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Research Article

Modeling the Impact of Urban Land Use Characteristics on Road Network Accessibility in a Case Study of Addis Ababa City

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Rapid urbanization in emerging nations such as Ethiopia encourages participants in the area to consider the sustainability and balanced growth of metropolitan centers from a variety of angles and to offer suitable solutions. This study aims to comprehend how urban land use influences the efficiency and connection of road networks, which in turn affects how accessible different parts of the city are, to determine the influencing factors and critical indicators that enable a systematic categorization of subcity accessibility from the perspectives of urban land use. Geographic information system (GIS) techniques are used to gather and analyze precise geographical data on road networks, land use patterns, and other pertinent properties. In addition, a regression model is created to measure the effect of land use features on the accessibility of the road network. The primary questionnaire data are used to estimate the current situation of road accessibility and are used in the study validation process. This research has incorporated qualitative and quantitative approaches to sustainability. The findings imply that residential areas are 90% significant in making transport along the city, and 98% of the accessibility of the road network is dependent on land use features, including road density and subcity areas. Among the subcities, Bole, Kirkos, and Arada have 87% road network accessibility and better access to public transportation. Overall, these techniques emphasize the value of spatial analytic tools in planning procedures to better comprehend and control the intricate relationships between transportation and land use dynamics and to assist in the sustainable design and growth of cities.

1. Introduction

The development of road transportation networks is vital for countries, especially in developing regions, where road transportation has increased significantly in recent years. Road networks are also essential components of human settlements, such as cities, towns, and villages, as they provide a buffer against pollution and traffic congestion and facilitate economic growth.

Road transportation networks are strongly influenced by the availability of land, as they are interrelated. However, land is scarce and in high demand for various economic activities, including road infrastructure. Land use is scarce due to the high levels of private vehicle ownership, rapid economic growth, urbanization of metropolitan areas, population growth, and increases in the availability and output of various modes of transportation [1]. The city land divided into municipal services, social services, and residences are grouped into functional zones, with high-density mixed dwelling, medium-density mixed residence, and low-density mixed residence sectors accounting for 67.5% of the urban green surface, as stated by the authors in references [2, 3].

Urbanization in sub-Saharan Africa is a critical issue due to population growth, which affects the land use patterns and transportation, services, housing, and job opportunities [4]. Ethiopia has a low urbanization rate, with only 18% of its population living in urban areas. In 2022, Addis Ababa's population increased by 4.43%, and the Ministry of Transport Ethiopia reported 1,200,110 registered vehicles, with 630,440 registered vehicles in Addis Ababa [5–7].

Transportation network design is influenced by development patterns on land surfaces, influencing infrastructure location, type, and characteristics of roads and buildings [8]. Urban transportation faces traffic congestion due to the growth of the road network, necessitating a sustainable approach to improve efficiency and reduce costs. According to the AACRA, the city's road network length was 6,715 kilometers in 2022, up from 6,715 kilometers in 2022. Asphalt covered 4,873 km or approximately 72% of the city's roads.

As reported by the authors in reference [9], urban transport planners and road authorities collaborate to develop integrated strategies for land use management, addressing the complex interaction between transportation infrastructure and land use characteristics. This collaboration is crucial for social, economic, and environmental sustainability in today's urban environment, as stated by the authors in reference [10]. Moreover, the existing lands have limitations from the developer's perspective. This indicates a gap between the demand and supply of land [4].

As a result, this paper aims to assess and model the influence of urban land use and road network accessibility in Addis Ababa city and propose a solution to this problem.

1.1. Description of the Case Study

1.1.1. Location. The capital city of Ethiopia, Addis Ababa, has a reputation as the political capital of Africa due to its role in the history, diplomacy, and politics of the continent. It is situated in the Horn of Africa, with coordinates 9°1′48″ and 38°44′24″ east. It lies on a plateau of mountain ranges, at an average elevation of 2355 m above sea level, in the middle of the country. Its landscape varies from flat to hilly, with several river stream valleys and relatively high grades. The city has a total land area of approximately 526.86 km^2, consisting of 11 subcities for administrative purposes, as shown in Figure 1, and 131 TAZs. The spatial growth of cities is mainly guided by topography and road network expansion. The southern, eastern, and southwestern regions of the city experienced the greatest spatial expansion. The ring road development resulted in new settlements in the southeastern area of the city. The city has a high demand for transport, and it is difficult to access it due to its changing land characteristics and rapid economic growth and change, which enhances passengers mobility.

1.1.2. Population Distribution of Addis Ababa. Transport activity is largely influenced by demographic status, so this important component needs to be examined to understand how and why people travel. Therefore, this study covered the population and land use characteristics of the city. Table 1 shows the projected population of Addis Ababa city for 2023.

2. Materials and Methods

2.1. Data Collection. This study used a methodical technique that dissected each target into its component pieces to identify the data. The methodology employed for this study consisted of four main steps: data identification, data collection, data analysis, and data presentation.

In Addis Ababa, primary data were collected through interviews with road stakeholders, including passengers and vehicle owners. This study aimed to understand the current network accessibility practices, transportation system standards, and areas lacking infrastructure. The interviews also highlighted subcities with poor land use management, aided by visual inspection and site observation.

The Addis Ababa Plan and Development Commission and Addis Ababa City Roads Authority have provided secondary data on the relationship between road networks and land use in the city. These data include current and future road plan maps, land use maps, satellite images, and open street maps from Google Maps and Google Earth.

2.2. Sampling Technique and Sample Size. The sampling technique used in this study was cluster sampling, which is a nonprobability sampling technique. A random sample from each cluster was selected and included in the final sample [11]. The selection of a simple random sample (SRS) method for our study in Addis Ababa, which spans an area of 529 km^2 and has a population exceeding 5 million, was driven by specific considerations. The city's extensive size and dense population present unique challenges, such as significant traffic congestion and varying travel demands across its 11 subcities. These factors necessitate a sampling method that can provide an unbiased representation of the entire city's conditions. The questions were taken from all subcities that had a high population density in road traffic and land use. The sample size was determined using the formula described by the authors in reference [12] as shown in the following equation:

$$\text{Sample size} = \left((Z\text{-Score}Z\text{ - Score})^2 \right) * \left(\text{Std Dev} * \left(\frac{1\text{ - Std Dev}}{\text{Margin of error}^2} \right) \right). \quad (1)$$

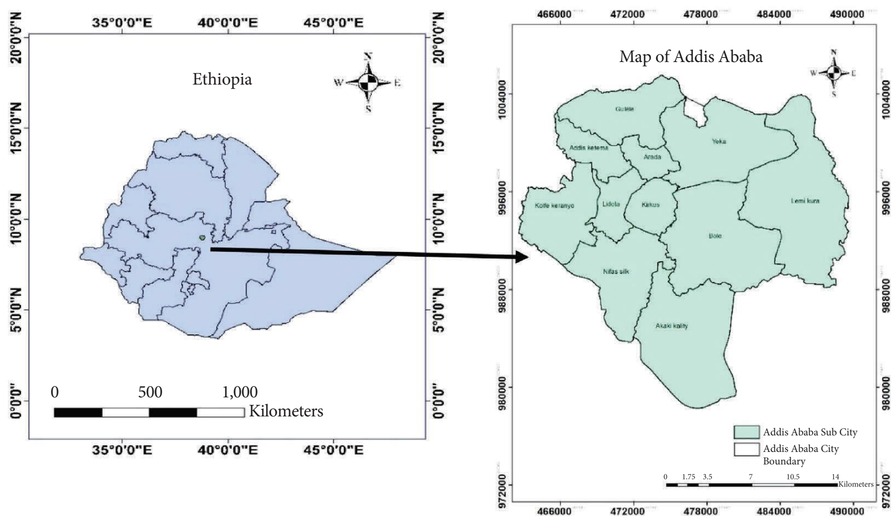


Figure 1: Location of the map of the study area.

Table 1: Population estimates of Addis Ababa city in 2023 (source: Central Statistics Agency of Ethiopia, 2023).

Year	Subcity	Size of population	Area (km^2)	Density
2023	Addis Ketema	182,800	7.41	24,669
	Akaki Kality	515,300	118.08	4,364
	Arada	111,400	9.91	11,241
	Bole	451,100	95.08	4,744
	Gulele	237,800	30.18	7,879
	Kirkos	170,000	14.62	11,628
	Kolfe Keranio	375,000	61.25	6,122
	Lemi Kura	645,500	63.87	10,106
	Lideta	164,300	9.18	17,898
	Yeka	427,700	48.98	8,732
	Nifas Silk-Lafto	446,800	68.3	6,542
Total in Addis Ababa		3,727,700	526.86	7,075

Assuming a 90% confidence level, 0.6 standard deviations, and a margin of error (confidence interval) of ±4%. Then, we have

Sample size $= ((1.64)^2 \times 0.6(1 - 0.6))/(0.04)^2$,

$=(2.68 \times 0.24)/0.0016$,

$=0.645/0.0016$,

$=403.44$.

Therefore, 404 respondents were needed for the study, and this analysis and modeling were performed.

2.3. Materials Used for This Study. SPSS, a widely used statistical package, was utilized for regression analyses, Microsoft Excel, a versatile spreadsheet application, was utilized for large datasets, and ArcGIS, a powerful tool for geospatial data visualization and interpretation, was employed for regional planning applications.

2.4. Method of Data Analysis. Figure 2 Illustrates the data analysis steps that were followed in this study.

2.4.1. Land Use Weight Calculation. The city land-use map reveals the spatial context of mobility by showing the location and intensity of different land uses. The map categorizes the land into twelve main types of use, as illustrated in Figure 3.

We obtained the land use database file from the Addis Ababa City Plan and Development Commission and used ArcGIS to create a spatial and statistical representation of the land uses. To extract the study's land use attributes from the city's land use map, we followed these steps:

(i) The city land-use shape file and the subcity boundary were added to the GIS program.

(ii) The city land use map was updated by removing the land use attributes that were not relevant to this study.

(iii) The coverage area of each land use type for each subcity was calculated by using a GIS-attribute database.

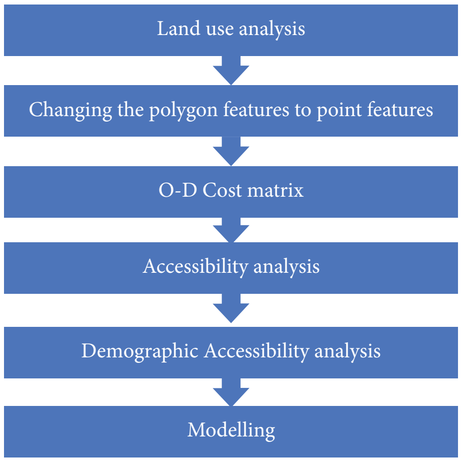


Figure 2: Analysis procedure.

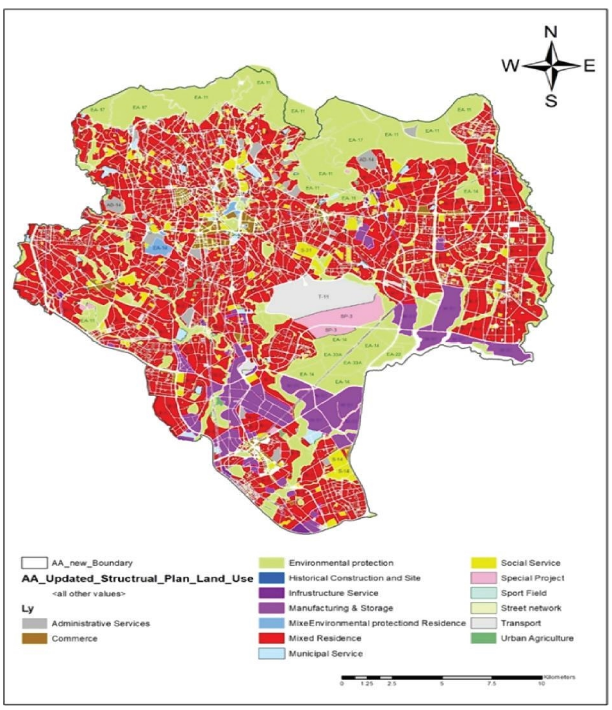


Figure 3: Land use map.

(iv) The data were grouped and exported by attribute and subcity identities to an Excel spreadsheet for further analysis.

This study applies an equation that Schaffer [13] originally formulated and Liu and Zhou [14] later adapted for land use purposes to assign weights to different land use types. Equation (2) shows how this equation can be used as a proxy for land use [15].

The following equation shows the land use weight type [15]:

$$\text{Lki} = \frac{\text{Ski}/\sum_{i=1}^{m}\text{Ski}}{\text{Si}/\sum_{i=1}^{m}\text{Si}}, \qquad (2)$$

where Lki is the land use weight type k characteristics in subcity i, Ski is the land use size/area type k characteristics in subcity i, Si is the total land size/area subcity, n is the number of significant characteristics in the area, m is the number of subcity in the study area, $\sum$Ski is the summation of selected characteristics area in the subcity, and $\sum$Si is the total land size of the study area.

The higher the value of Lki is, the more significant the land use type is. LKI also helps to determine whether the urban sprawl in each subdivision is consistent with that in the other subdivisions. Large variations in the Lki values indicate that urban sprawl is uneven within the city.

2.4.2. Changing the Polygon Features to Point Features. The first step is to identify the functional centers of the neighborhood, which are the destinations for travel. The following steps are used to locate these centers using the land use geodatabase and the data collection methods:

(1) The land uses that are relevant to the study are selected from the spatial geography of land uses.

(2) The database tables of land use maps that contained GPS coordinates of public facilities were added.

(3) The center points of the densest areas for each land use type were identified by measuring and inspecting them and obtaining their X- and Y-coordinate GPS coordinates.

(4) ArcGIS was used to display the X and Y coordinates of all public facilities on a map.

(5) The most central and interactive points for each land use type were chosen and exported as a single shapefile.

2.4.3. Origin Destination Cost Matrix Calculation. The next step is to calculate the travel time and distance between the origin and the destination, which are the center points of the resident areas and the functional centers, respectively. Google Earth Pro is used to perform this calculation with the following steps:

(1) The easting and northing coordinates of the origin point are entered on Google Earth.

(2) The easting and northing coordinates of the destination point are entered on Google Earth.

(3) Google Earth will display the travel time and distance between two points for three different modes of transportation.

2.4.4. Accessibility Analysis. Accessibility is the ability of a person or a group of people to participate in certain activities in each location. It is influenced by the mobility of the person or group and the geographic distance between the location and the person's starting point. This study uses the gravity/potential accessibility formula developed by Geurs and van Wee [16] to measure accessibility. The following equation shows the gravity/potential accessibility formula for measuring accessibility measure as:

$$\text{Ai} = \sum \text{Dj} * e\beta * \text{Cij}, \tag{3}$$

where Ai is the summation of the accessibility in zone i to all opportunities D in zone j, β is the cost sensitivity parameter, Cij is the cost of travel (distance or time) between subcities i and j, i is the initial point of travel (origin), and j is the end point of travel (destination).

The Hansen formula, a sensitive measure of accessibility, considers factors such as distance and travel time. A higher β value indicates greater accessibility, while a lower β value indicates less accessibility. This study uses a 2 β value to calculate accessibility by measuring travel time and distance between land use types in subcity areas.

2.4.5. Demographic Accessibility Analysis. The next step is to calculate demographic accessibility, which reflects how population density relates to land use type. This is performed by multiplying the accessibility of each land use type by the population density of each subcity. The following equation shows the formula for calculating demographic accessibility:

$$\text{DA} = \sum (\text{Land attribute accessibility} * \text{Population density}), \tag{4}$$

where DA is the summation of demographic accessibility to all subcities.

2.4.6. Modeling Technique. Statistical methods are employed in models to simulate real-world phenomena, such as road network accessibility, considering factors such as travel time, distance, mode choices, and network connectivity.

Multiple regression modeling is employed to analyze the relationships between dependent variables and independent variables, providing a quantitative analysis of the factors influencing these relationships and predicting their strengths and directions. The accessibility of road networks is assessed using a time-based model and a regression model, both of which were developed using MS Excel and IBM SPSS, to account for temporal variations in travel patterns.

3. Results

3.1. Urban Land Use Weights. This study uses Addis Ababa city, the capital of Ethiopia, as a case example. Figure 1 shows the location of the city in the country. The researcher analyzed the city's land-use map and identified nine major land-use features that are relevant to the proposed research. These include administrative services, commerce, mixed residence, municipal services, education, health centers, sports venues, leisure spaces, and road networks as shown in Figure 4. The researcher then calculates the land use weights for each of these features by using the following equation, as explained earlier:

$$\text{Lki} = \frac{\text{Ski}/\sum_{i=1}^{m}\text{Ski}}{\text{Si}/\sum_{i=1}^{m}\text{Si}}, \tag{5}$$

where Lki is the land use weight type k characteristic in subcity i, Ski is the land use size/area type k characteristic in subcity i, Si is the total land size/area subcity, n is the number of significant characteristics in the area, m is the number of subcity in the study area, $\sum$Ski is the summation of selected characteristic areas in the subcity, and $\sum$Si is the total land size of the study area, which is 526 km^2.

The land use weight at which Addis Ketema was administered was calculated as follows:

$$\text{Lki} = \frac{\text{Area of admin in Addis Ketema/Area of selected attributes in Addis Ketema}}{\text{the total area of Addis ketema/total land size of A.Acity}}$$

$$\text{Lki} = \frac{10.74/1546.97}{1867.00/52600}, \tag{6}$$

where LKI = 0.20 is the land use weight of admin in Addis Ketema. This technique is used for all land attributes in all subcities.

3.2. Changing the Polygon Features to Point Features. The study also selected the most suitable and interactive locations for each type of land use and saved them as a single shapefile. This requires choosing one location point for each land use feature in each municipal subcity. Since there are 11 municipal subcities and eight land use features, the total number of key locations is 86. However, two subcities do not have leisure spaces, so the actual number of key locations is 88 − 2 = 86. Figure 5 shows the key locations for each land use feature in each subcity.

3.3. Origin Destination Cost Matrix. The first step is to locate each point in ArcGIS according to its north and east coordinates, as shown in Figure 6. Then, using the residential point as a reference point, the corresponding locations on Google Maps and Google Earth are found by entering the same coordinates on the Addis Ababa map. This allows us to compare the routes from the origin to the destination for each point (land use feature).

Google Maps provide the directions (routes) for traveling from one point to another using the city's existing road network as shown in Figure 7. The map displays three routes with different travel times and distances. The travel conditions vary depending on the level of traffic congestion on the roads: no congestion, slight congestion, or severe congestion.

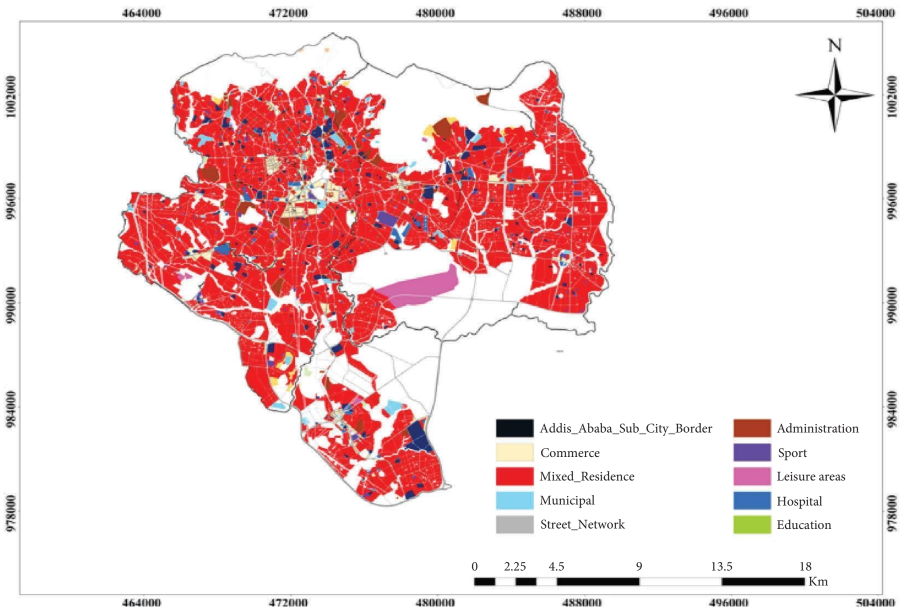


Figure 4: Spatial representation of important land uses in Addis Ababa city.

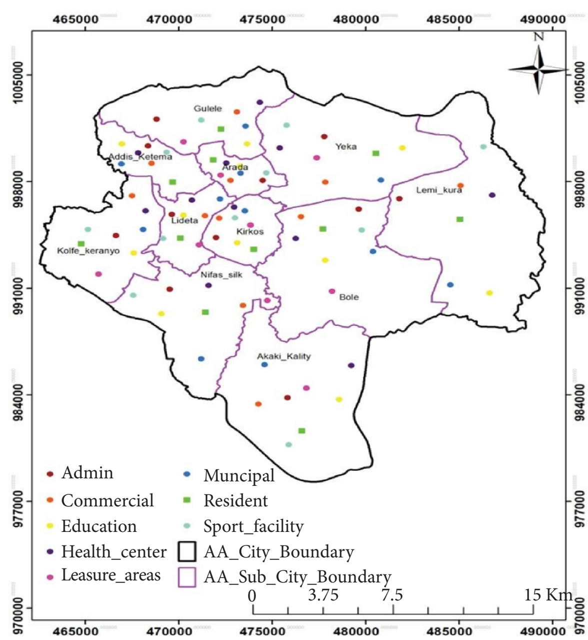


Figure 5: Critical center points of neighborhood land use.

This study measures accessibility based on the worst-case scenario, where the routes are fully occupied, as listed in Table 2. The technique uses the residential areas of each subcity as the origin points and calculates the accessibility for all land attributes across all subcities.

This measurement was performed for all subcities.

The travel time and distance are directly proportional during a voyage. This means that the longer the distance is, the more time it takes to travel. This is because the speed of travel is constant or slightly variable, while the distance covered increases.

This study depends on the journey distance and time, as Figure 8 illustrates. The route is at its maximum capacity and has a long travel time. The time increases with distance, but the distance stays constant at the same locations, while the time varies.

3.4. Accessibility Measurement. Accessibility was measured by using the following equation:

$$\mathrm{Ai} = \sum \mathrm{Dj} * e\beta * \mathrm{Cij}, \quad (7)$$

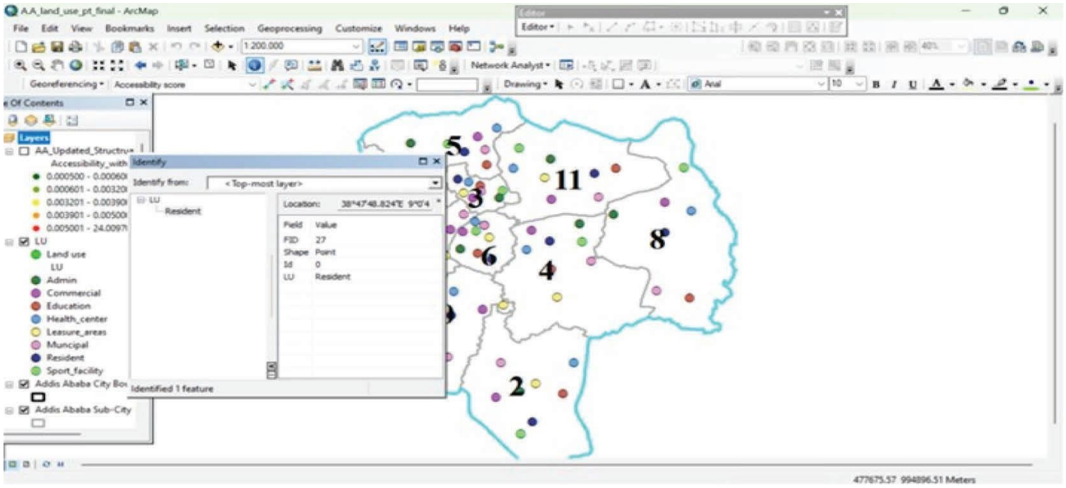


Figure 6: Locations of the resident areas.

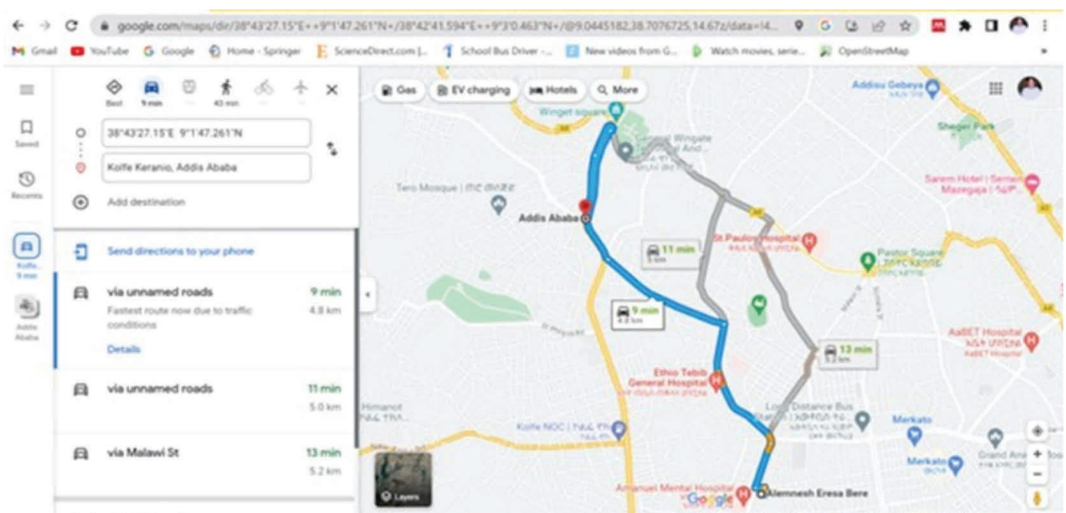


Figure 7: Travel distance and travel time.

Table 2: Distance and travel time for Addis Ketema resident areas to all subcity land attributes.

Subcity	Land use	Travel distance (km)	Travel time (min)
Addis Ketema	Resident	0	0
	Admin	3.3	11
	Commercial	2.4	11
	Municipal	4.1	19
	Education	7	20
	Health center	4.1	16
	Sport facility	2.5	11
	Leisure areas	0	0
Addis Ketema resident to Arada	Resident	4.4	15
	Admin	7.1	19
	Commercial	3.9	13
	Municipal	5.3	18
	Education	4.6	15
	Health center	4.3	16
	Sport facility	7.4	21
	Leisure areas	3.2	11

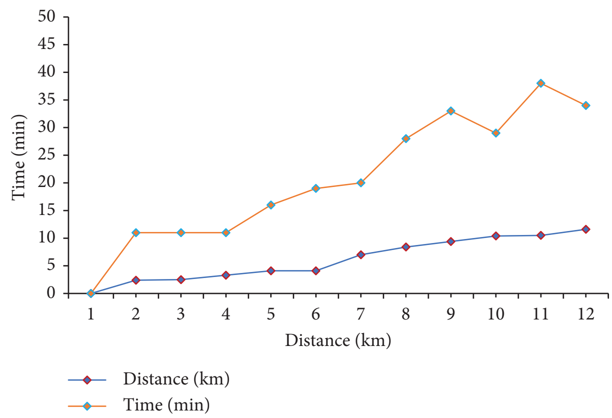


Figure 8: Relation between travel distance and travel time.

where Ai is the summation of the accessibility in zone i to all opportunities D in zone j, β is the cost sensitivity parameter (2 is the distance accessibility measurement and 1 is the time accessibility measurement), Cij is the cost of travel (time) between subcities i and j, i is the initial point of travel (origin), j is the end point of travel (destination), and Ai for the first case is as follows:

$\mathrm{Ai} = \sum \mathrm{Dj}\ e^{\beta \mathrm{cilj}}$

$\mathrm{Ai} = e^{11} = 1.67017E - 05$

$\sum \mathrm{Ai} = 3.000411734.$

This study uses two cost parameters, travel time and travel distance, as shown in Table 3. Accessibility is estimated for both cases, but this study focuses on accessibility based on time. The time function of road accessibility measures how easy or hard it is to reach a certain area by road at different times of the day. It considers factors such as traffic volume, road conditions, and peak hours. For example, an area may be easy to access during off-peak times when the traffic is low but hard to access during rush hour when the traffic is high. The time function in Figure 9 shows how the accessibility of the area changes with travel time. The time function can also predict future changes in road accessibility based on expected changes in traffic patterns or road conditions. This information can help people plan travel routes or choose the location of businesses or other facilities.

Road accessibility is more accurate and realistic when it is measured by time rather than distance. Distance alone does not consider factors that significantly affect travel times, such as traffic congestion, speed limits, and road conditions. Businesses and organizations can use a travel time function to plan routes, optimize their logistics, and schedule their transportation more efficiently. This can lead to higher productivity, lower costs, and better customer service. Moreover, the travel time function can help identify areas where infrastructure improvements are needed to enhance accessibility and reduce travel distances.

The spatial distribution analysis results reveal a comprehensive understanding of the city's land use accessibility, highlighting the importance and sustainability of the various land use types shown in Figures 10(a) and 10(b) using ArcGIS.

3.5. Demographic Accessibility Analysis. Population density, which is the number of people living in a specific area, significantly affects the accessibility of the road network. The transport demand increases with the population of an area. This causes more traffic congestion and longer travel times, especially during peak hours. This study compares the accessibility of land use types and subcities under two scenarios: with and without population density. The scenarios show the difference in accessibility based on the population effect.

Figure 11 shows that demographic accessibility and population density are directly proportional, with higher density indicating lower road accessibility. However, some areas have better road accessibility despite higher population density, as indicated by slight deviations from the linear line.

High population density and limited road network capacity are major challenges for road accessibility in Addis Ababa. As Figure 12 shows, the subcities of Addis Ketema and Lideta have the highest population densities of 24669.37 and 17897.60, respectively, which means that they have a greater demand for transportation options and a larger road system. Akaki Kality, despite its low population density of 4363.99, faces traffic congestion and long travel times due to inadequate road networks and a lack of public transit alternatives. Poor quality of transport affects quality of life, economic development, and displacement, necessitating the consideration of transport planners.

From the demographic accessibility measurement equation (10), we have

$$\mathrm{DA} = \sum (\text{Land attribute accessibility} * \text{Population density}),$$
$$\mathrm{DA}\,(\text{Bole sub-city}) = \sum (3 * 4744.43) = 14233.28. \tag{8}$$

Table 3: Accessibility of each land attribute in Addis Ketema to all subcities.

Subcity	Land use LU	Accessibility by distance Ai	Accessibility by time Ai
Addis Ketema	Resident	1	1
	Admin	0.001360368	$1.67017E-05$
	Commercial	0.008229747	$1.67017E-05$
	Municipal	0.000274654	$5.6028E-09$
	Education	$8.31529E-07$	$2.06115E-09$
	Health center	0.000274654	$1.12535E-07$
	Sport facility	0.006737947	$1.67017E-05$
	Leisure areas	1	1
Addis Ketema resident to Arada	Resident	0.000150733	$3.05902E-07$
	Admin	$6.80798E-07$	$5.6028E-09$
	Commercial	0.000409735	$2.26033E-06$
	Municipal	$2.4916E-05$	$1.523E-08$
	Education	0.000101039	$3.05902E-07$
	Health center	0.000184106	$1.12535E-07$
	Sport facility	$3.7363E-07$	$7.58256E-10$
	Leisure areas	0.001661557	$1.67017E-05$

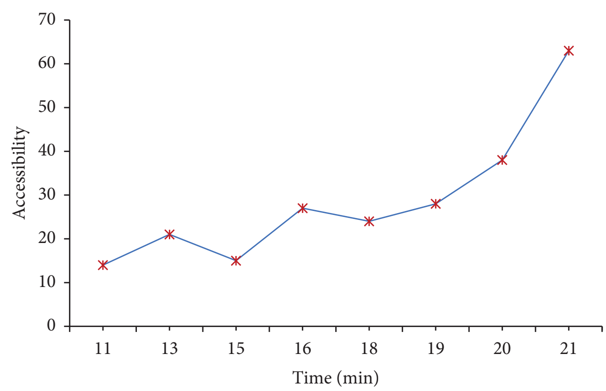
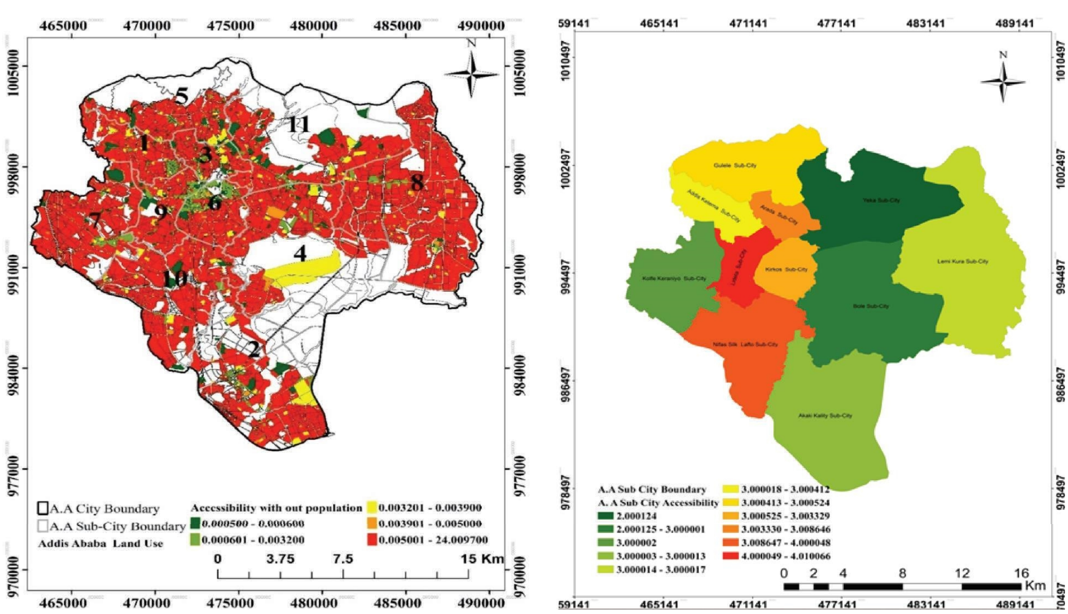


Figure 9: Relation between accessibility and travel time.



(a) (b)

Figure 10: Accessibility at the land attribute level (a) and accessibility value at the subcity level (b).

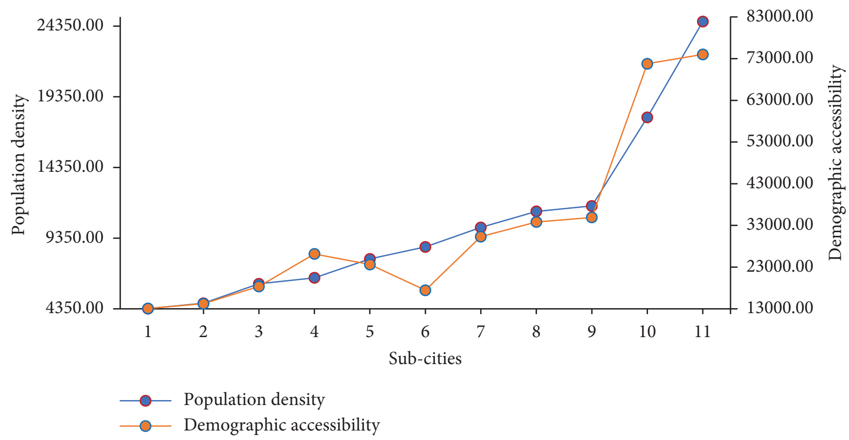


Figure 11: Relation between population density and demographic accessibility.

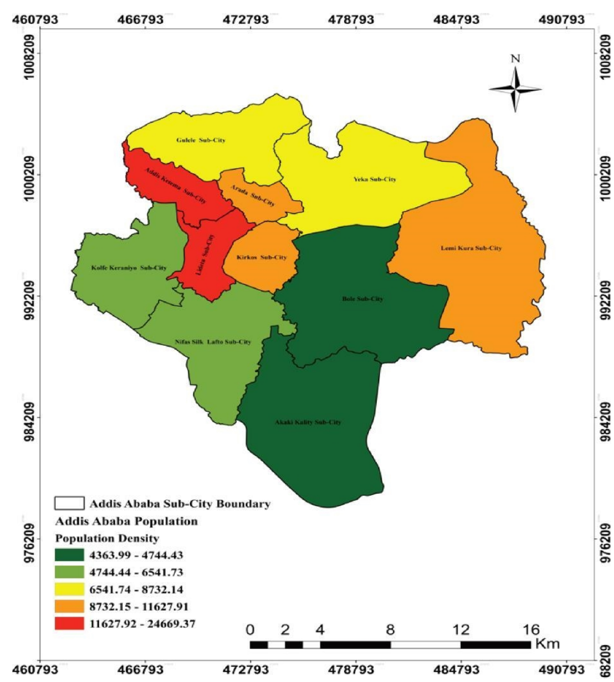


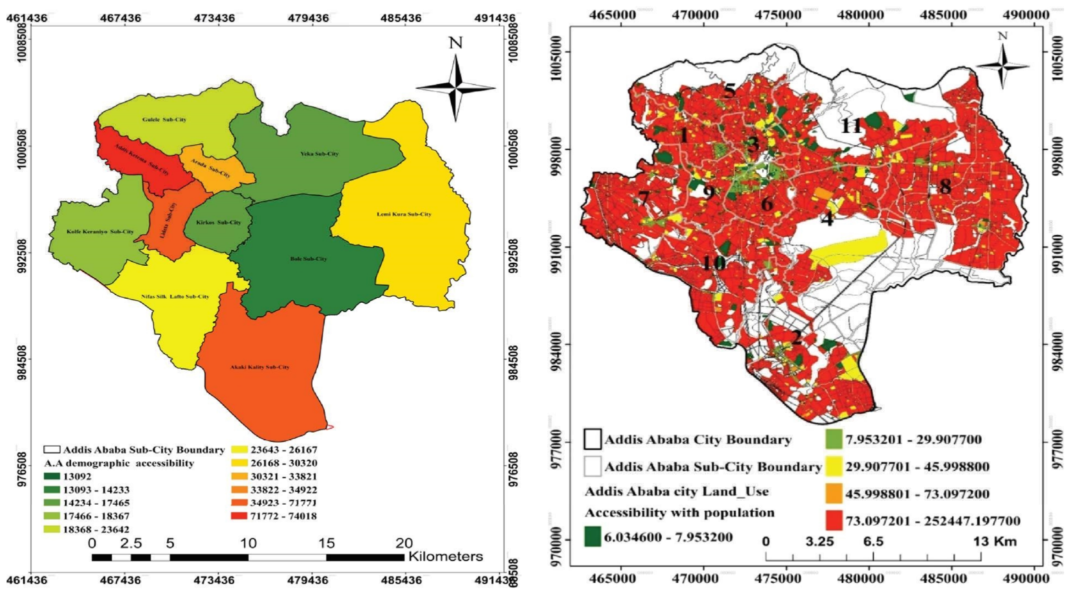
Figure 12: Population-density distribution at the subcity level.

Figure 13(b) shows that the numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 represent the subcities of Addis Ketema, Akaki Kality, Arada, Bole, Gulele, Kirkos, Kolfe, Lemi Kura, Lideta, Nifas Silk and Yeka, respectively.

3.6. Descriptive Analysis. The sample from Addis Ababa city was selected by cluster sampling to form subcity groups because of its wide geographical dispersion. With the subcity as a cluster, the respondents are selected using simple random sampling to address the questions. However, this cluster sampling does not fully represent the total population of the city.

A total of 37.5% of the respondents were male, and 62.5% were female, with females dominating in city areas. The majority of participants were aged between 26 and 35, with 25.56% aged 36 and 45. The percentages of patients aged 18–25, 46–55, and ≥56 years were 4.26% and 6.81%, respectively, for each age group, as shown in Table 4. Among the respondents, 107 were students (30.39%), 79 were personal workers (22.44%), 37 (10.51) were government workers, and the remaining 129 (36.64%) were job seekers in accordance with the working conditions of the workers. According to the respondents' monthly income, 115 (32.67%) received up to 3000 Birr, 92 (26.13%) received 3001–10,000 Birr, 75 (21.30%) received 6001–10,000 Birr, 53 (15.05%) received 1000–12,000 Birr, 12 (3.40%) received 2000–4000 Birr, and 5 (1.42%) received more than 40000 Birr.

3.7. Multiple Regression Analysis. The strength of the relationship between the independent and dependent variables in multiple regressions is measured by the correlation coefficient, which is expressed as the adjusted R-squared. It



(a) (b)

Figure 13: Demographic accessibility (a) and land use characteristics accessibility in Addis Ababa (b).

Table 4: Sociodemographic characteristics of the respondents.

S. No	Demographic variable	Category	Frequency	Percentage (%)
1	Sex	Male	132	37.5
		Female	220	62.5
		Total	352	100.00
2	Age	Under 18	24	6.81
		18–25	70	19.88
		26–35	130	36.93
		36–45	90	25.56
		46–55	23	6.53
		Over 56	15	4.26
		Total	352	100.00
3	Working condition	Student	107	30.39
		Personal work	79	22.44
		Government	37	10.51
		Job seeker	129	36.64
		Total	352	100.00
4	Monthly income	Up to 3000 Birr	115	32.67
		3001–6000 Birr	92	26.13
		6001–10000 Birr	75	21.30
		10001–20000 Birr	53	15.05
		20001–40000 Birr	12	3.40
		More than 40000 Birr	5	1.42
		Total	352	100.00

shows the percentage of the dependent variable's total volatility that the independent variables explain using the coefficient of determination (R). The multiple correlation coefficient of adjusted R^2 in this study measures the strength of the association between the three independent (predictor) factors (traffic congestion in the study queue, trip delay, and travel time) and the dependent variable Y (road network/demographic accessibility). This tool was developed using Pak, a primary data analysis tool in SPSS.

The adjusted R-square was used to quantify the variance in the dependent variable (road construction delay) that was anticipated from the independent variables (traffic congestion in the study queue, on-trip delay, and travel time). It evaluated the degree to which the data and explanatory factors agreed to explain the variations in operational performance.

The MR model is used to predict the demographic accessibility using primary data as follows:

$$Y = b + b1X1 + b2X2 + b3X3, \tag{9}$$

where Y is the dependent variable (demographic accessibility) and $X1$, $X2$, and $X3$ are the independent variables. The term b is the coefficient of the intercept, whereas $b1$, $b2$, and $b3$ are the coefficients of the independent variables. The independent variables are those parameters described, and the following results are obtained and summarized from the SPPS data analysis tool Pak.

The coefficients in Table 5 are substituted in equation (4) and the following MLR model equation was developed:

$$Y = b + b1X1 + b2X2 + b3X3, \tag{10}$$

where DA is the demographic accessibility, TC is the traffic congestion on the study line, DT is the delay on the trip, and TT is the travel time on the study line.

3.8. Study Validation (Correlation of Primary Data with Secondary Data). ArcGIS was used in a study in Addis Ababa to assess the impact of urban land use characteristics on road network accessibility. The study uses primary data collected through questionnaires and secondary data from city offices and authorities, processed using ArcGIS, QGIS, and AutoCAD, to represent geographic features such as roads, public transport routes, land use, and administrative borders. Figure 14 shows the accessibility values that gain from the primary and the secondary data in the city. The figure addresses the two data linearity relations and how they are validated.

Figure 15 compares the primary and secondary accessibility ratings for 11 subcities of Addis Ababa. The city's urban planning and development are crucial, as secondary data accessibility is more prevalent in subcities with high primary data accessibility. Kirkos ranks first, indicating factors affecting residents' use of roadways. The Gulele subcity intersects these lines, indicating equal accessibility ratings, highlighting the importance of integrating primary and secondary data for effective planning.

4. Discussion

4.1. Land Use Weight. Table 6 shows that the largest proportion of land in a city is occupied by residential areas, which are the dominant land use type in Addis Ababa in terms of land area which covers 82.22% of the land (Figure 4). However, urban sprawl, the uneven distribution of growth and development across different areas, *c* has both positive and negative effects on a city's economic, environmental, and social aspects. This uneven distribution can lead to pollution and social instability.

The residential area also reflects economic inflation and the rising cost-of-living index in the city, as shown in Figure 4. The commercial center is the second largest land use feature in the city, with a weight of 10.82. The other land use features have much lower weights than residential and commercial areas. The health centers and sports areas have the lowest weights in the city, indicating that they are neglected by the government and other stakeholders. This is a problem for the city's well-being and development.

4.2. Accessibility

(1) Residential land use: the road network plays a crucial role in promoting a sustainable community by ensuring accessibility for residents. By analyzing traffic patterns and addressing safety issues, the road network improved, attracting more people and businesses and ultimately fostering a more resilient community which is also exhibited in [17] study China. Table 7 indicates that residential zones have high accessibility scores (11.0002) and demographic accessibility (113928) shown in Table 8 but rank last out of all land uses. Improving road network accessibility could attract more people and businesses, supporting a more resilient and sustainable community which is shown in the study of [15].

(2) Commercial land use: Addis Ketema, a central business district, is known for its accessibility, with commercial land covering 3.08% of the city. This land, including Mixed Commercial, is the third largest in the city. The road network's design considers local traffic patterns, population density, and transit demand to maximize accessibility while reducing congestion also seen in the study of [18]. By utilizing technology such as intelligent transportation systems and traffic modeling software, Addis Ketema can optimize traffic flow and reduce congestion.

(3) Municipal land uses: the city's municipal land, covering 2.39% of total land, is the second most accessible area, with a demographic accessibility score of 6.1. This prioritizes sectors such as the festival site, civic center, fire and emergency service, green cemetery, and slaughterhouse, which require effective transportation infrastructure for convenient access. This investment promotes economic growth and prosperity.

(4) Educational land use: accessibility to education is a crucial aspect of urban planning, with transportation infrastructure playing a significant role in making land accessible for all community members, despite the limited connectivity of some educational locations, as shown in Figure 5. Educational areas should be prioritized to ensure equal access to education, regardless of socioeconomic status. Investing in transit infrastructure can improve attendance rates and academic performance, demonstrating a city's commitment to a more equitable society.

(5) Administrative land use: the Woreda administration, along with other government institutions, the city administration, and intergovernmental institutions, is the most accessible land use in the city. The road network, designed for government facilities and services, connects administrative areas with public transportation, reducing traffic congestion and improving city mobility. However, this affects other land use types, such as residential or commercial areas.

Table 5: Coefficients of independent variables.

Model		Unstandardized coefficients		Standardized coefficients
		B	Std. Error	Beta
1	(Constant)	2.304	0.829	
	Traffic congestion in the study line	−0.132	0.162	−0.257
	Delay of on-trip	−1.152	0.444	1.186
	The travel time in the study line	−1.051	0.830	−0.525

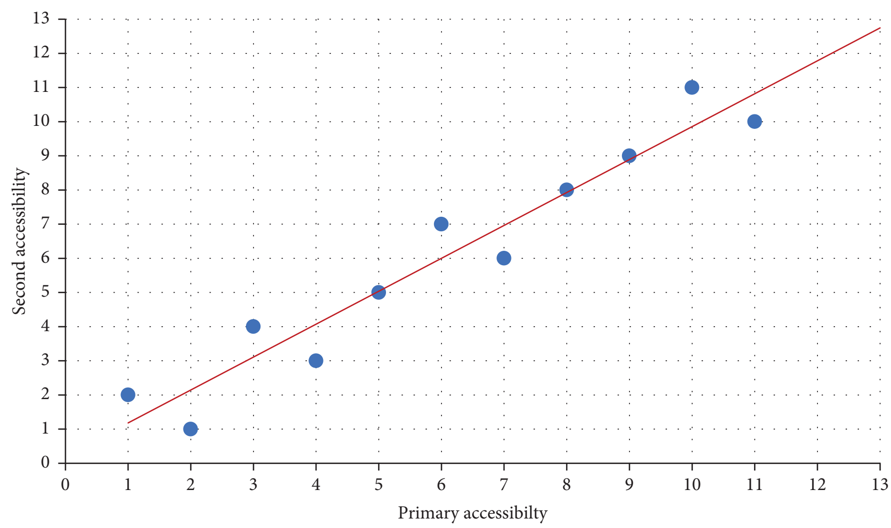


Figure 14: Relation between primary data and secondary data results (the accessibility, defined as the whole number in terms of /1000).

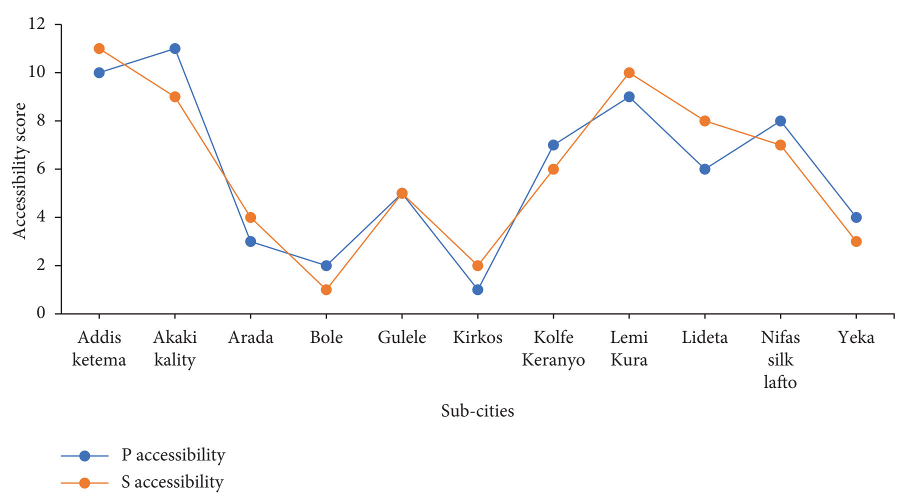


Figure 15: Study validation.

(6) Health land use: health land in Addis Ababa, covering 1.07% of the city's total land use, includes hospitals and specialized hospitals. Strategically located throughout the city, health land is the fourth most accessible area, with a demographic accessibility score of 40.7462. This accessibility value indicates good access to roads and transportation, ensuring the availability of essential facilities in the city.

(7) Sports land use: The accessibility of sports facilities, such as Woreda sports field, sports center, subcity-level stadium, and city stadiums, is a concern due to their proximity to recreational land uses. The demographic accessibility score is 73.1, ranking sixth or third-lowest among all land use types. This inaccessibility may cause traffic congestion and discourage people from using public transport, affecting the sustainability and efficiency of the transport

Table 6: The land use weights were calculated via statistical and spatial decomposition.

	Land use weight (Lki)							
Subcity	Admin	Commerce	Resident	Municipal	Education	Hospital	Sport	Luxury
Addis Ketema	0.20	1.28	21.29	0.63	1.11	0.18	0.27	0.00
Akaki Kality	0.13	0.19	1.91	0.16	0.40	0.05	0.03	0.03
Arada	3.27	2.03	33.33	2.98	3.27	0.66	0.21	0.17
Bole	0.10	0.06	5.35	0.08	0.20	0.03	0.18	1.37
Gulele	0.61	0.31	10.17	0.44	0.89	0.16	0.11	0.09
Kirkos	1.76	5.48	20.22	0.66	0.89	0.32	0.36	0.17
Kolfe Keranio	0.29	0.20	8.65	0.10	0.09	0.14	0.04	0.07
Lemi Kura	0.01	0.08	5.55	0.08	0.09	0.06	0.06	0.00
Lideta	2.41	0.92	22.49	0.31	1.12	1.23	0.12	2.56
Nifas Silk-Lafto	0.17	0.21	2.53	0.33	0.35	0.03	0.09	0.01
Yeka	0.43	0.06	3.63	0.21	0.21	0.03	0.02	0.01

Table 7: Accessibility values at the land attribute level.

Land attribute	Accessibility value
Admin	0.0005
Municipal	0.0006
Commercial	0.0026
Hospital	0.0032
Education	0.0039
Sport facility	0.0050
Mixed residence	11.0002
Leisure areas	24.0097

Table 8: Demographic accessibility at the land attribute level.

Number	Land attribute	Demographic accessibility
1	Admin	7.9532
2	Municipal	6.0346
3	Commercial	29.9077
4	Hospital	40.7462
5	Education	45.9988
6	Sport facility	73.0972
7	Mixed residence	113928.1815
8	Leisure areas	252447.1977

system. Therefore, it is crucial to improve the accessibility of sports facilities to improve the overall transport experience.

(8) Leisure land use: Access to recreational areas is crucial for a city's economy, as they are often the least accessible, leading to traffic congestion, reduced efficiency, and increased fuel consumption. In Addis Ababa, inaccessibility discourages public transport, increases dependence on private vehicles, and negatively impacts road safety and sustainability. To improve accessibility, new roads and alternative transportation modes, such as bike lanes or pedestrian paths, should be considered.

To summarize, Table 9 provides a summary of the data, methodology, strategy, and outcome value for many cities across countries.

4.3. Demographic Accessibility. The Bole subcity is the most accessible subcity in Addis Ababa, with an accessibility score of 14233.28, as illustrated in Table 10. The Yeka subcities of Addis Ababa, Bole, Kirkos, and Yeka, have high accessibility levels due to their well-connected transport systems. These subcities have efficient public transit options, including trains, buses, minibuses, and nonmotorized routes. Kolfe Keranio, Gulele, Nifas Silk-Lafto, Lemi Kura, and Arada are intermediate districts with moderate accessibility values shown in Figure 10. These districts are well-developed and have a well-developed road system, ensuring affordable and convenient transportation options. The average transport accessibility of a district reflects its road system and land use characteristics, as reported by Table 10. The district's design prioritizes accessibility for residents through efficient land use and transportation. It coexists with residential, commercial, and recreational spaces, meeting diverse needs. The

Table 9: Comparing similar research carried out in different countries.

No	Parameter	Xi'an city [17]	Beijing City [18]	Kandhara city [15]	Addis Ababa city (current study)
1	Country	China	China	Afghanistan	Ethiopia
2	Data	Cell phone data, POI data, and land-use data	Online map data and real-time traffic	Urban road transport networks and urban land use data	Land use data, road network data, and road user response
3	Methodology	XGBoost algorithm	Linear regression analysis	GIS and statistical software programs-based	GIS technique and regression modeling
4	Approach	A multisource data analysis	Quantitative research	Qualitative and quantitative approaches	Qualitative and quantitative research studies
5	Result	Residential land and residential population density have a major effect on the land use	The commercial land use on the traffic congestion was significant	Residential land use is the most dominant and it is significant in terms of accessibility	Residential areas are 90% significant in making transport along the city

Table 10: Demographic access at the subcity level.

Number	Subcity	Demographic accessibility
1	Bole subcity	14233.28
2	Kirkos subcity	17357.32
3	Yeka subcity	17465.36
4	Kolfe Keranio subcity	18367.36
5	Gulele subcity	23642.3
6	Nifas Silk Lafto subcity	26167.22
7	Lemi Kura subcity	30319.57
8	Arada subcity	33820.7
9	Akaki Kality subcity	35379.5
10	Lideta subcity	71770.58
11	Addis Ketema subcity	74018.25

district's design considers population density, urban planning techniques, and local constraints, influencing the accessibility of transport and land use in the area and affecting planning guidelines and circumstances. Akaki Kality, Lideta, and Addis Ketema are the three most inaccessible subcities in Addis Ababa, with accessibility scores of 35379.5, 71770.58, and 74018.25, respectively, as shown in Table 10 and Figure 13. Low transport accessibility in subcities hinders development, leading to traffic jams, delays, and accidents. Ineffective public transport options limit mobility, causing economic and social isolation. Ineffective land use planning and management techniques, such as residential neighborhoods being far from commercial or industrial sectors, create issues with noise, pollution, and safety, hindering economic progress. A well-planned public transport system, accessible road network, and other transport modes are essential for ensuring accessibility.

4.4. Descriptive Analysis. The demographics of interviewees influence perceptions of network accessibility, which entails analyzing the ways in which people's opinions about network accessibility can be influenced by age, gender, income, and working conditions.

Table 4 shows that younger participants, a significant age group, have unique preferences regarding road network accessibility. They prioritize real-time traffic updates, smartphone integration, and connectivity choices, as well as bike lanes, pedestrian-friendly infrastructure, and public transportation connectivity. Older adults, though making up a smaller percentage, have different demands and preferences, including accessibility for people with impairments or mobility issues, simplicity of navigation, and safety elements.

Higher incomes provide greater access to the road network, allowing individuals with lower incomes to live in areas with superior infrastructure and connectivity. This leads to less concern about road network accessibility, as they can choose where to live more freely based on their mobility demands, unlike those with lower incomes who are forced to live in less accessible areas due to financial constraints.

4.5. Multiple Regression Analysis. This analysis examines the relationship between the independent and dependent variables of the study. The researcher took three independent variables: traffic congestion ($X1$), trip delay ($X2$), and travel time in the study queue ($X3$). The accessibility of various destinations within a road network is greatly impacted by traffic congestion. Traffic jams cause delays, longer travel times, and a reduction in the general accessibility of some regions. The amount of time passengers has to wait (trip delay) or experience delays while traveling affects the accessibility of the road network. This is caused by a number of variables, including traffic congestion, poor road conditions, and infrastructure limitations. Since travel time has a direct effect on how well transport networks operate, it is an important indicator for evaluating accessibility. Extended trip durations have the potential to dissuade people from visiting specific places and restrict accessibility for those who depend on transport networks to obtain basic utilities and services.

The MR model has a high performance and is an efficient model for predicting demographic accessibility values. The R value of 0.866 is greater than 0.8, which indicates a strong correlation between the dependent and independent variables. The R^2 value of 0.75 is close to 1, which means that the three selected independent variables can explain 75% of the variation in the dependent variable (demographic accessibility), as shown in Table 11 and the prediction of the future accessibility is shown in Figure 16.

The coefficients in Table 5 are substituted into equation (4), and the following MLR model equation was developed:

$$\begin{aligned} Y &= b + b1X1 + b2X2 + b3X3, \\ Y &= 2.304 - 0.132\text{X1} - 1.152\text{X2} - 1.051X3. \end{aligned} \tag{11}$$

When the influence of traffic congestion in this study area increased by 1%, the demographic accessibility decreased by 13.2%. In addition, as the trip delay of the study increased by 1%, the demographic accessibility of the study area decreased by 115%. This has a major impact on traffic accessibility. The demographic accessibility was negatively

Table 11: Multiple regression model values.

Model	R	R^2	Adjusted R^2
1	0.866	0.750	0.675

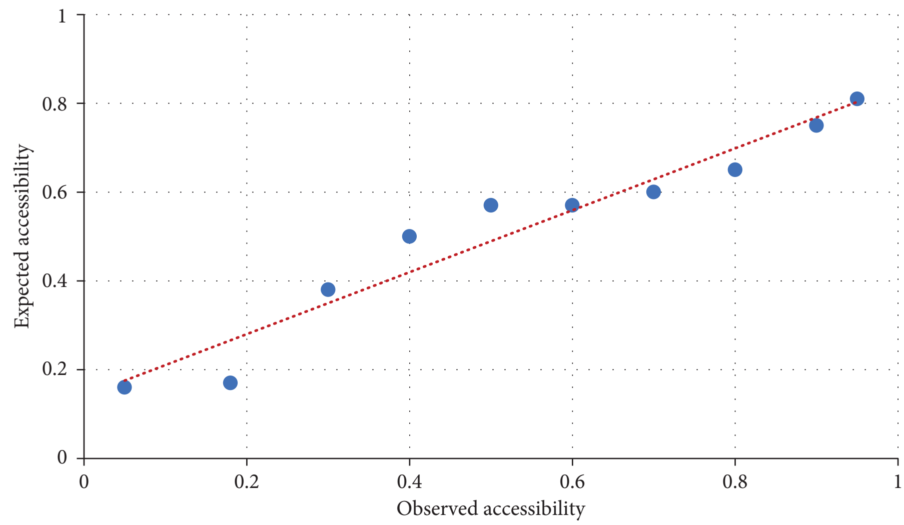


Figure 16: Expected versus observed accessibility.

impacted by 105% when the travel time in the study area increased by 1%. This negative beta value indicates that the dependent variable and independent components have a negative connection. The dependent variable tends to decrease along with the effect of these selected variables.

5. Conclusions

In this study, geographic information systems and regression modeling techniques were applied to the modeling of urban land use features in Addis Ababa city. This study assessed road user perception, which influences the social and economic advantages of land use. The results were used to inform land use planning in road network accessibility. Based on the analysis conducted in this study, the following conclusions were drawn:

(i) Residential areas are the most significant land use in cities and have a major impact on transport systems. The size of the urban built-up area, which consists of eight substantial land uses, determines the land use weight at the city and subcity levels. Larger subcities, such as Akaki Kality, have lower land use weights for urban built-up areas, while smaller subcities, such as Bole, have higher land use weights. Bole, with the highest concentration of residential land use, has the lowest contribution to less accessibility.

(ii) The GIS analysis of Addis Ababa's subcities pinpointed a critical gap in land use planning, particularly affecting public transport access in Akaki Kality, Lideta, and Addis Ketema. These areas demonstrated poor integration of residential, commercial, and educational zones, leading to increased travel distances and reduced quality of life. This study calls for a reevaluation of urban planning to prioritize mixed-use development and address the challenges posed by urban sprawl, thereby enhancing overall accessibility and connectivity.

(iii) The regression analysis revealed that land use traits, notably the area of subcities, accounted for 98% of the variance in road network accessibility across Addis Ababa's subcities. It highlighted that denser, mixed-use areas, particularly in Bole, Arada, and Lideta, correlate with better transportation links. The findings suggest that increased residential and commercial densities contribute to improved accessibility within the road network.

(iv) This revealed dissatisfaction with the city's public sectors and transportation system due to inaccessibility, suggesting that urban planners and policymakers can use this information to improve transit, enhance connectivity, and create sustainable land use patterns.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

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