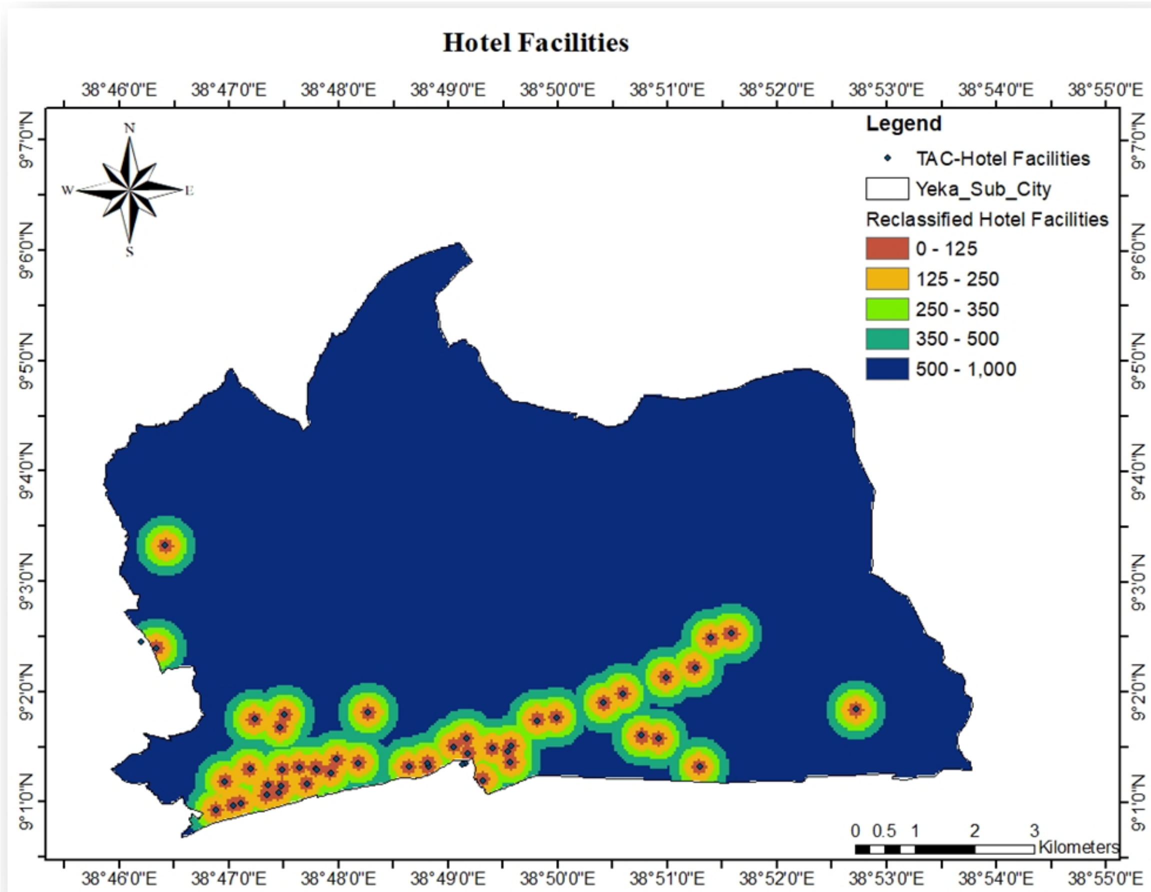

Figure 4. 14 Reclassified hotel facilities distance.

4.1.3.6 Educational Facilities

Data on educational facilities includes primary and secondary schools, technical high schools, private schools, kindergartens, polytechnics, colleges, and universities. Educational facilities are almost evenly distributed across the study region. Professors and students drive up the demand for off-street parking in educational buildings. Private automobile use is prevalent since several educational institutions are located far from public transportation. The demand for parking spots increased as a result of these factors. The studied data for educational facilities is displayed in Figure 4.15 below. Walking distances from educational institutions were calculated using the Euclidean distance technique. A distance layer up to 1000 meters was generated for the investigation, and it was separated into five ranges with discrete integer values between 1 and 5, namely zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters.

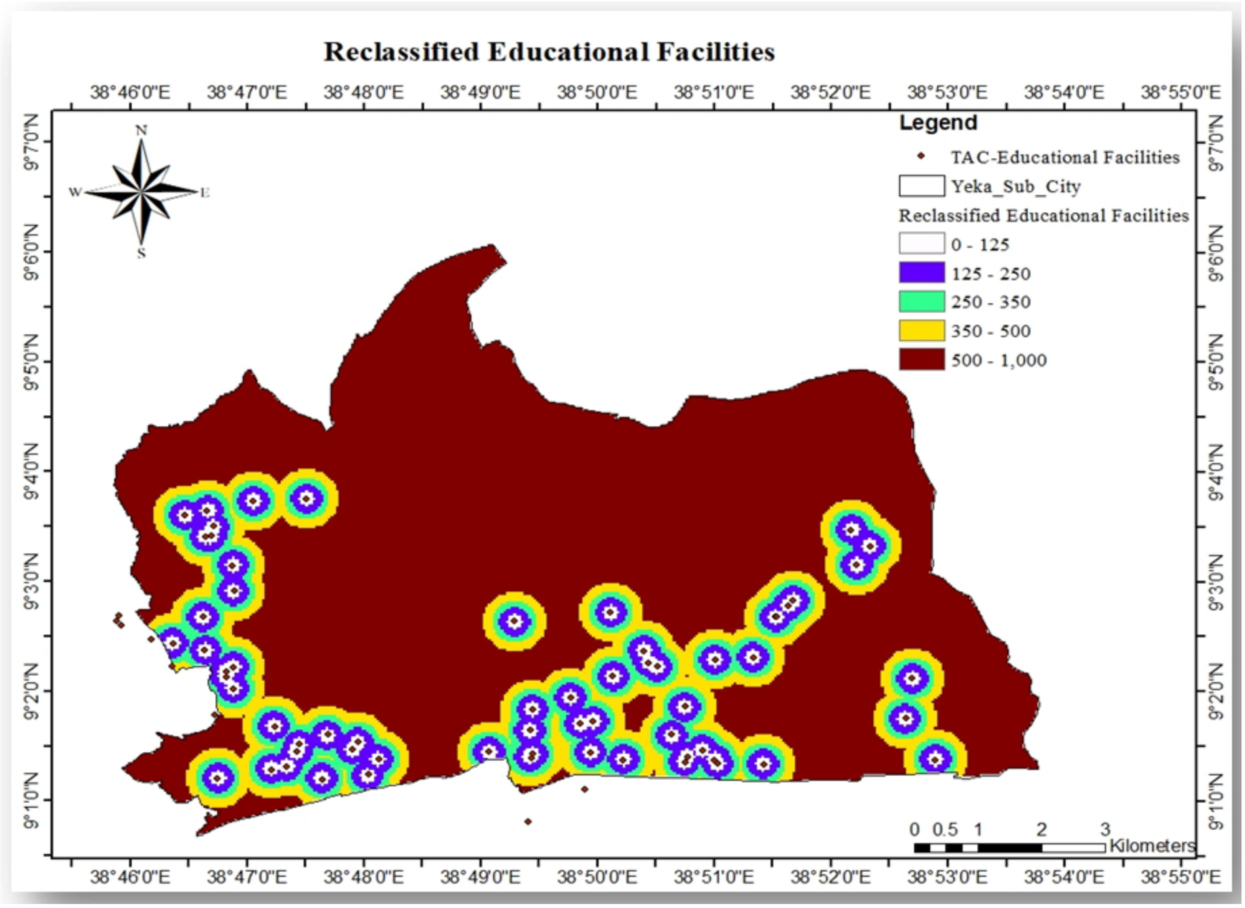

Figure 4. 15 Reclassified educational facilities distance.

4.1.3.7 Shopping Malls and Market facilities

A market is defined as the total number of buyers and sellers in the area or region under consideration, whereas a shopping mall is a collection of businesses that sell a wide range of brands and products, including apparel, items of furniture, electronics, restaurants, groceries, and entertainment areas, all in one location. Shopping malls can now be found in almost every major city, especially in high-traffic areas. Travelers search for a business that carries everything under one roof since they like to buy their necessities in one location. Weekends are often busy at shopping malls. In city centers, shopping malls are typically situated along major thoroughfares. When there is insufficient space for parking, automobiles are parked along the road, which exacerbates traffic congestion.

The figure 4.16 below illustrates the examined data for shopping malls and markets. The walking distance from the shopping malls and markets was calculated using the Euclidean distance technique. The study created a distance layer of up to 1000m and divided it into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters, each having a discrete integer value between 1 and 5.

Figure 4. 16 Reclassified shopping malls distance.

4.1.3.8 Church and Mosque Facilities

The term "church" has two distinct meanings: a physical facility where Christians worship and a Christian neighborhood, which can apply to any assembly of Christians. The name church comes from the Greek word Kyriake, which means "attachment to God," and was used as a synonym for a home or society of God. In the New Testament, the term refers to the global Christian community, Christians in a single geographical place, and a group in a particular place of worship. The term church has changed over time, having its origins in the German language and its use in the New Testament (Ahmad and Hossein, 2015). Masjids (Mosque) are places of worship for Muslims where the canonical prayer is the most prominent form of worship. Some believe that the word "masjid" is of Syriac origin and may have entered the Arabic language at some point. Other Orientalists attempt to associate the roots of Islamic words with non-Arabic languages, such as Italian or Spanish words meschita or mesqita. However, these claims are unlikely, as Arabic, Hebrew, Syriac, and Nabatean share a common root. The term "masjid" may have entered these languages after a period of time, as it was common among Arabs before the rise of Islam (Ahmad and Hossein, 2015).

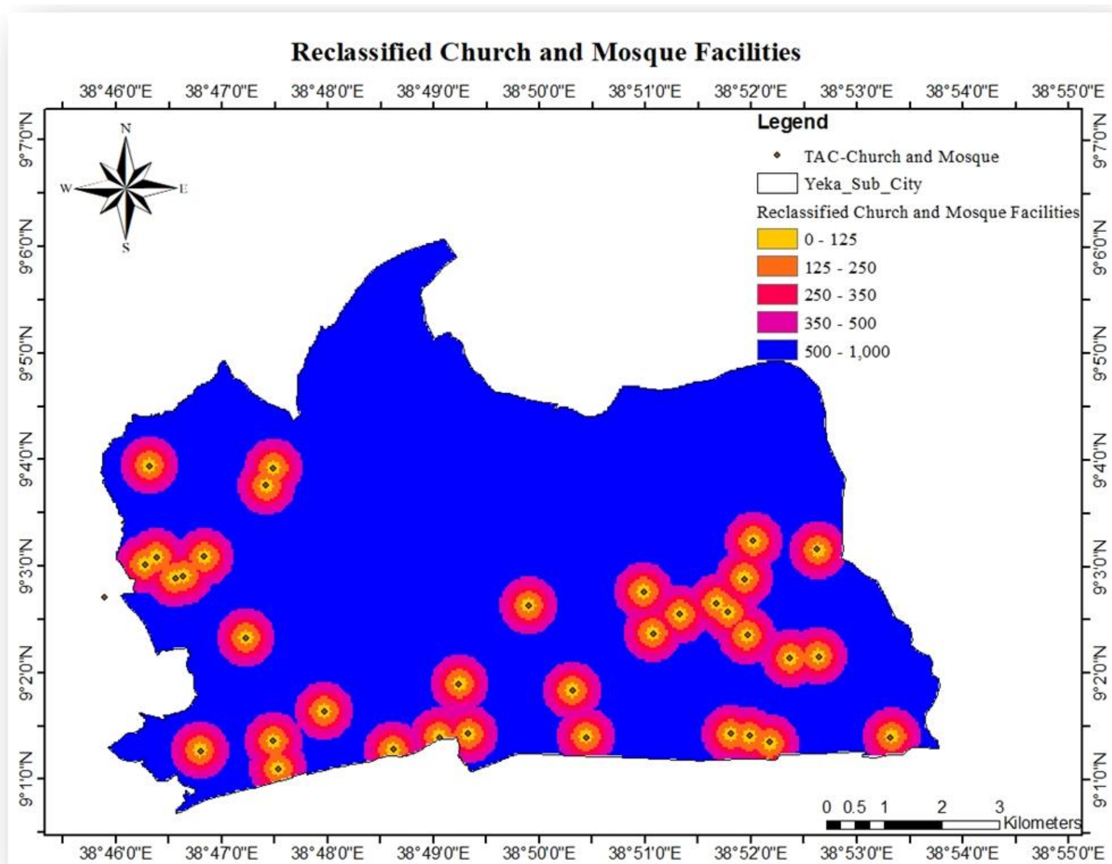

Figure 4. 17 Reclassified church and mosque facilities distance.

The walking distance from the Church and Mosque Facilities was calculated using the Euclidean distance technique. The study created a distance layer of up to 1000m and divided it into five ranges: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters, each having a discrete integer value between 1 and 5 as shown in figure 4.17.

4.2 Determination of Criteria Weights by AHP

The criteria that were selected as crucial elements were transportation, parking, and trip absorption for selecting parking locations in the study region after a thorough literature analysis and assessment of current guidelines, as well as cross-checking with national legislation and standards. Using the AHP method, the study do a pairwise comparison of linked items to determine their weight of both the main and supporting criteria. To acquire suitable values and results for the pairwise comparison matrix, a thorough literature review and examination of current guides are required, as well as cross-checking with national standards and guidelines. The total weight of entries obtained from the pairwise comparison matrix must be one. The Consistency Ratio (CR) can also be used to determine the consistency of the AHP method's pairwise comparison matrix. The CR's value can be compared to that of the Random Index (RI). The AHP approach can be defined in three steps (Ibraheem, 2016; Kumar, 2008): generating the pairwise comparison matrix, computing the criteria weights, and evaluating the consistency ratio.

The weights of the criteria were established using the above-described processes, and the results were merged with a GIS methodology to ascertain parking demand, leading to the construction of a necessary parking map. A parking area suitability map was produced by multiplying the weighted combination of the categorized maps by their weight in the raster calculation tool. Because the data was divided into three categories (transportation criteria, parking criteria, and TAC), the classified layer data of transportation sub criteria were first integrated into the raster calculator tool and multiplied by their weightage, parking sub criteria, and TAC sub criteria, respectively. The three major criteria were then merged into the raster calculation tool and multiplied by their weightage, resulting in the creation of a parking area suitability map.

A. Creating the pairwise comparison matrix

The pairwise comparison is conducted on an objective scale of one to nine, with each number representing the relative relevance of one criterion over another (Saaty, 1980; Taherdoost, 2017).

Table 4. 2 Relative importance scores of variables for pair-wise comparison.

Importance Scale (Value)	Relative Importance Scale
1	Equally important
2	Equally to Moderately Important
3	Moderately important

4	Moderately to Strongly Important
5	Strongly important
6	Strongly to Very Strongly Important
7	Very strongly important
8	Very Strongly to Extremely Important
9	Extremely important

The table depicts the relative importance of the criteria. This level requires a pairwise comparison of linked components. All components must be at the same level. In this research, the criteria for conducting the pairwise comparison were determined after a thorough literature analysis, examination of current guidelines, and inter reviewing with national regulations and standards.

The key factors used to determine parking spaces in the study area were transit criteria, parking criteria, and trip absorption centers. The weights of the criteria and sub-criteria were calculated using the AHP approach. To determine the weight of the criterion, the study should create a pairwise comparison matrix. As a result, each study area's criterion is stated in each table below using a pairwise comparison matrix.

Table 4. 3 Pairwise comparison matrix of TAC.

Criteria	Residential Place	Public Institution	Gov't office	Health Facilities	Hotel Facilities	Educational Facilities	Shopping Malls & Markets	Church & Mosque Facilities
Residential Place	1	3	3	5	7	9	5	9
Public Institution	1/3	1	1	1	5	5	4	8
Government office	1/3	1	1	3	5	3	5	7
Health Facilities	1/5	1	1/3	1	3	7	1	5
Hotel Facilities	1/7	1/5	1/5	1/3	1	2	1	3
Educational Facilities	1/9	1/5	1/3	1/7	1/2	1	7	5
Shopping Malls & Markets	1/5	1/4	1/5	1	1	1/7	1	3
Church & Mosque Facilities	1/9	1/8	1/7	1/5	1/3	1/5	1/3	1
Sum	2.4317	6.7750	6.2095	11.6762	22.8333	27.3429	24.3333	41.0000

Table 4. 4 Pairwise comparison matrix of parking criteria.

Criteria	Existing parking	Slope	Traffic volume	Car ownership	Land cost
Existing parking	1	1	5	3	5
Slope	1	1	1	3	3
Traffic volume	1/5	1	1	5	3
Car ownership	1/3	1/3	1/5	1	1
Land cost	1/5	1/3	1/3	1	1
Sum	2.7333	3.6667	7.5333	13.0000	13.0000

Table 4. 5 Transportation pairwise comparison matrix.

Criteria	Arteries	Taxi and Bus Stands	Highways	Train Station
Arteries/Main Road	1	5	9	7
Taxi & Bus Stands & Bus Stations	1/5	1	3	4
Highways	1/9	1/3	1	3
Train Station	1/7	1/4	1/3	1
Sum	1.4540	6.5833	13.3333	15

Table 4. 6 Pairwise comparison matrix of main criteria.

Criteria	Parking	Transportation	TAC
Parking	1	5	7
Transportation	1/5	1	3
TAC	1/7	1/3	1
Sum	1.3429	6.3333	11.0000

B. Computation of criteria weights

The following operations are included in this section. First, each column's total was found in the pairwise comparison matrix. The normalized pairwise comparison matrix was produced by summing each of the columns that were partitioned into the matrix. Next, for every row in the normalized matrix, the average of the components was calculated. The outcomes show how important the criteria are. Consequently, each table below shows the normalized Pairwise comparison matrix for each criteria, along with the criteria weight and criteria weight % for the research regions.

Table 4. 7 Normalized Pairwise comparison matrix of TAC.

Criteria	Residential I	Public Insti	Government (	Health Fac	Hotel	Educational I	Malls & I	Church an Facilities	Sum	Criteria wei	Criteria weigh
Residential Plac	0.4112	0.4428	0.4831	0.4282	0.3066	0.3292	0.2055	0.2195	2.8261	0.3533	35.3262
Public Institutic	0.1371	0.1476	0.1610	0.0856	0.2190	0.1829	0.1644	0.1951	1.2927	0.1616	16.1589
Government office	0.1371	0.1476	0.1610	0.2569	0.2190	0.1097	0.2055	0.1707	1.4076	0.1759	17.5945
Health Facilitie	0.0822	0.1476	0.0537	0.0856	0.1314	0.2560	0.0411	0.1220	0.9196	0.1150	11.4952
Hotel Facilities	0.0587	0.0295	0.0322	0.0285	0.0438	0.0731	0.0411	0.0732	0.3802	0.0475	4.7529
Educational Facilities	0.0457	0.0295	0.0537	0.0122	0.0219	0.0366	0.2877	0.1220	0.6092	0.0762	7.6153
Shopping Malls Markets	0.0822	0.0369	0.0322	0.0856	0.0438	0.0052	0.0411	0.0732	0.4003	0.0500	5.0036
Church and Mosque Faciliti	0.0457	0.0185	0.0230	0.0171	0.0146	0.0073	0.0137	0.0244	0.1643	0.0205	2.0535
									Sum	1.0000	100.0000

Table 4. 8 Transportation criteria's normalized pairwise comparison matrix

Criteria	Arteries/Main Road	Taxi and Bus Stands and Bus Stations	Highways	Train Station	Sum	Criteria weights	Criteria weights (%)
Arteries/Main Road	0.6878	0.7595	0.6750	0.4667	2.5889	0.6472	64.7233
Taxi and Bus Stands and Bus Stations	0.1376	0.1519	0.2250	0.2667	0.7811	0.1953	19.5280
Highways	0.0764	0.0506	0.0750	0.2000	0.4021	0.1005	10.0513
Train Station	0.0983	0.0380	0.0250	0.0667	0.2279	0.0570	5.6974
					Sum	1.0000	100.0000

Table 4. 9 Normalized Pairwise comparison matrix of parking criteria.

Criteria	Existing parking	Slope	Traffic volume	Car owners	Land co	Sum	Criteria weights	Criteria Weights (%)
Existing parking	0.3659	0.2727	0.6637	0.2308	0.3846	1.9177	0.3835	38.3536
Slope	0.3659	0.2727	0.1327	0.2308	0.2308	1.2329	0.2466	24.6573
Traffic volume	0.0732	0.2727	0.1327	0.3846	0.2308	1.0940	0.2188	21.8805
Car ownership	0.1220	0.0909	0.0265	0.0769	0.0769	0.3933	0.0787	7.8651
Land cost	0.0732	0.0909	0.0442	0.0769	0.0769	0.3622	0.0724	7.2435
						Sum	1.0000	100.0000

To achieve the desired result, the key criteria must also be combined. The pairwise comparison matrix of criteria with their weights is shown in Table 4.10 below, and the final result achieved by overlaying the primary criterion or the three above images is shown in Figure 4.21 below.

Table 4. 10 Main criteria's normalized pairwise comparison matrix

Criteria	Parkin g	Transp ortation	TAC	Sum	Criteria weights	Criteria weights(%)
Parking	0.7447	0.7895	0.6364	2.1705	0.7235	72.3506
Transportation	0.1489	0.1579	0.2727	0.5796	0.1932	19.3186
TAC	0.1064	0.0526	0.0909	0.2499	0.0833	8.3308
				Sum	1.0000	100.0000

C. Analysis of the consistency ratio

To ascertain whether or not the decision is consistent, the CR of the n items is evaluated in this section. The pairwise comparison may be updated if the CR is below the necessary level (Lee 2007). The following formula determines the (CR):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where; CI is a consistency index and

RI is a random index that is obtained by the Table below for a number of variables (n). (Kumar, 2013).

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \ldots\ldots\ldots\ldots\ldots..(2)$$

Where; λ_{max} is The largest eigenvalue of the comparison pair matrix.

n is the number of factors or criteria used in the study.

Table 4. 11 Values of Random Index (Golden and Wang, 1990).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If CR = 0.10, the ratio validates consistency in pairwise comparisons; if CR > 0.10, the ratio values are contradictory and require reconsideration of the pairwise comparison matrix (Al Garni, 2017). Therefore, consistency ratio each criteria's of the study areas are calculated using consistency index and random index are shown and listed in each table below.

Table 4. 12 Calculation of Consistency Index (CI) of Transportation criteria

Criteria	Arteries	Taxi Bus Stands & Bus Stations	Highways	Train Station	Weighted Sum Value (WSV)	Criteria Weights (CW)	Ratio (WSV/CW)
Arteries/Main Road	0.6472	0.9764	0.9046	0.3988	2.9271	0.6472	4.5224
Taxi & Bus Stands & Bus Stations	0.1294	0.1953	0.3015	0.2279	0.8542	0.1953	4.3740
Highways	0.0719	0.0651	0.1005	0.1709	0.4084	0.1005	4.0636
Train Station	0.0925	0.0488	0.0335	0.0570	0.2318	0.0570	4.0678
					Sum	1.0000	17.0279

Numbers of factors of Transportation criteria (n) = 4; the highest eigenvalue of pairwise comparison matrix (λmax) equals to averaging the ratio of the weighted sum value to the criteria weights, λmax = $\frac{(WSV/CW)_{total}}{n} = \frac{17.0279}{4} = 4.2570$

CI = $\frac{\lambda_{max}-n}{n-1} = \frac{4.2570-4}{4-1} = 0.0857$

CI=0.0857, RI (Random index) for n=4, RI=0.89 (from table 4.11)

CR = $\frac{CI}{RI} = \frac{0.0857}{0.89} = 0.0962$

Therefore, CR=0.0962

Table 4. 13 Calculation of Consistency Index (CI) of TAC

Criteria	Residential Place	Public Institution	Government office	Health Facilities	Hotel Facilities	Educational Facilities	Shopping Malls Markets	Church Mosque Facilities	Weighted Sum Value (WSV)	Criteria Weights (CW)	Ratio (WSV/CW)
Residential Place	0.3533	0.4848	0.5278	0.5748	0.3327	0.6854	0.2502	0.1848	3.3937	0.3533	9.6067
Public Institution	0.1178	0.1616	0.1150	0.1150	0.2376	0.3808	0.2001	0.1643	1.4921	0.1616	9.2338
Government office	0.1178	0.1616	0.0475	0.3449	0.2376	0.2285	0.2502	0.1437	1.5318	0.1759	8.7059
Health Facilities	0.0707	0.1616	0.0254	0.1150	0.1426	0.5331	0.0500	0.1027	1.2009	0.1150	10.4474
Hotel Facilities	0.0505	0.0323	0.0100	0.0383	0.0475	0.1523	0.0500	0.0616	0.4426	0.0475	9.3119
Educational Facility	0.0393	0.0323	0.0068	0.0164	0.0238	0.0762	0.3502	0.1027	0.6477	0.0762	8.5050
Shopping Malls Markets	0.0707	0.0404	0.2000	0.1150	0.0475	0.0109	0.0500	0.0616	0.5960	0.0500	11.9125
Church & Mosque	0.0393	0.0202	0.0000	0.0230	0.0158	0.0152	0.0167	0.0205	0.1507	0.0205	7.3401
									Sum	1.0000	75.0631

Numbers of factors of TAC criteria (n) = 8; the highest eigenvalue of pairwise comparison matrix (λmax) equals to averaging the ratio of the weighted sum value according to the weight criterion, λmax = $\frac{(WSV/CW)_{total}}{n} = \frac{75.0631}{8}$ = 9.3829, CI = $\frac{\lambda_{max}-n}{n-1} = \frac{9.3829-8}{8-1}$ = 0.1976 and RI (Random index) for n=8, RI = 1.41 (from table 4.11), CR = $\frac{CI}{RI} = \frac{0.1976}{1.41}$ = 0.1041

Therefore, CR=0.1041

Table 4. 14 Calculation of Consistency Index (CI) of parking criteria

Criteria	Existing park	Slope	Traffic volume	Car owners	Land cost	Weighted Sum Value (W	Criteria weights (CW	Ratio (WSV/CW)
Existing parking	0.3835	0.2466	1.0940	0.2360	0.3622	2.3223	0.3835	6.0549
Slope	0.3835	0.2466	0.2188	0.2360	0.2173	1.3022	0.2466	5.2811
Traffic volume	0.0767	0.2466	0.2188	0.3933	0.2173	1.1526	0.2188	5.2679
Car ownership	0.1278	0.0822	0.0438	0.0787	0.0724	0.4049	0.0787	5.1478
Land cost	0.0767	0.0822	0.0729	0.0787	0.0724	0.3829	0.0724	5.2864
						Sum	1.0000	27.0381

Numbers of factors of parking criteria (n) = 5; the highest eigenvalue of pairwise comparison matrix (λmax) equals to averaging the ratio of the weighted sum value to the criteria weights

$$\lambda\text{max}= \frac{(WSV/CW)_{total}}{n} = \frac{27.0381}{5} = 5.4076$$

$$\text{CI} = \frac{\lambda_{max}-n}{n-1} = \frac{5.4076-5}{5-1} = 0.1019$$

CI=0.1019, and RI (Random index) for n=5, RI=1.12 (from table 4.11)

$$\text{CR} = \frac{CI}{RI} = \frac{0.1019}{1.12} = 0.0910$$

Therefore, CR=0.0910

Table 4. 15 Calculation of Consistency Index (CI) of main criteria

Criteria	Parking	Transportation	TAC	Weighted Value (WSV)	Criteria weights (CW)	Ratio (WSV/CW)
Parking	0.7235	0.9659	0.5832	2.2726	0.7235	3.1411
Transportation	0.1447	0.1932	0.2499	0.5878	0.1932	3.0427
TAC	0.1034	0.0644	0.0833	0.2511	0.0833	3.0137
				Sum	1.0000	9.1975

Numbers of factors of main criteria (n) =3; the highest eigenvalue of pairwise comparison matrix (λmax) equals to averaging the ratio of the weighted sum value to the criteria weights,

$$\lambda\text{max} = \frac{(WSV/CW)_{total}}{n} = \frac{9.1975}{3} = 3.0658,$$

$$\text{CI} = \frac{\lambda_{max}-n}{n-1} = \frac{3.0658-3}{3-1} = 0.0329$$

CI=0.0329 and RI (Random index) for n=4, RI=0.58 (from table 4.11)

$$\text{CR} = \frac{CI}{RI} = \frac{0.0329}{0.58} = 0.0567$$

Therefore, CR=0.0567

4.3 Parking Demand by Combing GIS and AHP

The parking location selection analysis problem is solved using an MCDA approach to aid decision-making. The weightage of criteria used in the analysis is estimated, and potential parking solutions or site selections for new parking areas are identified using a combination of GIS and AHP techniques to identify primary and sub-criteria, with a focus on Land Use, Parking, and Transportation as the primary criteria for selecting parking lots. The combination of GIS and AHP provides an efficient and optimal strategy for site selection and locating suitable parking locations. The AHP approach, when applied to criteria, generated relative weights, whilst GIS permitted spatial analysis to discover optimal parking spaces. To obtain the overlay map of each criteria such as Transportation, parking and TAC criteria, multiply the categorized layer data by their appropriate weights in the raster calculator tool to get their respective overlay map and Car parking demand suitability map.

To obtain the TAC overlay map, multiply the categorized layer data by their appropriate weights in the raster calculator tool, as shown in Figure 4.18 below.

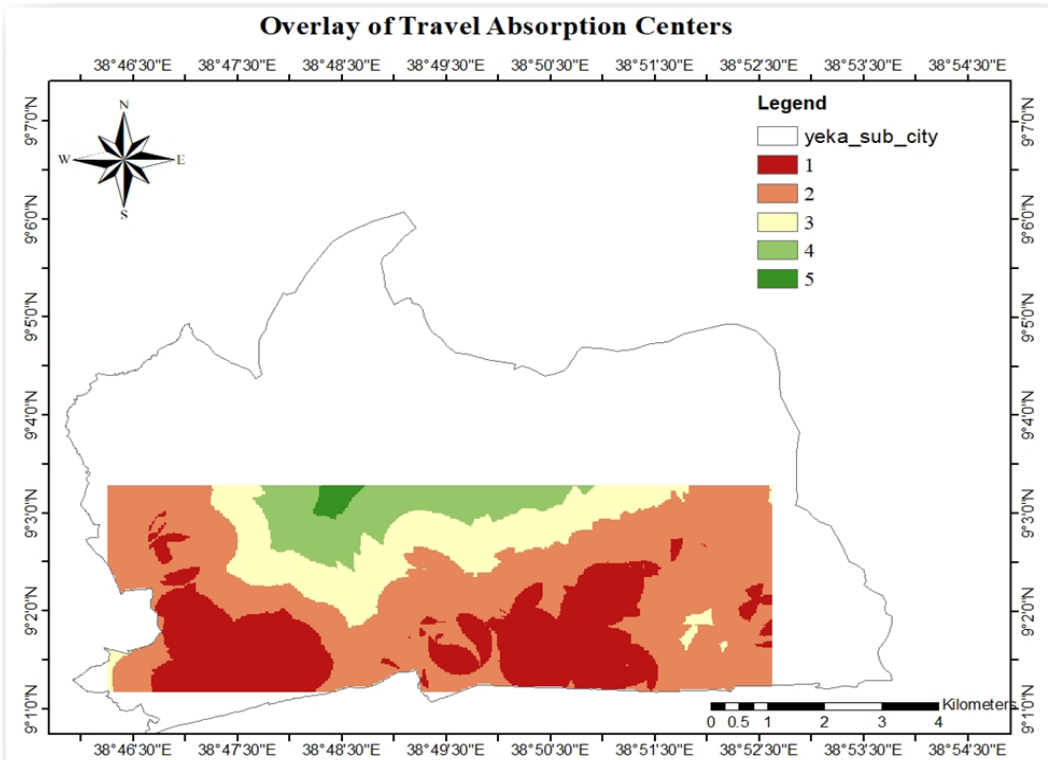

Figure 4. 18 Overlaid map of TAC.

The overlay map of parking criteria seen in Figure 4.19 below was created by multiplying the categorized layer data of parking criteria by their corresponding weights in the raster calculator tool.

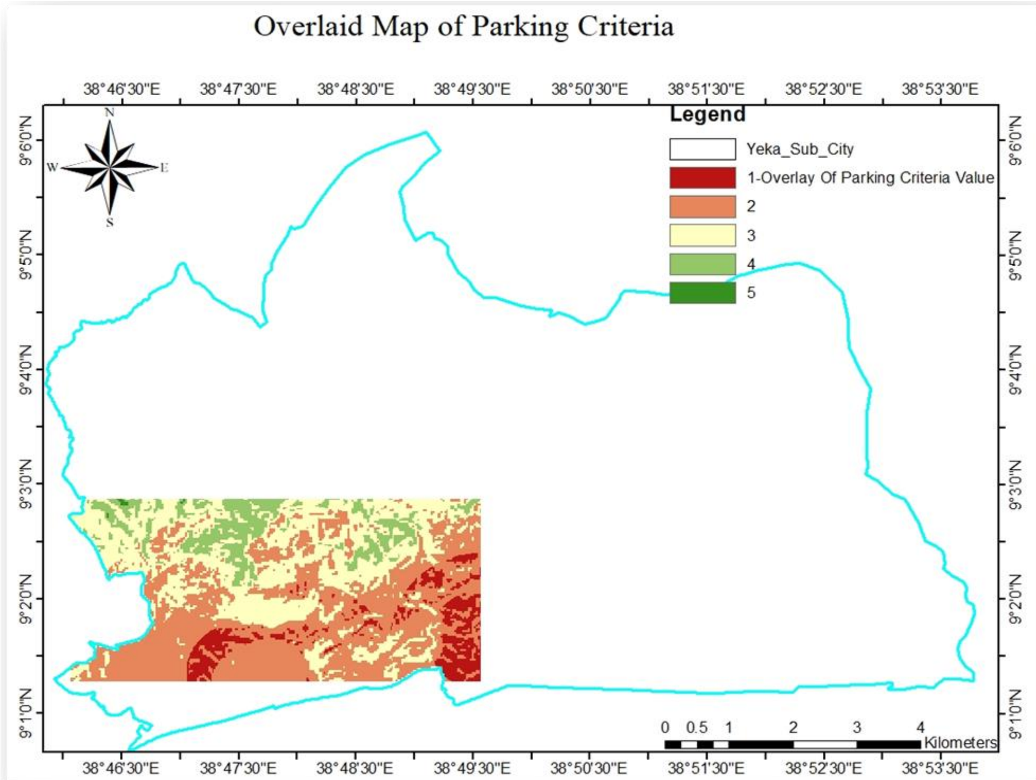

Figure 4. 19 Parking criteria overlay map.

The overlay map of transportation criteria seen in Figure 4.20 below was created by multiplying the categorized layer data of the transportation criterion by their corresponding weights in the raster calculator tool.

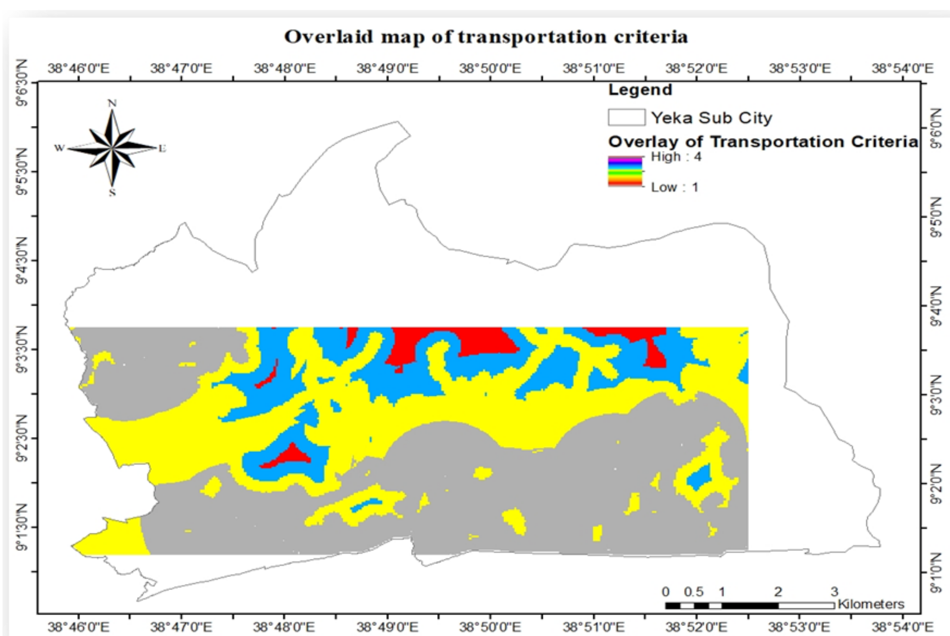

Figure 4. 20 Overlaid map of transportation criteria.

The raster calculator tool uses the layer data of the criteria and multiplies it by their weightage to produce the suitability map of parking spots, as seen in the figure below.

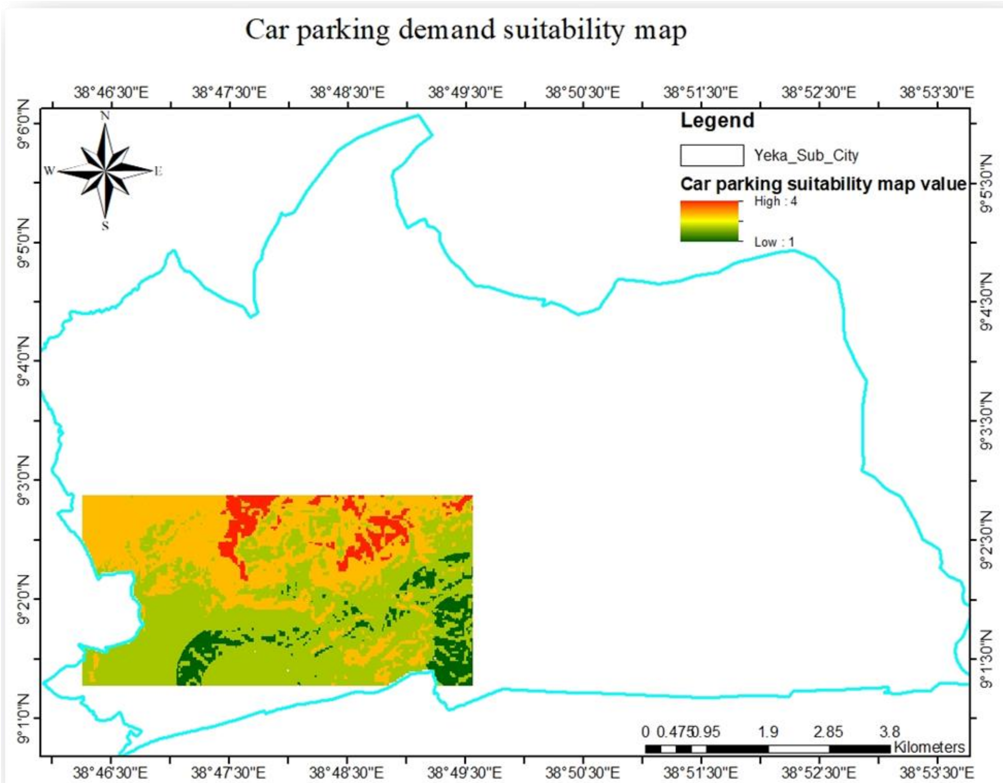

Figure 4. 21 Car parking demand suitability map.

The parking suitability map's red-colored sections represent high numbers, which imply strong demand, as a result of the GIS-AHP integration. Parking lots can be built in the most promising regions to the south and southwest of the research area.

Therefore, a consistency ratio of 0.10 or lower indicates acceptable comparison results, in which the overall criteria's value of consistency ratio each criteria's of the study areas are below 0.1 means acceptable result and the ratio represents the confirmation of the pairwise comparisons' consistency which used for the next procedures in GIS analysis. Parking demand was determined by combining the results with a GIS method, and the processes described above were utilized to define the weights of the criteria. This process led to the construction of parking demand maps of the research region.

4.4. Appropriate Site Selection of Parking Lots

Determining or Selecting Parking Lot Locations based on network analysts with integration of GIS and AHP were used to determine the best locations for parking spots. A point-based vector map was created from the demand map created with raster-based map algebra.

There are various alternative approaches to better estimate parking demand with extra information provision, such as integrating land use demand and allowing for geographic exploration of parking accessibility. The land use analysis then predicts the demand based on a number of parameters, such as changes and land use mixes, resulting in the projected actual parking demand across the research region based on the criteria previously established. Diverse criteria are used for diverse land use developments that are predicted to generate a high volume of vehicle, bike, and pedestrian traffic. A spatial analysis of the created regions suggests that a large amount of the property surrounding congested streets is suitable for parking development. The land uses are evaluated using "activity areas" rather than the complete study area in order to more properly simulate the parking and built environment link from the perspective of the user. Each activity area includes anticipated development projects and evaluates their influence on parking availability in comparison to existing land uses and parking demand. Parking demand based on land use is used as the primary criteria to estimate car parking demand. After doing an adequate number of parking observations for a land use, the data was examined.

This tool accepts input from facilities that provide commodities or services, as well as demand locations that consume those goods and services. The goal is to identify the facilities that supply the demand places most efficiently. The tool tackles this challenge by assessing alternative methods for assigning demand points to different facilities. The answer is the scenario that assigns the most demand to facilities while minimizing overall travel. The output consists of solution facilities, demand points connected with their assigned facilities, and lines that connect demand points to their respective facilities.

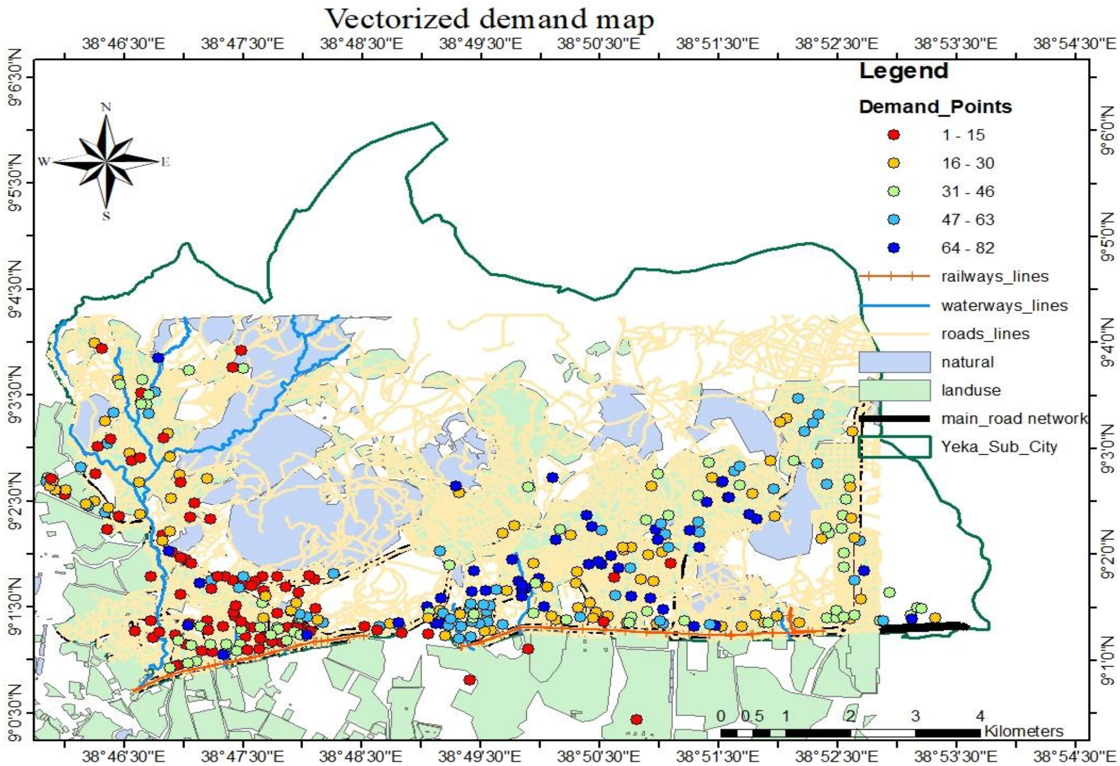

Figure 4. 22 Vectorized demand map.

The figure 4.22 depicts demand points and their respective demand weights. Data sets utilized in Determining or Choosing Parking Lot Locations: Problems are described below and are depicted in Figure 4.22. Facility: In order to accommodate the requirements of time and distance limits, the "Candidate" and "Current" parking spots are included in the study. Demand points are defined as a vectorized demand map with weighted values. The road network dataset is utilized to determine drive times and distances between facilities and demand points.

To employ proper parking lot site selection in each problem category, the impedance cut-off between needs and facilities must be limited by time or distance. An impedance cut-off between demands and facilities was established at 1000 meters for the duration of the case study (zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters). Point vector geometry may be used to represent polygon structures in order to find a digital representation of a structure that shows parking supply and demand. In a single Projected Coordinate System, each supply and demand point must be represented by a pair of x and y coordinates. Local governments do not have a database that calculates parking demand for building units based on actual parking availability. As a result, the data sets required for parking demand analysis are limited in size and difficult to manage. Given that the number of residences and/or offices in a building, the quantity of automobiles, parking space, how those attributes relate to one another, and the amount of space they occupy should all be included in the geographic database. ArcGIS software's network analyst works with raster data rather than vector data, so the basic components of appropriate site selection of parking lots can be done using GIS-supported MCDA method, only facility & demand point for illustration, must be in vector data.

The results showed that, for two reasons, certain facilities (needed parking) did not satisfy demands imposed within the distance restriction. First, the relevant facility's capacity was reached, and facilities satisfied demand without going beyond capacity. Second, the restricting demand weight prevented it from meeting increased demand even if it was capable of doing so. The reasons for the facilities failing to meet parking demands are as follows: they are placed far from parking demands, on the Yeka boundary, in the Bole sub-city, and in areas where parking demands have already been met by other facilities.

4.5 Summarized Interpretation of the Results

This study uses ArcGIS geographic analytic tools to calculate the walking distance to parking facilities based on parking criteria, transportation criteria, and land use criteria (TAC). Except for the slope, which came from a raster DEM, the data was in vector format. All of the layers were converted to raster format to generate the final layer. The rasterized maps were scored using a reclassifying algorithm, which gave each one five values. The distance to parking locations was used to calculate scores for the parking criterion, transit criteria, and TAC; the criteria with the shortest distances receiving the highest ratings. The highest slope values resulted in the lowest scoring results.

The parking criterion considers the following factors: existing parking, slope, traffic volume, land cost, and vehicle ownership. Criteria locations were determined, and density analyses were performed for the car ownership criterion; DEM was used to compute slope data; the Euclidean distance technique was used for existing parking; and land cost values were converted into raster data and graduated land lease rates using GIS. These maps were then classed using their respective approach to determine the levels to be used in the analysis. Above in section 4.1.1, all sub-criteria are discussed and presented with appropriate analysis maps, which are illustrated with figures in the analysis section.

The transportation criterion considers the following factors: arterials (main roads), highways, bus stations, and train stations. Following a literature review, examination of current guides, and discussions with national legislation and standards, the maximum allowable distance was decided to be 1 km. The locations of the criteria were identified, and Euclidean distance analyses were performed on each criterion using GIS. Reaching distances of up to 1000 meters was possible with the Euclidean distance method. After that, the study divided the distance into five ranges, each having a discrete integer value between 1 and 5, namely zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters. Above, in the analytical sections 4.1.2, all of the sub-criteria are described and shown with appropriate maps and figures.

Travel Absorption Centers are more likely the land use criteria; after conducting a complete literature review and evaluation of current guides, as well as interviewing nations' regulations and standards, 1km was determined to be the maximum permitted distance, and this criterion takes into account the following factors: residential places, public institution facilities, government offices and other office facilities, health facilities, hotel facilities, educational facilities, Shopping Malls and Market facilities and Church and Mosque Facilities. Criteria locations were determined, and density assessments were performed for the Residential Place criterion utilizing kernel density estimate on independent buildings, as well as the Euclidean distance technique with GIS for each criterion. The research then produced a distance layer with a maximum length of 1000 meters and separated it into five ranges, with a discrete integer value between 1 and 5, for each range: zero-one hundred twenty five, one hundred twenty five –two hundred fifty, two hundred fifty –three hundred fifty, three hundred fifty –five hundred, and five hundred –one thousand meters. Above, in the analysis section 4.1.3, all of the sub-criteria are described and provided with appropriate maps and figures.

Using the AHP approach, the study conducts a pairwise comparison of connected items to estimate the weight of criteria and sub-criteria. To obtain appropriate values and results for the pairwise comparison matrix, a thorough literature review and examination of current guidelines are required, as well as cross-checking with national standards and guidelines. The total weight of the elements from the pairwise comparison matrix must equal one. The Consistency Ratio (CR) can be used to assess the consistency of the AHP method's pairwise comparison matrix. The CR's value is comparable to that of the Random Index (RI). The AHP approach can be defined as three steps. The AHP approach employed in this study consists of a pairwise comparison of criteria to assess their relative importance on a scale of 1 to 9. The weights of the criteria are then computed, yielding pairwise comparison matrices. Tables 4. 16, 4. 17, 4. 18, and 4. 19 show the weights obtained for the criteria.

Table 4. 16 Weights of main criteria for determination or selection of parking lot sites

CR (Consistency Ratio) =0.0567	Criteria weights (W)
Parking	0.7235
Transportation	0.1932
TAC	0.0833

Table 4. 17 Weights of TAC (land use) sub-criteria for determination or selection of parking lot sites.

CR (Consistency Ratio) =0.01041	Criteria weights (W)
Accessibility to Residential Place	0.3533
Accessibility to Public Institution	0.1616
Accessibility to Government office	0.1759
Accessibility to Health Facilities	0.1150
Accessibility to Hotel Facilities	0.0475
Accessibility to Educational Facilities	0.0762
Accessibility to Shopping Malls & Markets	0.0500
Accessibility to Church and Mosque Facilities	0.0205

Table 4. 18 Weights of parking sub-criteria for determination or selection of parking lot sites.

CR (Consistency Ratio) =0.01041	Criteria weights (W)
Accessibility to Existing parking	0.3835
Slope	0.2466
Traffic volume	0.2188
Car ownership	0.0787
Land cost	0.0724

Table 4. 19 Weights of transportation sub-criteria for determination or selection of parking lot.

CR (Consistency Ratio) =0.0962	Criteria weights (W)
Accessibility to Arteries/Main Road	0.6472
Accessibility to Taxi and Bus Stands and Bus Stations	0.1953
Accessibility to Highways	0.1005
Accessibility to Train Station	0.0570

The criterion carrying the greatest weight is the accessibility to main roads with a weight of 0.6472. Conversely, the criterion of accessibility to church and mosque facilities holds the lowest weight of 0.0205. The weights assigned to the remaining criteria are as follows: accessibility to existing parking with a weight of 0.3835, accessibility to residential place with a weight of 0.3533, slope with a weight of 0.2466, traffic volume with a weight of 0.2188, accessibility to taxi and bus stands and bus stations with a weight of 0.1953, accessibility to government office with a weight of 0.1759, accessibility to public institution with a weight of 0.1616, accessibility to health facilities with a weight of 0.1150, accessibility to highways with a weight of 0.1005, car ownership with a weight of 0.0787, accessibility to educational facilities with a weight of 0.0762, land cost with a weight of 0.0724, accessibility to train station with a weight of 0.0570, accessibility to shopping malls & markets with a weight of 0.0500 and accessibility to hotel facilities with a weight of 0.0475.

Based on the overall criterion weight, that was calculated by weighing the primary and sub-criteria, in addition to the criteria weights used in the design of appropriate parking lots. The accompanying map was built with a raster program and the criteria weights from the Table of Weights of Main Criteria for Assessing or Selecting Parking Lot Locations. The geographical locations of the criteria were determined, and GIS was utilized to assess density and Euclidean distance for each criterion. The collected raster data was classified. This map indicates appropriate parking lot spaces in the Addis Abeba Municipality's Yeka sub-city (see figure 4.24 below).

According to the data presented in Figure 4. 24 below, the most suitable areas to set up new parking lots are the areas related to the municipality, the main courthouse, the city healthcare facility, market areas, and likely primary, secondary, and high schools. These locations have higher suitability scores for their ability to provide parking facilities. Table 4 displays the obtained results in tabular format.

Table 4. 20 The study findings obtained (Suitability classes for parking site selection in the study area).

Value	Class	Area (km^2)	Area (m^2)	Distribution in percentage (%)
1	Less Suitable	1.318	1317859.557	1.507
2	Moderately Suitable	8.325	8324527.778	9.520
3	Suitable	6.097	6096530.510	6.972
4	Extremely Suitable	0.924	923921.411	1.057
5	Not Suitable	70.781	70780898.357	80.945

In the ever-changing field of city planning and construction of infrastructure, a thorough understanding of optimal parking spaces within neighborhoods is essential. Our most recent study is a thorough investigation that not only identifies parking-friendly places but also provides a geodeterministic reason for their apparent predominance. Our findings are thoroughly collated and provided in a tabulated style, emphasizing the varied degrees of parking compliance amongst sub-city zones. These data not only assess the size of each group, but also offer stakeholders with a ratio, which helps them understand distribution trends.

4.6 Discussion

The study employs GIS-based maps of density and Euclidean analytics to discover the best parking lot locations in the Yeka sub-city core zone. It identifies districts with a sub-city square, significant marketplaces, governmental and healthcare services, and colleges and universities as potential locations for new parking lots. The study develops a thorough map of appropriate parking zones, offering useful information to local authorities and decision-makers. Planners in cities can use the research and accompanying materials to expedite the design process. This detailed research contributes to educated decision-making and comprehensive urban development programs.

Both the density maps as well as the Euclidean map eloquently highlight a major worry in Addis Abeba's sub-city: the concentration of society, educational, and health amenities in a compact and closely knit area. This spatial clustering indicates an anomaly inside the city and accentuates the problem of traffic congestion, resulting in an obvious lack of adequate and sufficient parking facilities.

The MCDA approach was used to combine all of the maps and produce a land suitability map for parking locations. Figure 4. 24 and table 4. 20 depict the final suitability map and its distribution percentage (Suitability classes for parking site selection in the study region), respectively.

According to the figure 4.24, the area with very high suitability for building public parking located mostly in the south-west of the sub city. The area and percentage of the suitability classes are shown in Table 4. 20. As can be seen, 0.924 square kilometers of the study area (1.057%) has extremely suitability for public parking. suitability, moderately suitability, less suitability, and unsuitable areas cover 6.972, 9.52, 1.507 and 80.945 percent of the study area respectively. Field studies were done in areas regarded as having a high level of appropriateness to compare the acquired results, and they showed good consistency.

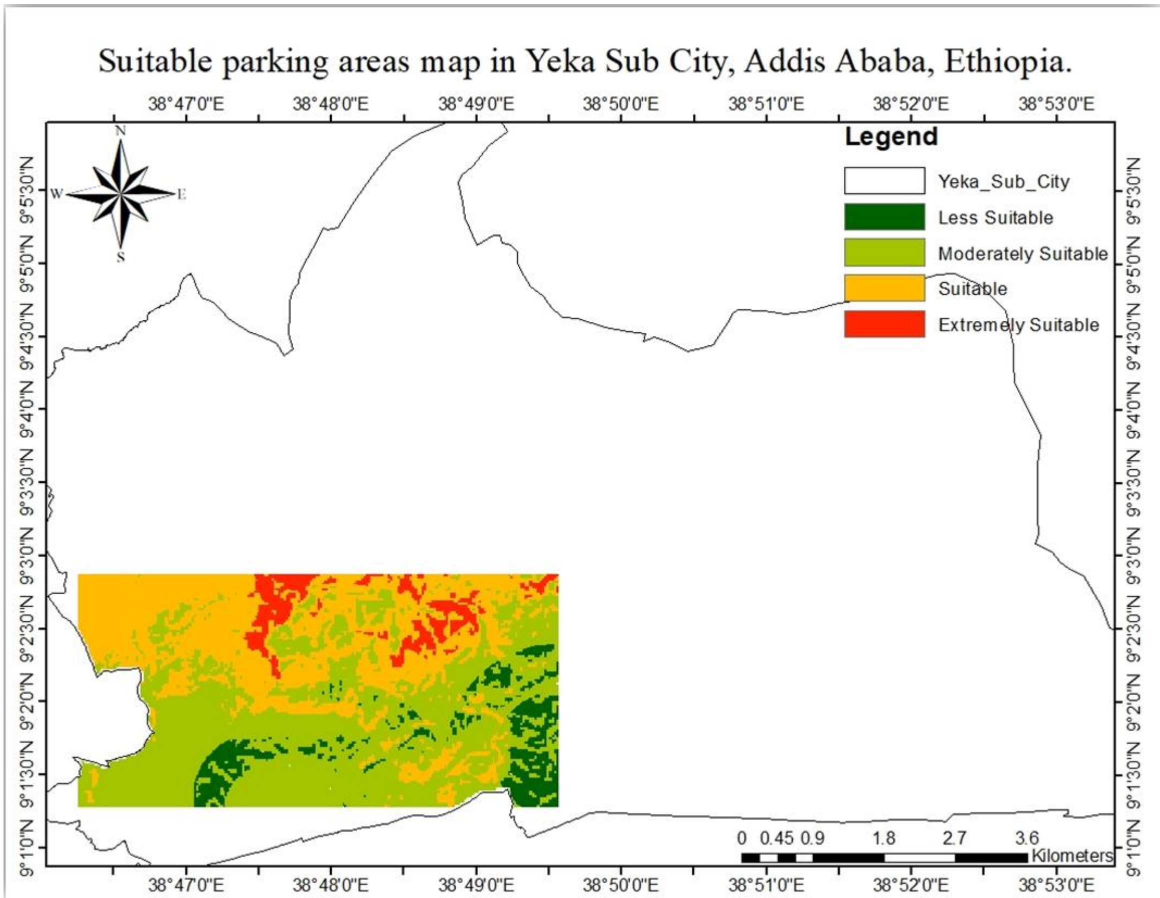

Figure 4. 23 Suitable parking areas map in Yeka sub city, Addis Ababa

The parking demand suitability will be determined by the kind, size, and transportation circumstances in the immediate area of the development based on land use. Different land use developments (higher composition) that are expected to generate a large concentration volume of vehicular, cyclist, and pedestrian traffic are more likely to have localized impacts, so the area of map is partial due to high concentration of different land use indication especially high composition of different land use like commercial & business, hotels, offices, markets, schools, religious and retails developments are often undertaken and the map shows parking demand suitability areas in which high-demand area means the remaining areas are not suitable based on land use.

A spatial study of congested streets indicates that a significant portion of property is suitable for parking development. As one moves away from these areas, parking becomes less convenient.

Most of these locations are near commercial districts and important thoroughfares. Public parking can help resolve traffic issues in the study region, but it's not the only option. Non-marginal parking and managing marginal parking can also be considered. Most tourist attractions, such as commercial, religious, and cultural buildings, are located in city centers, so it's preferable to relocate them to less congested areas. Factors such as land use type, density, and public transportation connections also impact parking spaces. The study illustrates the aerial possibility of building parking places based on demand possibilities, allowing for the minimization of parking by combining similar feature areas and capacity.

The other reason is, MCDA approach was used to combine all of the overlay maps of different criteria, which multiply the categorized layer data by their appropriate weights in the raster calculator tool and produce a land suitability map for parking locations. So when combined, the map depict the final suitability map and its distribution percentage based the above reason and intersection of all of the overlay maps of different criteria (Suitability classes for parking site selection in the study region).

Comparison of the Criteria's

The results of four criteria that were applied in the dissertation research are compared in this part. The weight of the criteria used to integrate GIS and AHP to choose suitable parking lot sites served as the basis for the comparison. This section compares these attributes in order to identify whether one provides more or greater coverage than the others. As part of the discussion in this study, a comparison analysis is performed, contrasting the conclusions reached herein with those of prior publications by various writers from different nations. The comparisons below are represented as follows:

1. Main criteria comparison

As previously said, this study took into account a variety of parameters. Based on sited standards and a hierarchy established based on literature analysis and assessment of current guidelines, as well as cross-checking with national legislation and standards, parking criteria (0.7235) received the most weight among the principal criteria, followed by transportation criteria (0.1932) and land use (TAC) criteria (0.0833). Given its obvious association with the city's widespread issue of high traffic, the study prioritized parking criterion. This ranking is consistent with findings from other studies; for example, a study revealed land use as the most weighted criterion (0.58), followed by transportation (0.42) (Alkan & Durduran, 2021). In contrast, the study found that transportation criteria had the highest weight (0.55), followed by land use criteria (0.33) (Demir et al., 2021). Another study (Iqbal, 2020) found that transportation (0.60) had a larger weight than land use criteria (0.35).

2. Parking sub-criteria comparison

The parking sub-criterion was evaluated using pairwise comparison matrices, with accessibility to existing parking (0.3835), slope (0.2466), traffic volume (0.2188), car ownership (0.0787), and land cost (0.0724) receiving the highest weights. This ranking is consistent with results from other studies.; for example, a study revealed existing parking as the most weighted criterion (0.347), followed by car ownership (0.37), land cost (0.186), traffic volume (0.062) and slope (0.035) (Iqbal, 2020).

3. Land use sub-criteria comparison

In the assessment of the TAC (land use) sub-criterion, the highest weights from pairwise comparison matrices were determined as follows: accessibility to residential places (0.3533), accessibility to public institutions (0.1616), accessibility to government offices (0.1759), accessibility to health facilities (0.1150), accessibility to hotel facilities (0.0475), accessibility to educational facilities (0.0762), accessibility to shopping malls and markets (0.0500) and accessibility to church and mosque facilities (0.0205). Studies reported similar weights derived from pairwise comparison matrices, listing being accessible to health institutions (0.357), being accessible to public institutions (0.165), accessibility to educational institutions (0.124), being accessible to shopping centers (0.119), and being accessible to cultural facilities (0.082) (Alkan & Durduran, 2021). Furthermore, some studies identified weights from pairwise comparison matrices as being accessible to shopping centers (0.354), access to health institutions (0.261), access to cultural facilities (0.151), access to public institutions (0.107), and access to educational institutions (0.047) (Demir et al., 2021). In another study, the weights from pairwise comparison matrices were listed as being accessible to shopping centers (0.197), being accessible to health institutions (0.172), being accessible to public institutions (0.084), being accessible to educational institutions (0.042), and being accessible to cultural facilities (0.024) (Iqbal, 2020).

4. Transportation sub-criteria comparison

In evaluating the transportation sub-criterion, the study assigned the highest weights from pairwise comparison matrices as follows: accessibility to main roads (0.6472), accessibility to taxi and bus stands and bus stations (0.1953), accessibility to highways (0.1005), and accessibility to train stations (0.057). The study revealed similar weights generated from pairwise comparison matrices, with accessibility to important roads (0.442), existing parking areas (0.249), and bus stations (0.308) (Alkan & Durduran, 2021). Another study found weights in pairwise comparison matrices for accessibility to current parking places (0.252), accessibility to major roads (0.151), and accessibility to bus terminals (or train, tramway, metro stations) (0.074) (Demir et al., 2021). In another study, weights from pairwise comparison matrices were described as accessibility to important roads (0.568), being accessible to bus stations (or train, tramway, metro stations) (0.397), and being accessible to existing parking lots (0.3) (Iqbal, 2020).

The findings of this study suggest that employing GIS can incorporate various levels of complexity into the decision problem. Weighting is an important consideration in this scenario. The study may not reach and agree on the same weights for the criteria and sub-criteria. This may result in varied findings for final maps, influencing the final decision. However, it should be remembered that the offered approaches are merely tools to help decision-makers, not the decision itself. This study used a variety of variables to identify public parking locations, which were created using a GIS structure. These factors were divided into three groups: parking criterion, transportation criteria, and TAC.

Similar studies, such as this one, were undertaken and took into account a variety of parameters, including physical infrastructure, social, and economic factors. For example, one study looked into physical substructures as well as social and economic criteria and sub-criteria for selecting the best car parking places in different regions (Jelokhani-Niaraki & Malczewski, 2015b; Aliniai et al., 2015; and Farzanmanesh et al., 2010). Furthermore, several resources took into account environmental parameters such as air pollution (Kazazi Darani et al., 2018). However, due to a lack of data access, the environmental requirements were overlooked in this work. Meanwhile, the Parking Suitability Site Selection Map was created using Ordered Weighted Averaging (OWA). This method is among the most commonly employed in multi-criteria decision analysis. GIS-based Multi-criteria Decision Analysis (MCDA) techniques evaluate locations using geographical data, weights, and an MCDA collection behave that combines spatial data and criteria weights (Jelokhani-Niaraki & Malczewski, 2015b), whereas OWA is a general method that can be applied to a wide range of situations and data types. Several authors propose the GIS-OWA procedure for urban development and administration (Mendes, 2000; Mendes & Motizuki, 2001) given that the

OWA method creates an intuitive setting in which a variety of decision methods may be developed and tested.

Although many other studies have used various methods to select a suitable site for public parking (Kazazi Darani et al., 2018 and Farzanmanesh et al., 2010), only a few studies have used the OWA method to do so (Aliniai et al., 2015 and Jelokhani-Niaraki & Malczewski (2015a) & (2015b). For example, studies have found that the OWA technique can create a flexible scenario in the site selection process for different risk levels and criteria (Aliniai et al. 2015). They have demonstrated that employing this method for public parking site selection yields a wide range of results in terms of accuracy, dependability, and criteria priority.

The parking demand suitability of a development is determined by factors such as land use, size, and transportation conditions. High-density areas, such as commercial and business, hotels, offices, markets, schools, and religious and retail developments, are more likely to generate localized impacts. A spatial study reveals that a significant portion of property around congested streets is eligible for parking development, but parking becomes less suitable as one moves away. Most of these areas are close to recognized commercial districts and important thoroughfares.

Creating public parking can significantly address traffic issues in the study region, but it is not the only option. Non-marginal parking can also be located and developed while managing marginal parking. The MCDA approach was used to combine overlay maps of different criteria, multiplying categorized layer data by their appropriate weights in a raster calculator tool. This produced a land suitability map for parking locations, displaying the final suitability map and distribution percentage based on the intersection of all overlay maps of different criteria.

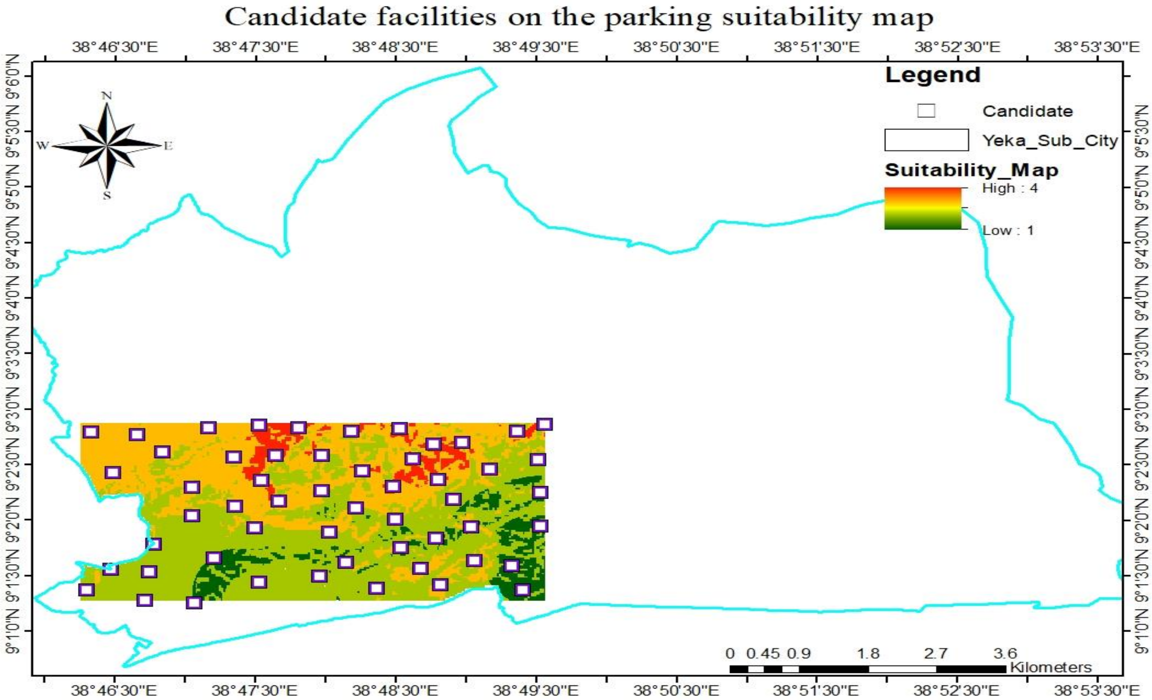

Figure 4. 24 Possible Candidate facilities on the parking suitability map.

This dissertation discussed why certain required and candidate services were not provided to meet their demands. The reasons are because it is positioned away from parking demands, on the boundary of the Yeka sub-city, as part of the Bole or Arada sub-city, and in areas where parking demands are currently met by other facilities. Figure 4.24 shows that some possible candidate facilities are situated in low-demand areas and will be unable to satisfy demand within the specified resistivity cutoff, while others are excessively close. This is a big reason why some candidates decide not to respond to any requests.

This dissertation aids parking policymakers and planners in selecting suitable candidate locations by creating an appropriateness map of parking demands. The study method helps identify optimal locations for applicants and provides a numerical comparison with other critical infrastructure elements in the sub city. It also explores the underlying geographical factors influencing parking lot concentration. The study provide a comprehensive overview of appropriate parking sites, promoting sustainable and efficient infrastructure development in the study area, and serves as a guiding beacon in urban planning complexities.

This dissertation also makes a contribution in terms of determining parking demand. It is commonly mentioned in literary evaluations and is not an easy procedure. Identify the demand ranges for the research area. Because this technique doesn't need any specific data, data collection and setup are straightforward. Even if the datasets aren't revised, validating data is still required for more accurate and reliable results. Because the weights assigned to the criteria were established by human judgment, the conclusions reached from certified data may be legitimate but not necessarily more accurate. A GIS system was used to apply many spatial analysis methodologies. It only offers temporary parking solutions. Simply identify the most in-demand parking places. Developed and developing cities can use this strategy by using more useful criteria.

In general, the study's findings are strongly connected with the selected criteria and the case study, indicating that some low-risk strategies, such as AHP and MCDA, are the most dependable approaches to selecting parking site placements. The MCDA method demonstrated various merits in this study for solving parking site selection in the Yeka sub city of Addis Ababa, but it also has a number of limitations.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The Yeka sub-city is grappling with a parking shortage due to rapid urban population growth and haphazard city construction. This dissertation research aimed to determine parking demand using GIS. Two strategies were explored: integrating the MCDM technique with GIS and conducting parking demand analysis within a GIS context. The strategy involved combining GIS and decision-making processes, using literature reviews and country guidelines to determine ideal car park locations. A spatial database of effective elements was developed and implemented in a GIS environment. GIS spatial analysis methodologies were investigated, using the AHP approach to determine criteria weight. Finally, a combination of GIS-MCDM was employed for site selection. Following data analysis, the following conclusions are drawn:

- The study introduces a method for allocating parking spaces, combining GIS and AHP techniques to optimize land resource allocation. This method is useful for dealing with extensive geographical data and identifying optimal parking spot locations. The parking Demand-Supply analysis is an effective tool for urban planning, particularly in transportation planning and management, and future modifications could help identify efficient parking spots in densely populated urban areas.
- The AHP approach was used to calculate the relative weights of the established criteria. Weights for the established criteria were calculated using pairwise comparison matrices. In this study, acceptable parking spaces were selected using TAC (Land Use), parking and Transportation criteria.
- The accessibility to main roads is the most important criterion, with a weight of 0.6472. The lowest weight is for church and mosque facilities (0.0205). Other criteria include existing parking, residential places, slope, traffic volume, taxi and bus stands, government offices, public institutions, health facilities, highways, car ownership, educational facilities, land cost, train stations, shopping malls, markets, and hotel facilities.
- Parking criteria (0.7235) received the most weight among the principal criteria, followed by transportation criteria (0.1932) and land use (TAC) criteria (0.0833). The parking sub-criterion was assessed using pairwise comparison matrices, with proximity to existing

parking (0.3835), slope (0.2466), traffic volume (0.2188), vehicle ownership (0.0787), and land cost (0.0724) obtaining the highest weights. In the analysis for the TAC (land use) sub-criterion, the highest weights from pairwise comparison matrices were determined as follows: access to residential places (0.3533), being accessible to public institutions (0.1616), accessibility to government offices (0.1759), availability to health facilities (0.1150), access to hotel facilities (0.0475), access to educational facilities (0.0762), accessibility to shopping malls and markets (0.0500), and accessibility to church and mosque facilities (0.0205). When considering the transportation sub-criterion, the study assigned the highest weights from pairwise comparison matrices as follows: access to main roads (0.6472), being accessible to taxi and bus stands and bus stations (0.1953), access to highways (0.1005), and access to train stations (0.057).

- The spatial locations of criteria and sub-criteria were determined using GIS, and density and Euclidean analysis were performed. Layer data of each criterion was incorporated into a raster calculator tool, multiplied by their weightage, to create an appropriateness map of parking spaces, highlighting the most suitable locations within Yeka sub-city. The study area, primarily in the south-west of the sub city, has high suitability for public parking, with 0.924 square kilometers (1.057%) being extremely suitable. The remaining areas are suitable, moderately suitable, less suitable, and unsuitable covers 6.972, 9.52, 1.507, and 80.945 percent of the study area. Field studies were conducted in areas with high appropriateness, resulting in consistent results

Public parking can address traffic issues in a study region, but non-marginal parking can also be developed. The MCDA approach combined overlay maps of different criteria, multiplying categorized layer data by weights in a raster calculator tool. This produced a land suitability map for parking locations, displaying the final suitability map and distribution percentage. This dissertation helps parking policymakers and planners select suitable locations by creating an appropriateness map of parking demands. It provides a numerical comparison with other critical infrastructure elements in the sub city and explores the underlying geographical factors influencing parking lot concentration. The study provides a comprehensive overview of appropriate parking sites, promoting sustainable and efficient infrastructure development and serving as a guiding beacon in urban planning complexities. It also contributes to determining parking demand, a process commonly mentioned in literary evaluations. Although the weights assigned to criteria were established by human judgment, certified data may not be more accurate. A GIS system was used to apply various spatial analysis methodologies, but it only offers temporary parking solutions. Developed and developing cities can use this strategy with more useful criteria.

5.2 Recommendation

The study includes findings, verdicts, and suggestions on proper parking lot site selection, concentrating on land use characteristics, resulting in reasonable recommendations taking numerous variables into consideration;

- The study demonstrates that GIS can handle complex decision problems, with weighting being a crucial factor. Differences in weights for criteria and sub-criteria may result in varying final maps, affecting the final decision. However, these approaches are tools to assist decision-makers, not the decision itself. The study used various variables to identify public parking locations using a GIS structure.
- The study explores the use of geographic information technology to gather data on transportation challenges, particularly car parking, and its potential to resolve complex issues like expropriation fees, emphasizing the need for early inclusion of essential characteristics in site selection methods.
- The dissertation found that the placement of various facilities is improper and does not meet standards. Even if some of the potential parking lots did not match any specifications. The study's goal is to improve user experience by lowering walking distance and boosting automobile parking near parking lots.
- The study's parking demand estimation was influenced by inconsistent certified data, highlighting the significant automobile parking issue in urban and metropolitan municipalities. To tackle this, institutions should invest in data-producing technologies, establish a sharing protocol, generate real-time data, and prevent data reproduction, resulting in more accurate results.
- The study's findings align with the chosen criteria and case study, suggesting low-risk strategies like AHP and MCDA are the most reliable methods for selecting parking site placements. The MCDA method was found to be effective in Yeka sub city of Addis Ababa, but has limitations.

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