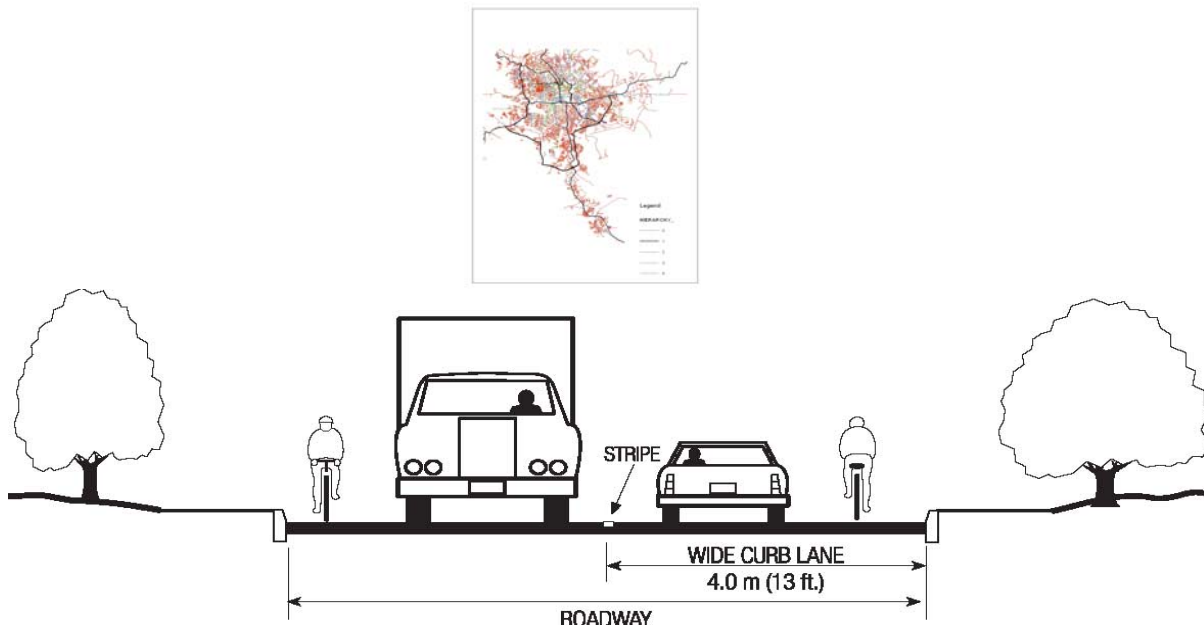


Addis Ababa University
School of graduate studies
Department of earth sciences



**A GIS-Based Bicycle Suitability Study
In Addis Ababa
MSc. Thesis**



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A thesis submitted to Addis Ababa university,
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Abstract

Various local and international organizations are located in Addis Ababa and hence a high level of mobility is existing in the city that demands various forms of transportations. Automobile is the most common form of transportation mechanism in the city. However there is high traffic congestion with greater impact on the day to day activity of the metropolis. This study considers the suitability of cycling as an additional means of transportation. In order to do this around 9048 streets in Addis Ababa are evaluated to find out the best road for cycling. Factors such as slope, traffic density and pavement surface condition were considered to assess the suitability of roads for bicycle. The study was conducted in two steps. The first step involved evaluation of the entire roads of the city. When considering all factors, the result indicated that riders can use bicycle only on 9% of the roads. The data analysis showed that the factor 'pavement surface' condition was the most influential to limit the suitability of roads for cycling. Using this factor alone about 65% of the total roads is found to be unsuitable.

As an attempt for detail study the second step considered only five roads among the total 9048 streets. The roads are selected from Arada sub-city where there exists high traffic density and people with different socio economic background. The detail analysis again considered the same three factors and the result indicated that the route running to Gullele found to be the best as its slope, traffic condition and pavement surface condition is suitable for cycling. In contrast the road that runs to Art Kilo is the worst because of the traffic density and pavement surface condition.

List of acronyms

AACRA	Addis Ababa City Roads Authority
AATA	Addis Ababa Transport Authority
AACA	Addis Ababa City Administration
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
BCI	Bicycle Compatibility Index
BLOS	Bicycle Level Of Service
CSA	Central Statistics Authority
DBMS	Database Management System
EMA	Ethiopia Mapping Agency
LOS	Level Of Service
GIS	Geographic Information System
GPS	Global Positioning System
JICA	Japan International Cooperative Agency

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1. Introduction

Addis Ababa is the seat for the Federal Government of Ethiopia and socio-economic center for the country. In addition it is home for the African Union, Economic Commission for Africa, United Nations, European Union and various international communities. Various activities are undertaken in the city including, international and national meetings, marketing, education, religious activities and the like.

The city is found at the high-lands of Africa with an average elevation of 2550 m a.s.l. The elevation is ranging between 2050 and 3026 m a.s.l. Most of high land areas are found at the northern and eastern parts of the city. Where as the central and western part is almost flat. The city's climatical setting is not bad with an average temperature of 22°C but becoming worst through time due to environmental degradation. There are two main rivers crossing the city and many tributaries, most of them draining north to south following the terrain.

The total length of roads in the city has increases from 1865 km in 1998 to 2146 km in 2004 of which 778 km (36%) was asphalt roads and the rest 1,368 km (64%) was gravel roads. Once again, roads with walkway & drainage in 2004 had the share of was 11.74% & 28.7% respectively from the total length of roads

According to the study by CES India, there is a very high travel demand in the city- 18 million passenger-km. Out of which more than 60% is satisfied by walking while the remaining 40% is by vehicles. Most of the roads – 88% - have not side walk and hence resulted in high traffic accident on pedestrians. By the year 2004 305 deaths are recorded due to traffic. The

city's transport authority tries to reduce these problems through education, increasing of traffic polices and facilities. However the rate of these problems is still increasing at alarming rate.

Concerns about increasing traffic congestion and deteriorating air quality have led to a search for alternatives to automobile use in many cities. The bicycle has received growing interest as one of these alternatives because it is emission free, energy efficient, and relatively inexpensive. In response to this interest, many communities and local agencies are now involved in planning bicycle transportation systems.

Despite the general attention, however, there have been few systematic studies of bicycle planning, whether directed at route selection or at design and safety criteria. Among the few, Replogle (1984) found that bicycles are particularly efficient for short trips and for access to and from public transportation. Several others have shown that cyclists are highly sensitive to motor traffic, particularly truck traffic (Berryhill, et al. 1977; Hamill and Wise 1974; Hudson, et al. 1982). An average daily traffic below 1200 vehicles is most desirable. This sensitivity is at least partially due to the emissions from motor vehicles, which bicyclists are forced to breathe in a highly concentrated form.

Daniel Smith was one of the first to study design and safety criteria for bicycle facilities. He recommended focusing on grades, stopping sight distance, lane width, and horizontal and vertical curvature when selecting bicycle routes (Smith 1975).

Others have studied the actual safety of bicycle travel. Plotkin and Komornick (1984) studied motor vehicle-bicycle accidents in the Boston

metropolitan area. They found that the accidents occurring with the highest frequency were those involving a motorist turning right or left at an intersection and hitting a bicyclist coming from behind or from the opposite leg of the intersection. Wachtel and Lewiston (1994) studied the same subject in the city of Palo Alto, California. They found that bicyclists riding on a sidewalk or dedicated bicycle path incur greater risk than those on the roadway, most likely because of blind conflicts at intersections. Both of these studies found that intersections are the least safe locations for bicyclists due to auto cross traffic.

The most comprehensive study of the process of bicycle planning is one based on experiences in Europe, Australia, and the United States, in which the authors emphasize the subjective nature of bicycle facility planning (Hudson, et al. 1982). The aim of planning for cyclists is not to provide a physical product, such as a cycle track, they say, but rather to ensure safe and efficient travel by bicycle. The process of selecting bicycle routes usually begins with the development of a list of criteria (such as safety, continuity, directness, and grade) that are to be employed in the route selection process. Then, considering the trade-offs between these criteria, a planner uses his/her best judgment to select bicycle routes. Hudson, et al. found no quantitative analyses or systematic weighting of criteria within existing bicycle planning processes.

Geographic information systems (GIS) technology provides an excellent opportunity to computerize the process of bicycle route selection. Bicycle route planning is quite different from traditional transportation planning because of the criteria mentioned above. In particular, bicyclists are more sensitive to the slope (or grade) and the surface quality of a route than are automobile drivers. As noted, they are also especially sensitive to

the level of automobile traffic on a route. Thus, bicycle route planning requires more data layers than traditional transportation planning. These data layers can be very costly to construct by traditional means, but GIS can easily integrate digital information which is already available from government or other institutional sources, thus greatly reducing the cost of data assembly. Furthermore, GIS can perform unique spatial operations, such as terrain modeling and network analysis, which are crucial to bicycle route planning; and its network analysis data model and path-finding algorithms make it a straight-forward way to implement sophisticated cycling models that incorporate crossing traffic, turn penalties, slope, and other more standard transportation factors.

To date, although there have been many studies on transportation planning and operations using GIS, none has applied GIS in the planning and selection of bicycle routes. Current GIS applications in transportation planning focus on its mapping function; and current GIS applications in vehicle routing focus on implementing mathematical algorithms. Critical factors to cycling – such as grade and crossing traffic – have not been touched upon, nor have the GIS capabilities of integrating inexpensive ancillary data been well explored.

The purpose of this study is to develop a procedure for selecting bicycle routes using GIS, and to apply it to the city of Addis Ababa. In order to identify those roads using GIS, suitability criteria that are cost effective and consistent to the study area's context are taken into consideration. Then analysis procedures are outlined based on previous works in the sector. Finally using the software ArcGIS9 suitable roads are identified.

1.1. Statement of the problem

The road network and transport system of Addis Ababa couldn't satisfy the travel demand of the metropolis. There exists high traffic on most roads and as result traffic accidents, unnecessary time delay and environmental degradation becomes common. Most of the problems are associated with the system's automobile dependency.

1.2. Objective

In general the core objective of this thesis is to develop a GIS based object oriented method and applying it on the existing road network to identify bicycle friendly routes.

Specific objectives

1. to assess the existing transport system and its efficiency to support the required travel demand
2. to identify factors influencing bicycle friendly routes selection in our country context
3. to develop a spatial database on the existing road network
4. to develop an object oriented model for the selection of bicycle friendly routes
5. to apply the model on the existing roads and identify suitable routes

1.3. Beneficiaries

The out put model of this project could potentially be used by the following governmental and non governmental institutions and sector professionals.

- Addis Ababa city roads authority to introduce bicycle friendly system through incorporating the required infrastructures and design considerations
- Addis Ababa transport authority to incorporate bicycle as one entity to the system considering their impact on reduction of traffic congestions
- Addis Ababa environmental protection agency to apply the output for non-motorized transport system development advocacy.
- Transport sector professionals to use the system for further studies.

2. Methodology and Material

GIS is one of the fastest growing technologies of present time. It has emerged as powerful and sophisticated means to manage vast amounts of geographic data. It provides a mechanism by which information on location, spatial interaction and geographic relationship of various facilities can be assessed and viewed in moments. It provides an opportunity to effectively view and access geographic data and thus to improve decision making process.

To solve the problem stated the study adopted GIS based project management because it is very powerful tool for spatial problems. Till now no one has applied this tool to address traffic related problems in the country. However GIS is becoming the most favorable choice for transportation management projects in different parts of the world. In a typical GIS analysis project, you identify the objectives of the project, create a project database containing the data you need to solve the problem, use GIS functions to create an analytical model to solve the problem, and present the results of the analysis.

2.1. Data collection

After properly identifying the problem, data relevant to address the project was collected from different sources. In this step three activities have been performed: data identification, data definition and collection. By the first activity data necessary to solve the problem properly identified as follows:

- Road network
- Traffic information
- Road geometrical condition
- Land use
- Demography
- Topography

Following the identification, those data were defined prior to collecting, that involves decision on working format and coordinate system. Hence the working data definitions were decided to be as follows:

Format *ESRI's shapefile*
 Coordinate system *Projected*
 UTM- zone 37
 Northern hemisphere
 WGS84

Finally potential data vendors are identified and the relevant data is collected. Fortunately and due to financial limitations there had not be any field work.

Data	Source	Format	Coordinate system	Remark
Road network	AACRA	MapInfo(.TAB)	Geographic	Only describing the links (no node)
Traffic information	AACRA	Database file (.dbf)	-	
Pavement condition	AACRA	Database file (.dbf)	-	
Topography	JICA	AutoCAD (.dwg)	-	Contour interval-5m
Administrative boundary	CSA	ArcView (.shp)		Kebele level

Landuse	EMA	Paper form	-	
Demography	CSA	MS Excel (.xls)	-	

Table 2.1 summary of the data collection

2.2. Data preprocessing

This step is very important component of the project. Because data collected from different sources commonly need harmonization in to a specific system. I used ArcGIS9 functions to preprocess those data as described briefly below:

Georeferencing

Raster data is commonly obtained by scanning maps or collecting aerial photographs and satellite images. Scanned map datasets don't normally contain spatial reference information (either embedded in the file or as a separate file). With aerial photography and satellite imagery, sometimes the locational information delivered with them is often inadequate, and the data does not align properly with other data you may have. Thus, in order to use some raster datasets in conjunction with your other spatial data, you often need to align it or georeference—it to a map coordinates system.

Data brought with paper form was georeferenced to pinpoint the input scanned image to world reference using known ground control points. This will make every spatial data of the study area to fall in the same place and hence facilitates various analyses.

Format conversion

Media conversion

Digitizing

Digitizing is the process of converting features on a paper map into digital format. To digitize a map, you can use a digitizing tablet (also known as a digitizer) connected to your computer to trace over the features that interest you. The x,y coordinates of these features are automatically recorded and stored as spatial data.

Data collected as manual or paper forms have been converted to digital form using digitization techniques. For this specific project the data in paper form is digitized using the relative or scan-digitize method.

File format conversion

As described before, the data collected from different sources had different formats. We couldn't perform spatial analysis with these differences. Therefore most of them have been converted to the working file format as follows:

MapInfo (.TAB) to ESRI (.shp)

- Data - Road network
- Conversion techniques - MapInfo (.TAB) to MapInfo (.mif)
Table - export
MapInfo (.mif) to ESRI (.shp)
Tool- Tool manager-Universal Translator

AutoCAD (.dwg) to ESRI (.shp)

- Data - Elevation
- Conversion techniques - AutoCAD (.dwg) to ESRI (.shp)
- Data - Export Data

Coordinate transformation

The working coordinate system for the project is decided to be projected. Therefore data with coordinate system other than this was transformed using the techniques in ArcGIS.

A projected coordinate system is defined on a flat, two-dimensional surface. Unlike a geographic coordinate system, a projected coordinate system has constant lengths, angles, and areas across the two dimensions. A projected coordinate system is always based on a geographic coordinate system that is based on a sphere or spheroid.

2.3. Database development

At the heart of any GIS systems there is always a well developed database. Therefore database development has been given a due attention in this project and involved entity and attribute identification and the database assembly.

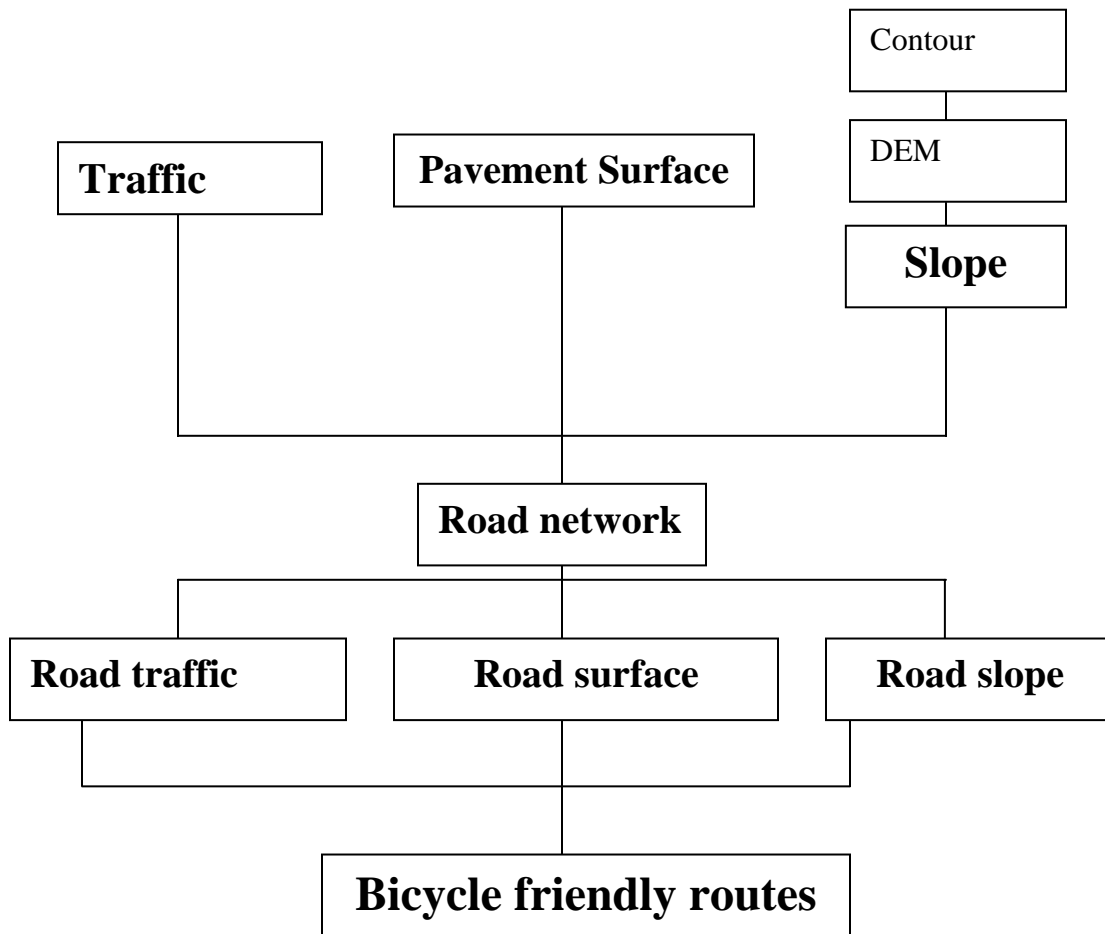
Entity	Attributes
Road network	ID, name
Operational parameters	Road_ID, AADT
Geometrical parameters	Road_ID, surface condition, width, length, lane number
Topography	Elevation
Landuse	Name, Type, location (wereda and Kebele)

Table 2.2 the database framework

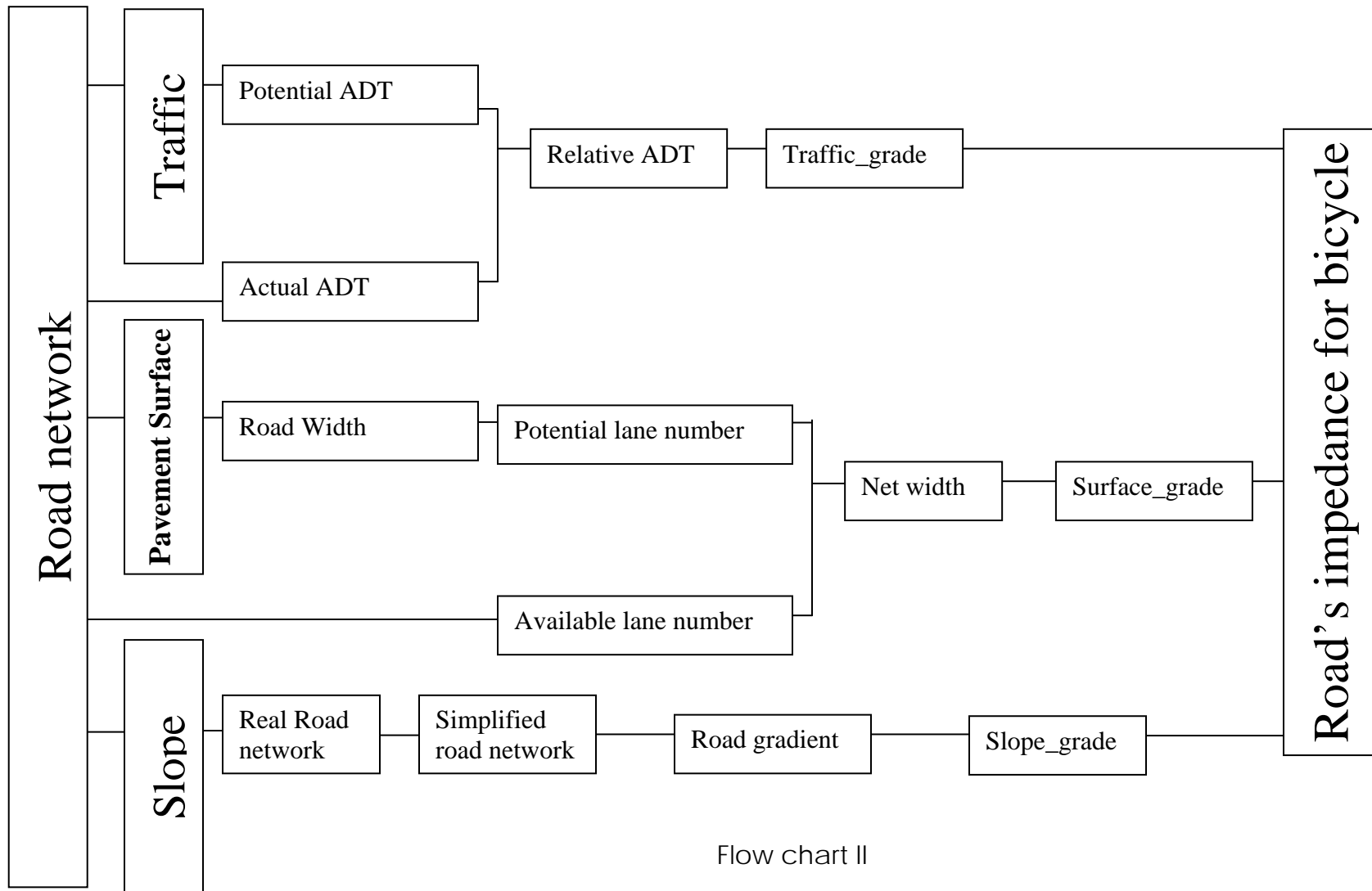
2.4. Data analysis

Task	Tool	Input	Output
Surface Generation	Spatial Interpolation	Contour	TIN And Surface Raster
Simplification Of The Real Network	Simplify Line	Real Network	Simplified Network
Identifying Nodes	Feature Vertices To Point	Simplified Network	Fnode and Tnode
Identifying The Nodes Coordinates	Add XY Coordinates	Fnode And Tnode	Node's XY Coordinate
Adding The Vertical Component	Surface Spots	Fnode And Tnode	Node's Z Coordinate
Adding The Coordinates Of Nodes To The Road Network	Spatial Join	Nodes And The Real Road Network	Real Road Network With Fnode And Tnode Coordinate
3D length calculation	Surface length	Real Network and surface raster	3D length

Table 2.3 Summary of data analysis in ArcGIS



Flow chart I



Flow chart II

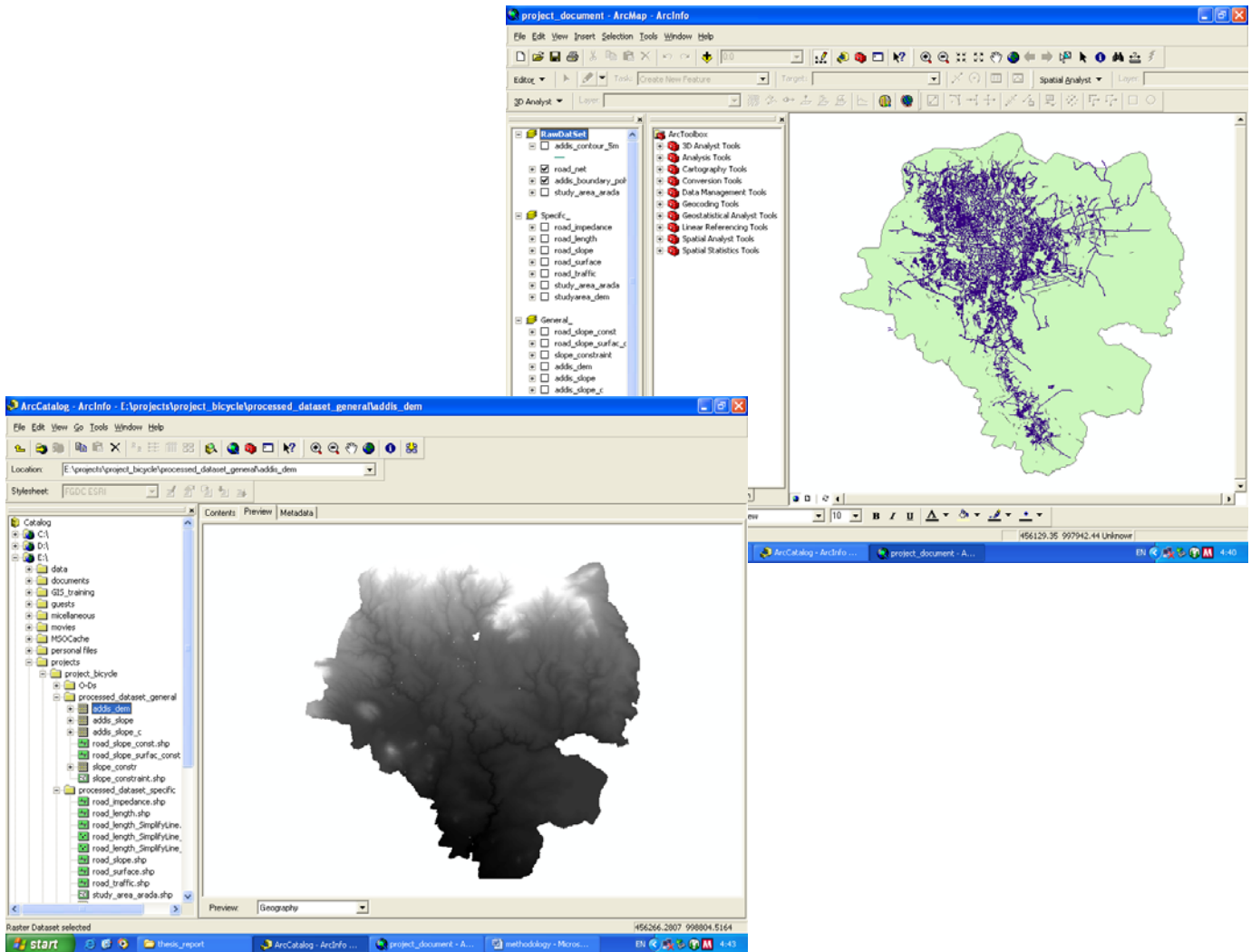


Fig 2.1 data analysis in ArcGIS

3. Study area description

Addis Ababa being the centre of the country of Africa as well as the seat of many international organizations has a significant role in local, regional and international settings in economic, social, political & administrative perspectives.

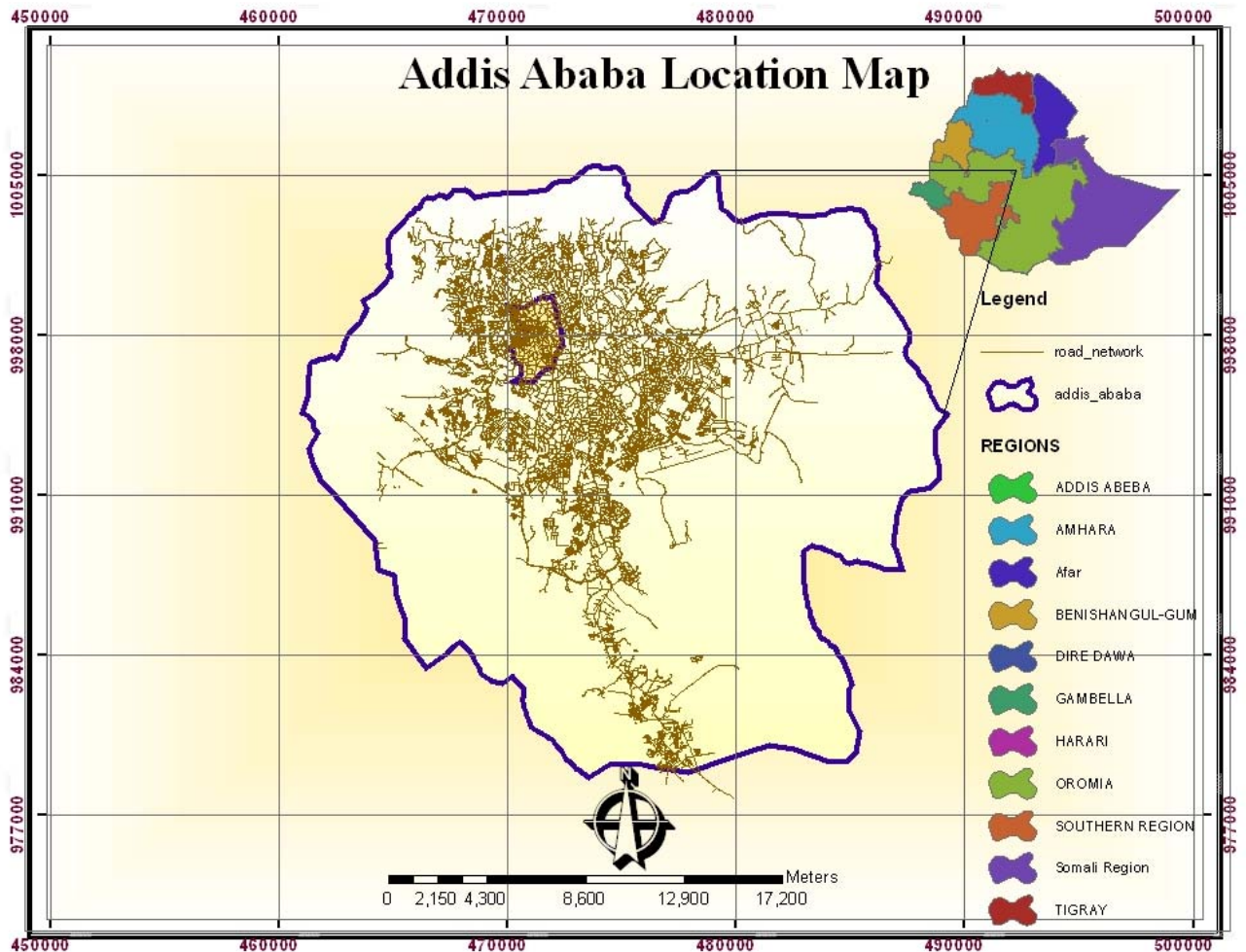


Fig 3.1 study area location map

3.1. Demography

Based on the project of 1994 population and housing census result, the total population of Addis Ababa is projected to be 2.969 million in 2005. At high variant, of which 52% are female and 48% are male. The average annual growth rate of the population of the city is 2.9%.

No	Demographic Indicator	Indicator Values
1	Total fertility rate (children per women)	1.9
2	Life Expectancy at Birth	
	Male	62.8
	Female	66.5
3	Annual population growth rate (in %)	2.9
	Rate of natural increase	1.21
	Net migration rate	1.69
4	Economic dependency ratio	130.5
5	Sex Ration (number of male per 100 female)	92
6	Infant mortality rate (the number of deaths of infants under age one per 1000 live births)	50
7	Under five mortality rate (The number of deaths of infants under age five per 1000 live births)	66
8	Crude death rate (the number of deaths per 1000 population)	6.7
9	Crude birth rate (the number of live births per 1000 population)	27.6
10	Female literacy rate	68
11	Female employment rate	36.8

Source: CSA 1994 population and housing census & report on urban bi-annual employment unemployment survey April 2004.

Table 3.1 Demographic Indicator

3.2. Housing Sector

Based on the information obtained from Urban Information and Documentation Department (UIDD) the City Government of Addis, the housing unit ration in the city. (i.e., total number of house per total households¹) is 0.64.

No	Housing Indicators	Indicator Values (%)
1	Type of building	
	• Non storied	97.15
	○ attached	58.14
	○ detached	39.01
	• Multi Storied	2.66
	○ attached	1.99
	○ detached	0.67
2	Housing ownership	
	• Privately owned	34.42
	• Rented from government	40.4
	• Rented from private household	16.4
	• Others	8.78
3	Construction Material	
	• Wall	
	○ Mud and wood	75
	○ Stone, Birck, hollblock and Cement	15
	○ Others	10
	• Roof	
	○ Corrugated iron sheets	96
	○ Others	4
	• Floor	
	○ Mud	52.8
	○ Wood tiles	17.9
	○ Cement concrete and brick tiles	24.8
	○ Others	1.9
4	Housing Facilities	

	• Toilet	
	○ Private with flush	8
	○ Private without flush	18.16
	○ Shared	48.94
	○ No toilet	24.9
	• Kitchen	
	• Private	37.66
	• Shared	35.96
	• No Kitchen	26.38
	Water	
	• Housing unit with private water meter connection	26.8
	• Tap water shared meter	70.9
	• Others	2.3
	Electric light	
	• Housing unit with private electric meter connection	45.05
	• Shared electric meter	50.49
	• No electric light	4.46
	Houses with one room	30.7
	Households with television set	75
	House with telephone line	47
5.	Over –Crowding	
	• Household size	5.1
	• Household per housing size	1.1
	• Person per room	2.1

Source: 1994 Population and housing census (UIDD) of the City Government of Addis A.A, 2001

Table 3.2 Housing condition and facilities

According to the 1994 population and housing census report, 97% of the total housing stock are non storied of which 75% are made of mud and

wood. Modern construction materials are used only for 15% of the total housing stock.

Regarding the ownership condition of houses in the city nearly 40.4% is owned by government, followed by private owned houses, which accounts above 34.42%.

About 30% of the housing units in Addis Ababa have one room. Most of the houses in the city are deprived of basic facilities. Accordingly, of the total houses, 25% of houses have no toilet facilities and 26% houses have no kitchen facilities.

When we see electric and water connection at housing unit level, about 96% & more than 97% of the housing unit have private as well as shared electric and water connection respectively.

3.3. Land Use

The land use pattern of the city is dominated by the existing mixed use built up (31.3%), parks, green along the rivers and forest (23.4%), agriculture (13.8%), mixed up expansion (13.41%) & so on from the total area (54,000 hectare) of the city as shown on the following table.

No.	Land use categories	Area/in hectare	Percentage share
1	City centers	1317	2.4
2	Forest	12647	23.4
3	Agriculture	7453	13.8
4	Existing industry	1292	2.4
5	proposed industry	1846	3.4
6	Mixed use built up	16900	31.3

7	Proposed Social Service	624	1.2
8	Existing social service	514	1.0
9	Reserved	1085	2.0
10	Transport	1029	1.9
11	Mixed use expansion	7243	13.4
12	Road Network (AS)	2050	3.8
	Total	54000	100

Source: ORAMP December 2002

Including AS – (Arterial Street only) & excluding local street, Collector Street.

Table 3.3 Land use

According to the table shown above, the area proposed for city center & road networks is 1317 hectare (2.4%) & 2050 hectare (3.8%) respectively of the total area of the city.

Besides, 1085 hectare (2%) of the total area are designated for unforeseen upcoming activities and functions, 1029 hectares (1.9%) of the total area of the city is reserved for different types of transport/ air, train and mass transport /terminal.

From the table above, one could tell that the existing social service land use is 514 hectares (1%) and about 624 hectares (1.2%) of the total area of the city is reserved for expansion of these functions.

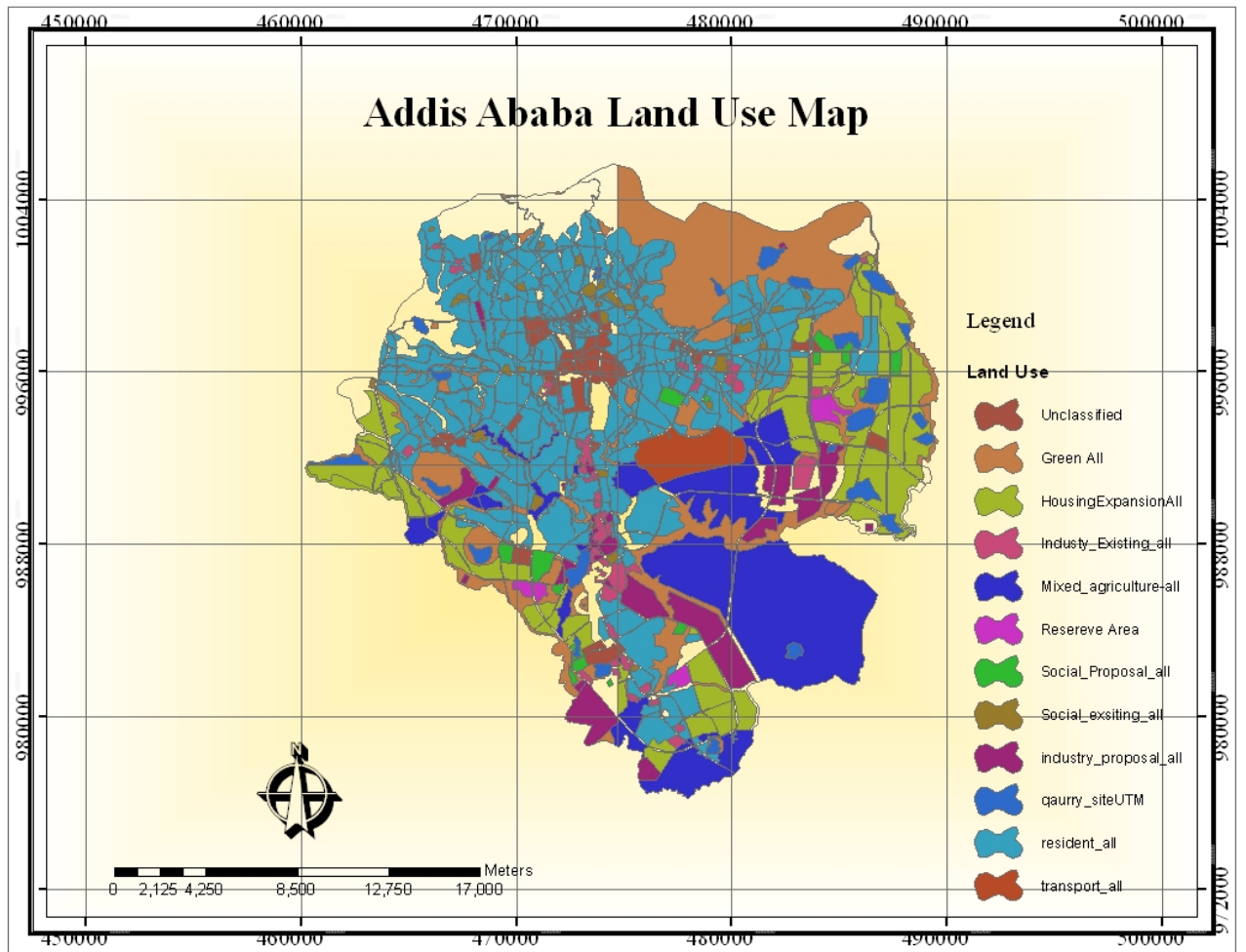


Fig 3.2 study area land use map

3.4. Road

As indicated here under the following table, the total road area coverage of the city in 2004 was 17.62 km², which is only 6.1% of the total built up area of the city.

No	Road Category /Indicators	Unit of measure	Annual Trend						
			1998	1999	2000	2001	2002	2003	2004
A	Total asphalt road length	Km	681	684	688	698	716	756	778
	Principal arterial road							308	327
	sub arterial road							118	119
	Collector road							178	180
	Local road							152	152
B	Gravel Road	"	1184	1223	1235	1266	1286	1,300	1,368
C	Total road length (I+II) = a	"	1865	1907	1923	1964	2002	2056	2146
D	Sidewalk Way	Km	199	203	206	207	217	192	252
E	Road Length with drainage	Km	528	530	534	534	551	559	615
F	Total Road Area ² (a*0.007km ³)	Km ²	13.06	13.35	13.46	13.75	14.01	14.39	15.02
G	Road length with drainage + sidewalk way* 0.003km ⁴		2.18	2.20	2.22	2.25	2.30	2.25	2.60
H	Total Road Coverage (F+G)	Km ²	15.24	15.55	15.68	16.00	16.31	16.64	17.62
	Length of road indicators								
	% of sub arterial road (1/a)* 100	%						15	15.24

	% of sub arterial road (2/a)*100	"						5.8	5.55
	% of collector road (3/a) * 100	"						8.7	8.38
	% of local road (4/a)* 100	"						7.4	7.08
L	Total built up area	Km ²	290	290	290	290	290	290	290

Source: Addis Ababa Roads Authority (AACRA)

Table 3.4 Road length and area coverage

As indicated on the table above, the total length of roads in the city has increases from 1865 km in 1998 to 2146 km in 2004 of which 778 km (36%) was asphalt roads and the rest 1,368 km (64%) was gravel roads. Once again, as we can see from the table above, roads with walkway & drainage in 2004 had the share of was 11.74% & 28.7% respectively from the total length of roads.

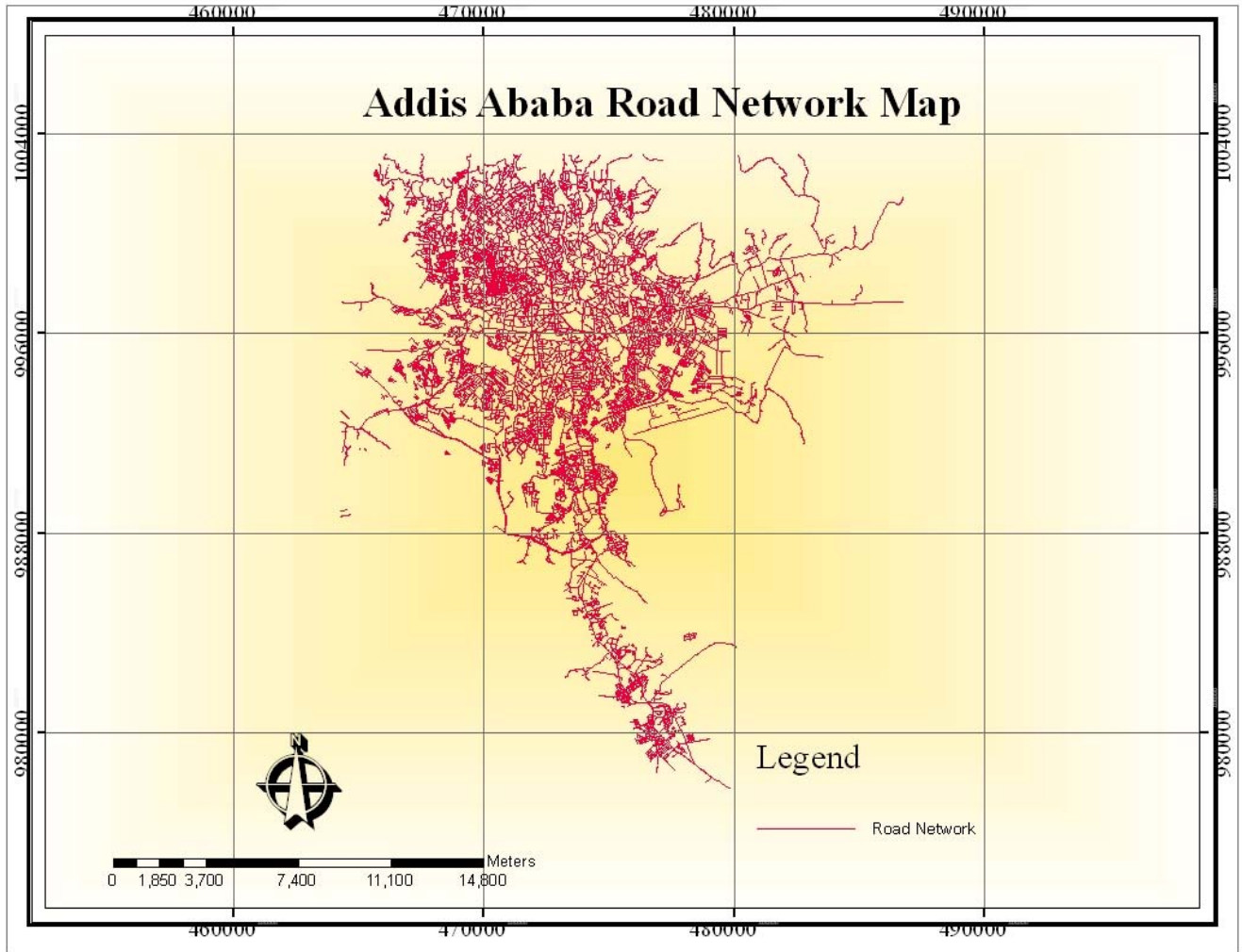


Fig 3.2 study area road network map

3.5. Transport

The metropolitan has a total of 137,536 different cars owned by different owners in 2003. As indicated on the following table, the annual growth rate of vehicles was on average 5.3% from 1997 to 2003 & at high variant with a total population of 2.777 million, there were about 50 cars per 1000 persons.

Types of Vehicle	Annual Trend						
	1997	1998	1999	2000	2001	2002	2003
Total population at high variant (in 1000)	2,291	2,362	2,437	2,516	2,599	2,686	2,777
Taxi (as per registration)	10765	11093	11855	12501	13165	14553	15704
% age share of taxis	10.67	10.77	10.78	10.84	10.85	11.29	11.42
Private	41650	41650	44968	46409	48469	51348	54501
%age share of commercial cars	41.29	40.44	40.90	40.24	39.93	39.82	39.63
Commercial	36277	37604	39855	42623	45273	47859	51151
%age share of commercial cars	35.96	36.51	36.25	36.96	37.30	37.12	37.19
Government	7820	8041	8360	8503	8827	9128	9731
%age share of Gov't cars	7.75	7.81	7.60	7.37	7.27	7.08	7.08
Red cross	730	764	811	859	902	954	1000
%age share of red cross cars	0.72	0.74	0.74	0.74	0.74	0.74	0.73
International & NGOs	36.35	3847	4102	4429	4742	5094	5449
%age share of Int'l & NGO cars	3.60	3.73	3.73	3.84	3.91	3.95	3.96
Total	100877	102999	109951	115324	121378	128936	137536
Total no. of cars per 1000	44	44	45	46	47	48	50

Source: Addis Ababa Transport Authority (AATA)

Table 3.5 Annual trend of vehicle

4. Geographic Information System (GIS)

4.1. Introduction

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the Earth's surface and the events (non-spatial attributes linked to the geography under study) that taking place on it. The meaning to represent digitally is to convert analog (smooth line) into a digital form.

"Every object present on the Earth can be geo-referenced", is the fundamental key of associating any database to GIS. Here, term 'database' is a collection of information about things and their relationship to each other and 'geo-referencing' refers to the location of a layer or coverage in space defined by the co-ordinate referencing system.

Work on GIS began in late 1950s, but first GIS software came only in late 1970s from the lab of the ESRI. Canada was the pioneer in the development of GIS as a result of innovations dating back to early 1960s. Much of the credit for the early development of GIS goes to Roger Tomilson. Evolution of GIS has transformed and revolutionized the ways in which planners, engineers, managers etc. conduct the database management and analysis.

4.2. Need of GIS

Many professionals, such as foresters, urban planners, and geologists, have recognized the importance of spatial dimensions in organising & analysing information. Whether a discipline is concerned with the very practical aspects of business, or is concerned with purely academic research,

geographic information system can introduce a perspective, which can provide valuable insights as

1. 70% of the information has geographic location as its denominator making spatial analysis an essential tool.
2. Ability to assimilate divergent sources of data both spatial and non-spatial (attribute data).
3. Visualization Impact
4. Analytical Capability
5. Sharing of Information

4.3. Advantages of GIS

The Geographic Information System has been an effective tool for implementation and monitoring of municipal infrastructure. The use of GIS has been in vogue primarily due to the advantage mentioned below:

Planning Of Project

Advantage of GIS is often found in detailed planning of project having a large spatial component, where analysis of the problem is a pre requisite at the start of the project. Thematic maps generation is possible on one or more than one base maps, example: the generation of a land use map on the basis of a soil composition, vegetation and topography. The unique combination of certain features facilitates the creation of such thematic maps. With the various modules within GIS it is possible to calculate surface, length, width and distance.

Making Decisions

The adage "better information leads to better decisions" is as true for GIS as it is for other information systems. A GIS, however, is not an automated decision making system but a tool to query, analyze, and map data in support of the decision making process. GIS technology has been used to assist in tasks such as presenting information at planning inquiries, helping resolve territorial disputes, and siting pylons in such a way as to minimize visual intrusion.

Visual Analysis

Digital Terrain Modeling (DTM) is an important utility of GIS. Using DTM/3D modeling, landscape can be better visualized, leading to a better understanding of certain relations in the landscape. Many relevant calculations, such as (potential) lakes and water volumes, soil erosion volume (Example: landslides), quantities of earth to be moved (channels, dams, roads, embankments, land leveling) and hydrological modeling becomes easier.

Not only in the previously mentioned fields but also in the social sciences GIS can prove extremely useful. Besides the process of formulating scenarios for an Environmental Impact Assessment, GIS can be a valuable tool for sociologists to analyze administrative data such as population distribution, market localization and other related features.

Improving Organizational Integration

Many organizations that have implemented a GIS have found that one of its main benefits is improved management of their own organization and

resources. Because GIS has the ability to link data sets together by geography, it facilitates interdepartmental information sharing and communication. By creating a shared database one department can benefit from the work of another--data can be collected once and used many times.

As communication increases among individuals and departments, redundancy is reduced, productivity is enhanced, and overall organizational efficiency is improved. Thus, in a utility company the customer and infrastructure databases can be integrated so that when there is planned maintenance, affected people can be informed by computer-generated letters.

4.4. Components of GIS

Hardware

It consists of the computer system on which the GIS software will run. The choice of hardware system range from 300MHz Personal Computers to Super Computers having capability in Tera FLOPS. The computer forms the backbone of the GIS hardware, which gets it's input through the Scanner or a digitizer board. Scanner converts a picture into a digital image for further processing. A digitizer board is flat board used for vectorisation of a given map objects. Printers and plotters are the most common output devices for a GIS hardware setup.

Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. GIS softwares in use are MapInfo, ARC/Info, AutoCAD Map, etc. The software available can be said to be application

specific. When the low cost GIS work is to be carried out desktop MapInfo is the suitable option. It is easy to use and supports many GIS feature. If the user intends to carry out extensive analysis on GIS, ARC/Info is the preferred option. For the people using AutoCAD and willing to step into GIS, AutoCAD Map is a good option.

Data

Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. The digital map forms the basic data input for GIS. Tabular data related to the map objects can also be attached to the digital data. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organization to maintain their data, to manage spatial data.

People

GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. The people who useGIS can be broadly classified into two classes. The CAD/GIS operator, whose work is to vectorise the map objects. The use of this vectorised data to perform query, analysis or any other work is the responsibility of a GIS engineer/user.

Method

And above all a successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to

each organization. There are various techniques used for map creation and further usage for any project. The map creation can either be automated raster to vector creator or it can be manually vectorised using the scanned images. The source of these digital maps can be either map prepared by any survey agency or satellite imagery.

4.5. Applications of GIS

Computerized mapping and spatial analysis have been developed simultaneously in several related fields. The present status would not have been achieved without close interaction between various fields such as utility networks, cadastral mapping, topographic mapping, thematic cartography, surveying and photogrammetry remote sensing, image processing, computer science, rural and urban planning, earth science, and geography.

The GIS technology is rapidly becoming a standard tool for management of natural resources. The effective use of large spatial data volumes is dependent upon the existence of an efficient geographic handling and processing system to transform this data into usable information.

The GIS technology is used to assist decision-makers by indicating various alternatives in development and conservation planning and by modelling the potential outcomes of a series of scenarios. It should be noted that any task begins and ends with the real world. Data are collected about the real world. Of necessity, the product is an abstraction; it is not possible (and not desired) to handle every last detail. After the data are analysed, information is compiled for decision-makers. Based on this information, actions are taken and plans implemented in the real world.

Major areas of application

- *Different streams of planning*
Urban planning, housing, transportation planning architectural conservation, urban design, landscape.
- *Street Network Based Application*
It is an addressed matched application, vehicle routing and scheduling: location and site selection and disaster planning.
- *Natural Resource Based Application*
Management and environmental impact analysis of wild and scenic recreational resources, flood plain, wetlands, aquifers, forests, and wildlife.
- *View Shed Analysis*
Hazardous or toxic factories siting and ground water modelling. Wild life habitat study and migrational route planning.
- *Land Parcel Based*
Zoning, sub-division plans review, land acquisition, environment impact analysis, nature quality management and maintenance etc.
- *Facilities Management*
Can locate underground pipes and cables for maintenance, planning, tracking energy use.

5. Bicycle as a mode of transport

Concerns about increasing traffic congestion and deteriorating air quality have led to a search for alternatives to automobile use in many cities. The bicycle has received growing interest as one of these alternatives because it is emission free, energy efficient, and relatively inexpensive. In response to this interest, many communities and local agencies are now involved in planning bicycle transportation systems.

5.1. How It Is Implemented

Bicycle encouragement programs are usually implemented by community groups such as cycling organizations, local transportation agencies, employers, Transportation Management Associations, chambers of commerce, Tourist Promotion Organizations, and individual businesses.

5.2. Travel Impacts

These programs can help increase nonmotorized transportation. Travel impacts tend to be greatest during a particular campaign and contest, but the experience can lead participants to long-term changes in travel habits.

Objective	Rating	Comments
Reduces total traffic.	2	
Reduces peak period traffic.	2	
Shifts peak to off-peak periods.	0	
Shifts automobile travel to alternative modes.	2	Encourages nonmotorized transportation.
Improves access, reduces the need for	0	

travel.		
Increased ridesharing.	0	
Increased public transit.	0	
Increased cycling.	3	Encourages cycling.
Increased Telework.	0	
Reduced freight traffic.	0	

❖ Rating from 3 (very beneficial) to -3 (very harmful). A 0 indicates no impact or mixed impacts.

Table 5.1 Travel Impact Summary

5.3. Benefits and Costs

Shifts from driving to cycling can reduce traffic congestion, road and parking facility costs and environmental impacts, and increase community Livability and improved Public Health. Programs to encourage and support cycling can increase Transport Choice by raising public acceptance and support for nonmotorized travel.

Shifts from automobile to nonmotorized transportation can be particularly effective at Energy Conservation and Emission Reductions by reducing short motor vehicle trips which have high per-mile fuel consumption and emission rates. As a result, each 1% shift of mileage from automobile to nonmotorized modes tends to reduce energy consumption and pollution emissions by 2-4%. A short pedestrian or cycle trip often replaces a longer automobile trip (for example, consumers may choose between shopping at a local store or driving to a major shopping center).

Safety impacts vary depending on circumstances and perspective: although nonmotorized modes tend to have higher casualty rates per passenger-mile,

this is offset by reduced risk to other road users, reduced total mileage, and improved health from aerobic exercise. A major study found that Danish workers who regularly commute by bicycle have a 40% reduction in mortality compared with people who do not cycle to work (Andersen, et al, 2000), which suggests that the incremental risks of bicycle transportation are outweighed by health benefits, at least for experienced adult cyclists riding in a bicycle-friendly community. Pucher and Dijkstra (2000) discuss these risks and describe ways to minimize crash risk to pedestrians and cyclists.

Objective	Rating	Comments
Congestion Reduction	1	Reduces automobile travel.
Road & Parking Savings	2	Reduces automobile travel.
Consumer Savings	2	Reduces automobile travel.
Transport Choice	1	Increases choice for people who can walk or cycle.
Road Safety	2	Mixed crash impacts. Overall beneficial to public health.
Environmental Protection	3	Reduces automobile travel.
Efficient Land Use	2	Reduces automobile travel. Encourages higher-density.
Community Livability	3	Reduces automobile travel, improves street environment.

❖ Rating from 3 (very beneficial) to -3 (very harmful). A 0 indicates no impact or mixed impacts.



Table 5.2 Benefit Summary

5.4. Equity Impacts

Most people can walk or cycle, although many cannot use these modes for transportation because they live in automobile-dependent areas. Programs that promote cycling for transportation can benefit lower-income and transportation disadvantaged people by increasing public acceptance and support of nonmotorized travel. These programs may require subsidies,

although these are usually smaller than per-trip subsidies for automobile travel (such as free automobile parking).

Criteria	Rating	Comments
Treats everybody equally.	0	Some people who cannot cycle may feel excluded.
Individuals bear the costs they impose.	0	May require subsidies, but often less than for a car trip.
Progressive with respect to income.	1	Many lower-income people cycle for transport.
Benefits transportation disadvantaged.	1	Many non-drivers cycle for transport.
Improves basic mobility.	1	Yes

❖ Rating from 3 (very beneficial) to -3 (very harmful). A 0 indicates no impact or mixed impacts.

Table 5.3 Equity Summary

5.5. Applications

Cycling is appropriate in almost any geographic area, and can be particularly effective in areas with pedestrian and bicycle friendly environments. Such programs can be sponsored by local governments, business associations, neighborhood associations or educational organizations.

Geographic	Rating	Organization	Rating
Large urban region.	2	Federal government.	1
High-density, urban.	2	State/provincial government.	2
Medium-density, urban/suburban.	2	Regional government.	2
Town.	2	Municipal/local government.	3
Low-density, rural.	1	Business Associations/TMA.	3

Commercial center.	3	Individual business.	2
Residential neighborhood.	2	Developer.	0
Resort/recreation area.	2	Neighborhood association.	3
College/university communities.	3	Campus.	3

❖ Ratings range from 0 (not appropriate) to 3 (very appropriate).

Table 5.4 Application Summary

5.6. Barriers to Implementation

These programs require organizational leadership and funding. There is seldom opposition to such programs, but some people may be skeptical of their benefits.

5.7. Best Practices

Organizations listed below have experience operating various types of cycling campaigns, and provide resources for developing local programs. Cleary and McClintock (2000) provide recommendations for employee cycling program development. Best practices include:

- Create a clear, consistent and positive message about the benefits of nonmotorized travel.
- Use promotional campaigns as part of an overall program to improve cycling conditions. Identify and overcome barriers to nonmotorized transport, including bottlenecks in the street system, lack of education resources, lack of bicycle parking, and inadequate support from employers.

-
- Find opportunities for cooperation with other organizations, including recreation, public health, community development, schools, tourist promotion and neighborhood organizations.
 - Work with local planners, employers and employees who cycle to design and improve cycling facilities and services. Include people who current do not cycle in program development to help identify and overcome the barriers they perceive to cycle transportation.
 - Use cycling and recreational organizations to enlist volunteers.
 - Emphasize cycling skills and safety education.

5.8. Examples and Case Studies

National Bike to Work Month (www.bikeleague.org)

The League of American Bicyclists has declared May to be National Bike Month since 1956. The League also promotes Bike to Work Week and Bike-to-Work Day. They invite communities, corporations, clubs, and individuals to join in sponsoring bicycling activities during the month of May in order to increase awareness and acceptance of bicycling. The League produces a *National Bike Month Event Organizer's Kit*, to help individuals and organizations that promote these events.

Eugene Encourages Bicycle Transportation (www.ci.eugene.or.us/PW/bike)

Eugene, Oregon has a well-planned and well used cycling network that includes 28 miles of off-street paths, 78 miles of on-street bicycle lanes, and 4 bicycle/pedestrian bridges spanning the Willamette River. This results in 8% of commute trips by bicycle.

Bicycle Commuting Contest (www.climatesolutions.org)

The Thurston County, Washington Bicycle Commuter Contest encourages individuals to bicycle to work, school, and to run errands throughout the month of May. The contest has been a participatory event for Thurston County residents and employees since 1988. The goal of the Bicycle Commuter Contest is to promote cycling as an efficient, non-polluting method of travel. Participants keep track of how often and how far they commute by bicycle, and win prizes in a variety of categories. In 1999 574 participants rode a total of nearly 15,000 miles. Individuals and teams compete to see who can:

- Ride the most miles.
- Ride the most number of days in their age category.
- Tally more total miles than any other team.
- Ride the most days per team-member (advantage to smaller teams).
- Compile the most days ridden by all members (advantage to larger teams).
- Compile the most days ridden by first-time participants (advantage to teams that recruit first-time riders).

Bike To Work Week Campaign (www.biketoworkvictoria.bc.ca)

A *Bike-to-Work-Week* campaign is held annually in Victoria, British Columbia. In 2000 it included:

- A bicycle commuting contest with more than 200 teams at different worksites competing in various classes to see which can achieve the most bicycle commuters. All participants are eligible for prizes and drawings.

-
- A friendly contest between drivers and cyclists determines who gets the first cup of hot coffee at a downtown coffee shop without violating traffic rules.
 - Free, bicycle skills training workshops for employees who want to learn more about bicycle commuting.
 - An elementary school literary competition between bikes and cars. Cycling and driving parents leave the school at a specified time, travel to the downtown public library, check out a book and return to the school while following all the rules of the road. Students that estimate the closest time differences between the two modes are eligible to win great bike prizes.
 - A Bike-to-Work-Week non-profit organization that plans and coordinates activities.

6. Bicycle infrastructure engineering

6.1 Introduction

Most bicycling occurs on existing streets and roads because these facilities connect all destinations directly. Bicycle use is allowed on all roads except for limited access highways where bicycles are legally prohibited. Therefore, all highways, except those where bicyclists are legally prohibited, should be designed and constructed under the assumption that they will be used by bicyclists. Bicycles should be considered in all phases of transportation planning, new highway design, highway reconstruction, and capacity improvement and transit projects. The most effective way to improve conditions for bicyclists and integrate them into the transportation system is to accommodate bicycle travel on all new and existing highways. Even if it were desirable to create a system of bikeways separated from the highway it would not be practical or affordable. Shared use paths and rail trails should be thought of as a complementary system of off-road routes for bicyclists and others that serve as an extension to the roadway network. Separated facilities should not be used to preclude on-road bicycle facilities. Rather they should be used to supplement on-road bikeways. In general, low volume rural roads satisfactorily accommodate large numbers of bicyclists annually and could better accommodate cycling through the implementation of marginal improvements. On higher volume rural roads, paved shoulders provide increased operating width for bicyclists and motorists as do bicycle lanes on major streets in downtown and village settings. Wide curb lanes and shared roadways are used where width constraints prevent the development of separate lanes or paved shoulders of adequate width to serve bicyclists.

6.2 Bicycle friendly route design

Bicycle Characteristics

Bicycle Styles and Dimensions. The three most popular styles of multi-gear adult bicycles available today are: the road bike (also called a touring or racing bike), the mountain bike (characterized by wide, fat smooth or knobby tires) and the hybrid bike (which blends the agility of the road bike and the durability and upright riding position of the mountain bike).

Variations of these styles abound with regard to gearing, passenger and baggage carrying capability, and rider position.

Wheels and tires. The wheels and tires of a bicycle are narrow and sensitive to variations, imperfections and debris in the riding surface. In addition, the pressure in bicycle tires is high compared to other, larger vehicles. This makes bicycle tires more susceptible to damage and punctures from potholes, small pieces of glass, sharp stones and pieces of metal. Sensitive to these characteristics, bicyclists sometimes must suddenly swerve to avoid an obstacle in their path, a maneuver that may appear unpredictable or erratic to a motorist sharing the same lane.

Design considerations include:

- Minimal tire surface contact with the ground (as little as 2 sq cm or 0.3 sq in.).
- Road shock transmitted directly through the bicycle to the rider (many bicycles do not have suspensions systems).
- Sand, mud, algae, snow, wet or icy leaves, metal utility covers and decking, and skewed railroad tracks can precipitate a crash.
- Longitudinal seams and cracks (as narrow as 6 mm or 0.25 in) can

cause loss of control.

- Surface edges and objects higher than 12 mm (0.5 in) can damage some rims or cause a crash.
- Underlying concrete roadways, which are common in Vermont, often create longitudinal cracks that wander on and off the shoulder and pose a significant hazard to bicyclists.

Brakes and braking

Design considerations include:

- Reaction and braking times vary widely among users (allow 2.5 sec normal reaction time; allow 3.0 sec more for a surprised reaction time).
- Application of the brake and mechanical delay can account for 1.5 sec of additional braking time.
- Maximum deceleration for a bicycle is 17 km/s^2 (11 mph per sec).
- When rims are wet or coaster brakes are used, performance is 50 to 80 percent less efficient.

Steering

Bicyclists maintain balance by steering the front wheel of the bicycle under the combined center of gravity of both bicycle and rider.

Consequently, emergency or evasive steering maneuvers cannot be accomplished quickly by most bicyclists. The initiation of an intentional sudden turn is counter intuitive (i.e., the rider must sharply steer the front wheel out from under the center of gravity in the opposite direction he or she intends to go to set up the sudden turn).

Design considerations include:

- Emergency turns cannot be accomplished as quickly on a bicycle as in an automobile.
- To initiate a turn the operator must first steer the bicycle in the opposite direction to set up a counter lean (precipitating a controlled fall).
- Allow 1.5 sec to set up a normal turn.
- Bicycles steer more slowly when heavily loaded.
- The lower the center of gravity the more stable the bicycle (high loads such as rider-mounted backpacks and bicycle-mounted child seats raise the center of gravity and make a bicycle less stable).

Tracking widths and grades

Due to steering wobble, bicyclists may track over a 1.0 m width. An increase in climbing grade can generate more wheel wobble due to the slower speed, requiring even more operating width. Also, extra operating width on descents can allow bicyclists to more safely avoid debris or surface hazards at higher speeds. Therefore, where practicable, it is desirable to provide a paved shoulder or bicycle lane at least 1.8 m (6 ft) in width on uphill and downhill grades that exceed 5 percent to provide bicyclists with additional space for maneuvering.

With multi-gear bicycles, many bicyclists can comfortably manage 10 percent grades for short distances. Experienced bicyclists can accomplish steeper grades for much longer distances (e.g., the 13 percent grade on Vermont Route 132 between South Strafford and Sharon). Grades of 5 percent are the more common limit, with grades of 4 percent or less preferred by the majority of bicyclists.

Design considerations include:

- Average operating width on level terrain is 1 m (40 in).
- Average operating width over hilly terrain is 1.2 to 1.4 m (4 to 6 ft).
- Preferred grade is 4 percent (1:25) or less.
- Acceptable grades over limited distances range from 6 to 10 percent (1:16 to 1:10).

User Characteristics

Although riders vary greatly in age, skill, dimensions and needs, the characteristics below encompass virtually all bicyclists:

Profile and visibility

Most motorists involved in car-bicycle crashes report they did not see the bicyclist before the crash. Their slender profile (and sometimes low height) of bicyclists may make them difficult to see, especially in complex visual situations. The problem is even worse in low light conditions or at night. Bicyclists can improve their own visibility by making sure their bicycles are properly equipped with reflectors, wearing bright clothing, using retro-reflective fabrics, using flashing tail lights at night, and using headlights at night. However, motorists need to be on the lookout for bicyclists. Ultimately, increased bicycle use will result in increased motorist awareness.

Considerations for design include:

- Bicyclists exhibit a thin or low profile.
- Their curbside location can reduce their being seen by overtaking, turning or parked motorists.

-
- Signs and stripes can warn motorists to expect increased bicycle use.
 - Even when using lights, bicyclists are extremely difficult to detect under low light conditions or at night time.

Motorists should be trained and expected to detect bicyclists more readily.

6.3. Types of On-Road Bikeway Facilities

The types of on-road bicycle treatments include:

- *Bicycle lane.* A portion of the roadway that has been designated by signs and pavement markings for preferential or exclusive use by bicyclists.
- *Wide curb lane.* A wider than normal travel lane that better accommodate bicycles and motor vehicles in the same lane while providing enough space for motorists to overtake and pass bicyclists without changing travel lanes.
- *Paved shoulder.* –The paved portion of the highway contiguous with the outside travel lane of the roadway that can be used by bicyclists as well as for the accommodation of pedestrians, stopped vehicles, emergency use and the lateral support of sub-base, base and surface courses.
- *Shared lanes.* Travel lanes with no additional width provided for bicyclists.

In addition, traffic calming techniques can effectively reduce the speed of motor vehicles along a roadway and signs and pavement markings may be used to alert motorists of increased bicycling activity in certain locations, designate routes and convey information to bicyclists .

Selecting Appropriate Bicycle Facilities

The wide variation in ability needs and desires among bicyclists can make it difficult to plan and design facilities that meet all the needs of these users.

Indeed, no one type of bicycle facility or highway design will suit all bicyclists and no bicycle facility can overcome a lack of bicycle operator skill. It is important to recognize that the choice of any one particular design will affect the type of rider that will be attracted to a facility, the level of use along the facility, and the level of access and mobility that will be afforded to bicyclists.

Design users

Accommodating bicyclists begins with the understanding that not all bicyclists are alike. The characteristic that best differentiates bicyclists is ability, which may be defined as a combination of skills, knowledge and judgment.

The Bicycle Federation of America estimates that one out of three people (100 million) in the United States own a bicycle, yet it is believed that fewer than 5 percent of these bicycle owners qualify as experienced or highly skilled bicyclists. Therefore, the vast majority of bicycle riders may be considered intermediate and novice bicyclists.

The 1994 FHWA report, *Selecting Roadway Design Treatments to Accommodate Bicyclists*, identified three general categories of bicycle user types (A, B and C) to assist highway designers in choosing different facility types for different roadway conditions for different types of bicyclists. AASHTO recognizes the same bicycle user types in their *Guide for the Development of Bicycle Facilities*.

The three general bicycle user types are:

Group A — Advanced Bicyclists

These bicyclists exhibit the following characteristics:

- Experienced riders.
- Have a level of comfort operating in traffic conditions.
- Use existing roadway system.
- Operate at maximum speed with minimum delay.
- Require minimal operating space on the roadway or shoulder to reduce the need for either the bicyclist or the motor vehicle operator to change position when passing.

Group A bicyclists are best served by:

- Wide outside lanes on urban arterials and collectors.
- Usable shoulders on rural highways.

Group B — Basic Bicyclists

Group B bicyclists exhibit the following characteristics:

- Casual or new adult or teenage riders.
- Less confident of their ability to operate in traffic without special provisions for bicycles.
- Some will become advanced bicyclists, most will remain basic riders.
- Prefer low-speed, low traffic-volume streets or designated bicycle facilities.

Group B bicyclists are best served by:

- Extra operating space when riding on the roadway.
- Ensuring low speeds on neighborhood streets.
- Network of designated bicycle facilities (bicycle lanes, side-street

bicycle routes and shared-use paths.

- Usable shoulders on rural highways.

Group C — Children

The bicycle riders that comprise Group C share these traits:

- Children, usually pre-teen riders.
- Roadway use initially monitored by parents.
- May not comply with traffic regulations.
- They (and their parents) prefer residential streets with low motor vehicle volumes and speed limits, and well-defined separation of bicycles and motor vehicles or separate pathways.

Group C bicycle riders are best served by:

- Ensuring low speeds on neighborhood streets.
- Extra operating space when riding on the roadway or facilities separated from motor vehicle traffic.
- Network of designated bicycle facilities (bicycle lanes, paved shoulders, side-street bicycle routes, shared use paths, and rail trails).
- Riding on a sidewalk where pedestrians are not endangered or when pedestrian activity is low. The design values in this chapter are aimed at meeting the needs of all bicyclists including Group B and C riders.

As a goal, a particular bicycle facility design should be chosen to encourage use by the lowest caliber bicyclist expected to frequently use the facility. For basic adult and child bicyclists (Groups B and C), bicycle lanes, wide curb lanes and paved shoulders — facilities that provide extra operating space on a roadway — or an alternate route using neighborhood streets, or shared use paths and rail trails are the design treatments that are favored.

Wide Curb Lanes

Wide curb lanes are suited for use in village or urban areas where insufficient widths for bike lanes exist. They are distinguished from bike lanes by the absence of signs or pavement markings which specifically designate them for bicycle use. The intent of wide curb lanes is to provide extra space to better accommodate bicycles and motor vehicles in the same lane while providing enough space for motorists to overtake and pass bicyclists without changing travel lanes.

Design Considerations

- Wide curb lanes are usually preferred in restrictive settings such as village centers and urban environments where shoulders or bike lanes cannot be provided.
- Where steep grades exist, additional operating width for bicyclists may be required.
- Provide a 100 mm (4 inch) white line or tick marks between wide curb lanes and on-street parking
- Widths greater than 4.2 m (14 ft) that extend continuously along a highway for long distances may encourage the undesirable operation of two motor vehicles side by side in one lane. In such situations, consider striping bicycle lanes or shoulders.

Restriping existing multi-lane facilities may result in enough room to install wide curb lanes where travel lanes and left-turn lanes can be narrowed or the existing number of lanes can be reduced (refer to Section 4.3.9, Reallocation Roadway Space). However, this should only be considered after careful review of traffic characteristics along the corridor and where supported by a documented engineering analysis.

Width

Refer to the Vermont State Standards for minimum widths of wide curb lanes. The widths are dependent on roadway classification, design speed and traffic volume and range from 3.6 m to 4.5 m (12 to 15 ft). Consideration should be given to providing additional width when large numbers of trucks are expected (i.e., 30 or more overtaking heavy vehicles per hour in an outside lane) or limited sight distances exist.

On uphill grades, a bicycle climbing lane or wide paved shoulder can provide slowly moving bicyclists with extra width to accommodate wobble and maneuvering.

Wide curb lanes are suited for use in village or urban areas where insufficient width for bike lanes exists.

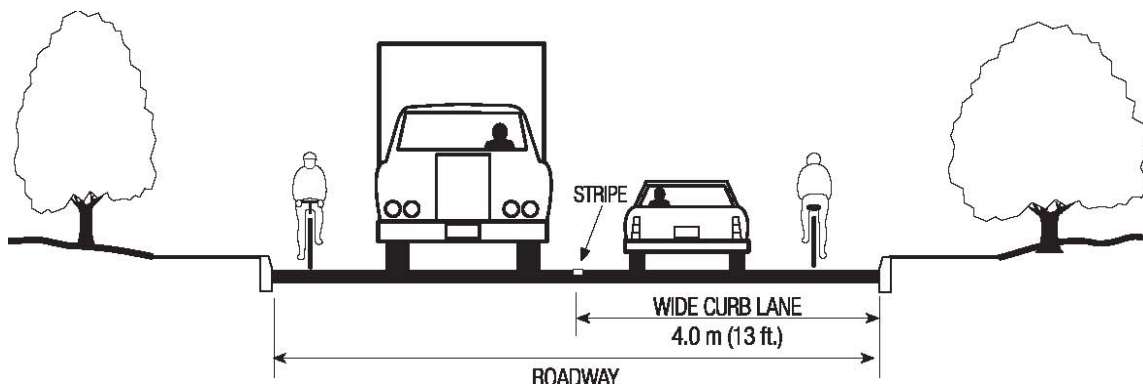


Fig 6.1 Wide Curb Lane with No Parking.

Bicycle Suitability Measures for Roadways

Bicycle planning has been a rapidly growing field over the past decade. Local, regional, state and federal units of government are recognizing that

bicycling is an efficient, healthy, inexpensive and viable form of transportation that can help ease traffic congestion and air quality problems while providing access to destinations for people who cannot or choose not to drive.

Although cycling is a popular recreational activity, it is underutilized as a form of transportation, in part due to a lack of comfortable, safe and direct biking facilities. Transportation plans and policies from the national to local level now call for bicycle-friendly roads to more safely accommodate those who bike by choice or necessity.

To improve the cycling environment, many communities are developing bikeway networks, a combination of on and off road routes that are specifically designated for bicycle travel. Designation as a bikeway implies a road or path has bicycle "friendly" features, such as comfortable traffic volumes and speed, enough room for different road or path users traveling at different speeds, easy to navigate intersections and directness. For example, the 2000 edition of the city of Chicago's bikeway map features a 300-mile network of streets with existing and planned bicycle lanes, recommended routes, and shared-use paths. Cyclists can use it to find streets that are more hospitable to cyclists than others, particularly for longer trips, and planners can use it to coordinate bicycle accommodations with other road projects. For example, 13 miles of bike lanes are scheduled to be implemented in Chicago in 2001 as part of various IDOT and CDOT reconstruction and resurfacing projects.

Technical resources are available to assist in the development of bicycle friendly facilities. In 1999, the American Association of State and Highway Transportation Officials (AASHTO) released the *Guide for the Development of*

Bicycle Facilities. It includes design guidance for bike lanes, paved shoulders, wide outside curb lanes, marked routes and shared used paths. For example, it suggests that bicycle lanes have a minimum width of five feet when placed next to a parking lane to provide enough room for cyclists to avoid opening car doors. It also outlines operational concerns associated with sidepaths (shared-use paths that are located immediately adjacent to a roadway), such as intersection conflicts and cycling against the flow of motorized traffic

Including bicycle facilities that are designed to meet AASHTO standards can improve a transportation corridor's suitability for cyclists. However, the type of facility chosen and the character of the traffic mix and adjacent land-use will influence the level of suitability. Cycling in a wide outside curb lane on a road with heavy truck traffic and many driveways feels different than cycling on one without. Other factors that influence a cyclist's comfort and perception of safety include pavement conditions, parking turnover rate and motorized traffic speed and volume (or, in the case of shared use paths, non-motorized traffic speed and volume). Objective performance measures, analogous to those used for motorized travel, are useful for helping planners, engineers and decision makers evaluate existing road and path facilities, identify appropriate improvements and prioritize projects.

7. Suitability Measures for Bicycles as Planning Tools

Most bicycle suitability measures quantify a cyclist's *perceived* safety on a particular roadway, as a function of factors including traffic volume, traffic speed, pavement condition, and lane width. This perception of a safe bicycling environment is a major determinant in an individual's mode choice of bicycling. Suitability scores are translated into a "Level of Service" (LOS) from A to F, consistent with the terminology of other transportation performance measures. Other travel modes use measures based on vehicular flow and capacity, but their LOS gradations are also ultimately based on human perception – for example, motorist tolerance of traffic delays and conditions.

A quantified measure of roadway suitability for bicycle travel could be used for:

- Identification of needs and missing links
- Comparison of various design options
- Prioritization of bicycle facility projects
- Development of bicycle suitability maps
- A term in project evaluation formulas, to provide "credit" for making roads bike-friendly
- The "travel impedance" in both the trip distribution and assignment steps of travel forecasting models for urban utilitarian bicycling – a field still under development

7.1. Bicycle Compatibility Index (BCI)

The Federal Highway Administration developed the Bicycle Compatibility Index (1998), based on the research of the University of North Carolina

Highway Safety Research Center, Sorton and Walsh, and others. Like the other three measures surveyed here, BCI evaluates mid-block road segments but not intersections. Bicyclists in the study were shown videotapes of selected road segments. Eight independent variables related to their perceived safety were selected along with three adjustment factors. BCI stresses the importance of bike lanes and paved shoulders over 3' wide. It has a linear dependence on traffic volume, resulting in a very small effect until traffic volumes are quite high. Included are terms for parking occupancy and turnover, heavy vehicle volume, and smaller terms for adjacent development type and right-turning traffic. The basic model, excluding adjustment factors, has a very high correlation coefficient of $R^2 = 0.89$.

$$\text{BCI} = 3.67 - 0.966\text{BL} - 0.410\text{BLW} - 0.498\text{CLW} + 0.002\text{CLV} + 0.0004\text{OLV} + 0.022\text{SPD} + 0.506\text{PKG} - 0.264\text{AREA} + \text{AF}$$

Where:

BL = presence of bike lane or paved shoulder > 0.9m: no 0, yes 1

BLW = bike lane (or paved shoulder) width in meters (to the nearest tenth)

CLW = curb lane width in meters (to the nearest tenth)

CLV = curb lane volume in vehicles per hour in one direction

OLV = other lane(s) volume, same direction, in vehicles per hour

SPD = 85th percentile speed of traffic in km/hr

PKG = presence of parking lane with more than 30% occupancy: no 0, yes 1

AREA = type of roadside development: Residential 1, other type 0

AF = $f_t + f_p + f_{rt}$

f_t = adjustment factor for truck volumes (see below)

f_p = adjustment factor for parking turnover (see below)

f_{rt} = adjustment factor for right-turn volumes (see below)

Bicycle Compatibility Index ranges associated with level of service (LOS) designations:

BCI Range	1.50	1.51-2.30	2.31-3.40	3.41-4.40	4.41-5.30	> 5.30
LOS Level	A	B	C	D	E	F
Compatibility Level	Extremely High	Very High	Moderately High	Moderately Low	Very Low	Extremely Low

Table 7.1 BCI grading

7.2. Bicycle Level Of Service (BLOS)

Landis et al. developed the Bicycle Level of Service (1997) using a different technique. The research involved riders on actual field courses, instead of cyclist reaction to filmed conditions. BLOS is similar to BCI in its sensitivity to curb lane width. Its traffic volume dependence is logarithmic, increasing the impact of changes at low and medium traffic levels. Additional paved shoulder or bike lane width affect the BLOS score somewhat more than the BCI. Ignored are development type, parking, and right-turning traffic, but bad pavement surfaces and higher heavy vehicular traffic having a major impact. Further work is planned for rural highways and for central business district roads with high parking turnover. The model has a high correlation coefficient ($R^2 = 0.73$) and can be used in metropolitan areas throughout the United States.

$$BLOS = 0.507 \ln(Vol15/Ln) + 0.199 Spt(1+10.38HV)^2 + 7.066(1/PR5)^2 - 0.005 We^2 + 0.760$$

Where:

$$Vol15 = \text{volume of directional traffic in 15 minutes} = (ADT * D * Kd) / (4 * PHF)$$

ADT = Average Daily Traffic on the segment

D = Directional Factor

Kd = Peak to Daily Factor

PHF = Peak Hour Factor

Ln = number of directional through lanes

SPT = effective speed limit = $1.1199 \ln(\text{SPp}-20) + 0.8103$, where SPp is the posted speed limit

HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)

PR5 = FHWA's 5-point pavement surface condition rating (5=best)

We = average effective width of outside through lane:

$We = Wv - (10' * \text{OSPA})$ where $Wl = 0$

$We = Wv + Wl (1 - 2 * \text{OSPA})$ where $Wl > 0$ & $Wps = 0$
 $We = Wv + Wl - 2 (10' * \text{OSPA})$ where $Wl > 0$, $Wps > 0$, and a bike lane exists.
 Wt = total width of outside lane (and shoulder) pavement

OSPA = fraction of segment with occupied on-street parking
 Wl = width of paving between outside lane stripe and edge of pavement
 Wps = width of pavement striped for on-street parking
 Wv = effective width as a function of traffic volume

$Wv = Wt$ if $\text{ADT} > 4000$ veh/day
 $Wv = Wt (2 - (\text{ADT}/4000))$ if $\text{ADT} < 4000$ and road is undivided and unstriped.

Bicycle Level of Service ranges associated with level of service (LOS) designations:

BLOS Range	1.50	1.51-2.50	2.51-3.50	3.51-4.50	4.51-5.50	> 5.50
LOS Level	A	B	C	D	E	F

Fig 7.2 BLOS grading

7.3. IDOT (Illinois Department of Transportation) Bicycle Map Criteria

This formula was created by IDOT before other algorithms were available. It has been used since 1994 to automatically generate IDOT’s district bike suitability maps from its database of state, county, and township roads. The ratings were derived from a consensus of a panel of bicyclists. Each of four terms – type of pavement, lane width, paved shoulder width, and average daily traffic – is discretized into three ranges. It is primarily intended to rate rural roads – no speed limit term exists and typical rural speeds are assumed. Almost all urban roads, particularly in the Chicago area, appear as red (poor). The upper range for Average Daily Traffic volume per lane covers a wide range, starting at 2000 vehicles/day. Very low ADT/lane (<750) rural roads have a higher suitability score than those of other measures. Significant credit is given for a 12’ (or more) curb lane and for a 4’ (or more) paved shoulder/bike lane.

Add these four terms for a maximum of 1.000:

Roadway Surface:	High = 0.054	Low = 0.019	Oil/chip = 0.006
Lane Width:	12' = 0.189	10' - 11.9' = 0.052	< 10' = 0.019
Shoulder Width (paved):	4 = 0.132	1' - 3' = 0.033	None = 0.012
ADT/Lane:	< 750 = 0.374	750-2000 = 0.082	> 2000 = 0.028

For ADT/Lane < 2000 (or 200 trucks): For ADT/Lane > 2000 (or 200 trucks):

No road segment with a CRS (surface condition rating) of less than 4.5 (new pavement = 9.0) can be rated GREEN, regardless of ADT. The ratings are interpreted as follows:

-
- Good/Green roads are “most suitable for the average or experienced cyclist.”
 - Fair/Yellow roads are “cautionary for cycling, but may be suitable for more experienced cyclists who are comfortable with riding in traffic conditions.”
 - Poor/red roads “should be avoided by cyclists.”

8. Result and Discussion

The road network of Addis is very short, low quality, highly deteriorating and badly loaded with traffic. As a direct consequence of these problems there exists high delay of time and traffic accidents on most roads of the city. The total length of roads in the city has increases from 1865 km in 1998 to 2146 km in 2004 of which 778 km (36%) was asphalt roads and the rest 1,368 km (64%) was gravel roads. Once again roads with walkway & drainage in 2004 had the share of 11.74% & 28.7% respectively from the total length of roads.

The average width of roads in the city is 6.5 m. Most of the roads are two-lane that means two cars can use a segment of the given road at a time. There are only two roads with eight lanes out of the total 9093 road segments.

Lane number	Count
0	6918
1	116
2	1831
3	166
4	43
5	16
6	1
8	2

Table 8.1 lane summary

AACRA categorized the roads into five hierarchies according to its geometrical, operational and locational conditions. Each of these roads has its own characteristics with respect to the indicated parameters. For

instance, Hierarchy-1 roads are those main roads including the ring road with moderately large width that are serving the central parts of the city. These roads are commonly serve as the main arterials of the city and highly congested by traffic.

Hierarchy	Count
0	6918
1	524
2	352
3	526
4	773

Table 8.2 hierarchy *summary*

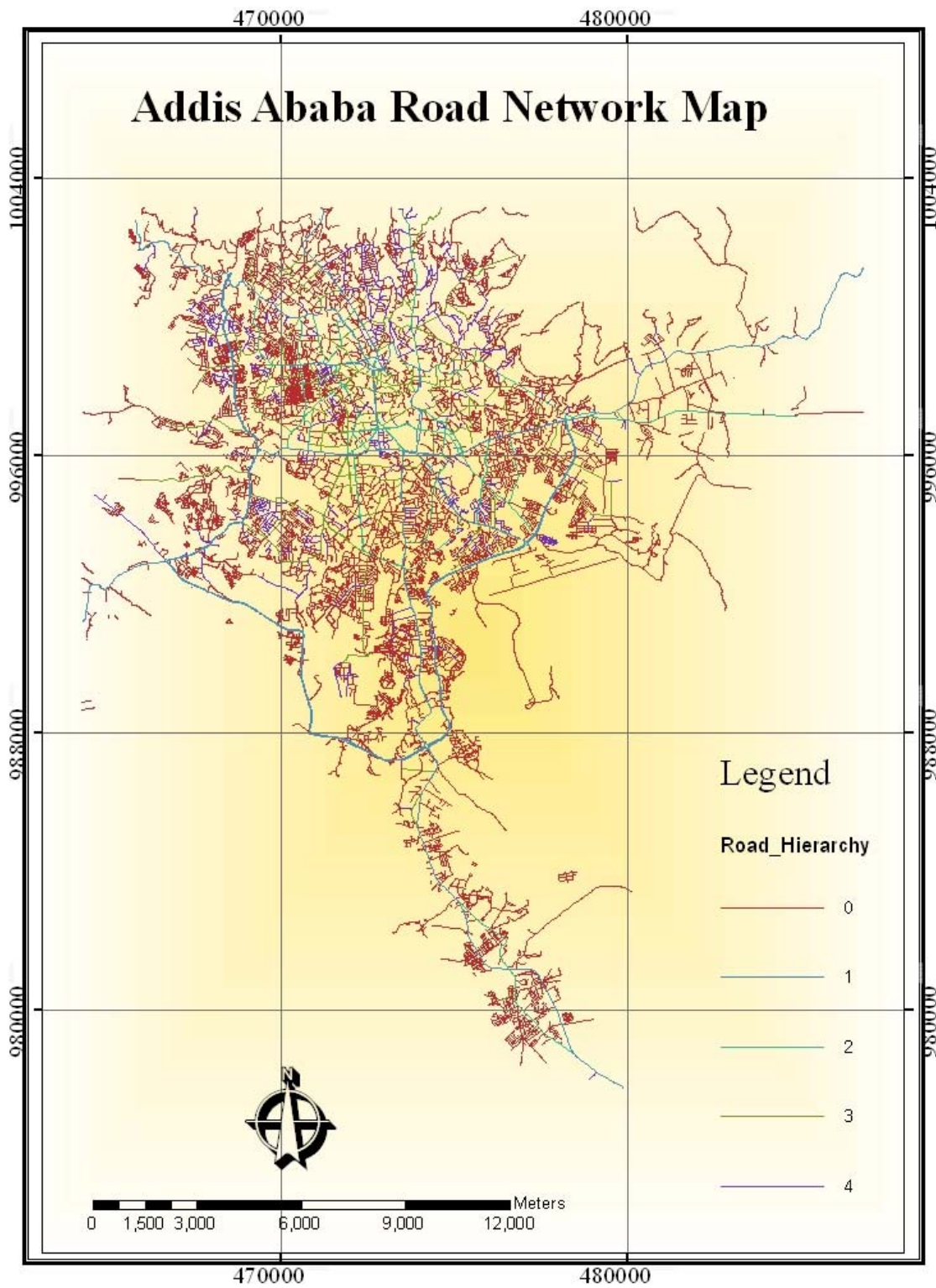


Fig 8.1 roads based on hierarchy

The existing system – the road network and transport system- couldn't satisfy the city's mobility demand. The least cost and effective solution to these problems is, diversifying the existing modes of transport. The most common form of this diversified transport system is use of bicycle as a mode of transport. In multimodal transport systems each mode has its own advantage and needs proper information of use on the existing network.

In this project three factors are considered to have a major impact on selection of routes for cycling namely, slope-gradient, segment traffic load and road surface condition. Even though there are many factors that can potentially influence selection of bicycle friendly routes; this research was limited by only to these factors with a consideration of data availability, financial constraint and the study areas context.

For the case of simplicity the evaluation of road network is done in two consecutive phases. By the first phase all the roads of the city were evaluated using general criteria. Considering the result from the general evaluation and by applying more detail criteria faithful results were obtained for some selected roads of arada sub-city.

8.1. General discussion

Addis Ababa is amongst those cities found at high elevation in Africa. Its terrain varies between 2050 and 3026 m a.s.l. Most of high elevation areas that exhibits extreme roughness found at the northern and eastern part of the city. While the central and southern part of the city is predominantly flat as shown in the figure below.

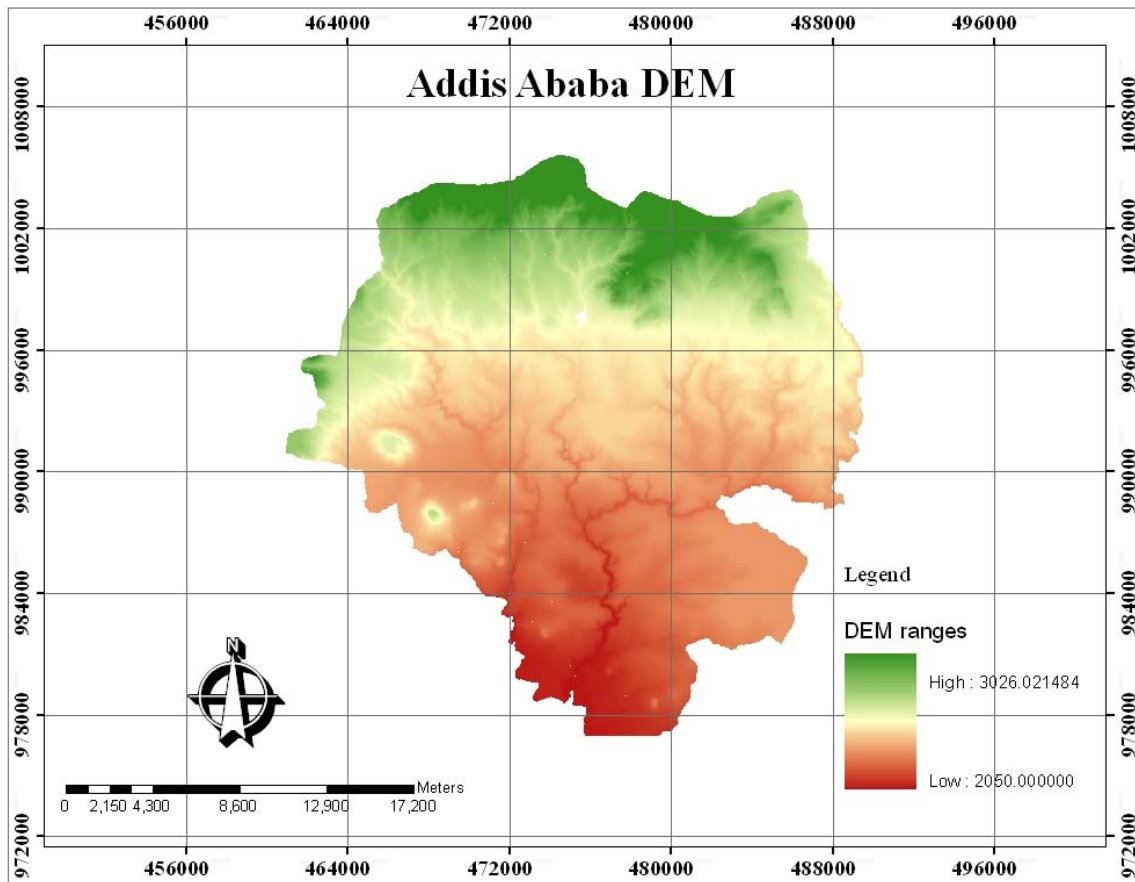


Fig 8.2 Addis Ababa DEM

MIN	MAX	RANGE	MEAN	STD
2050	3026.02	976.02	2345.06	179.26

Table 8.3 summary statistics of terrain variation

In addition to high elevation and roughness, the city's topography exhibits high variation in slope. Practically there are slope ranges from 0° and 39°. Most of high slope areas are found again in the northern and eastern part of the city as direct consequence of high roughness.

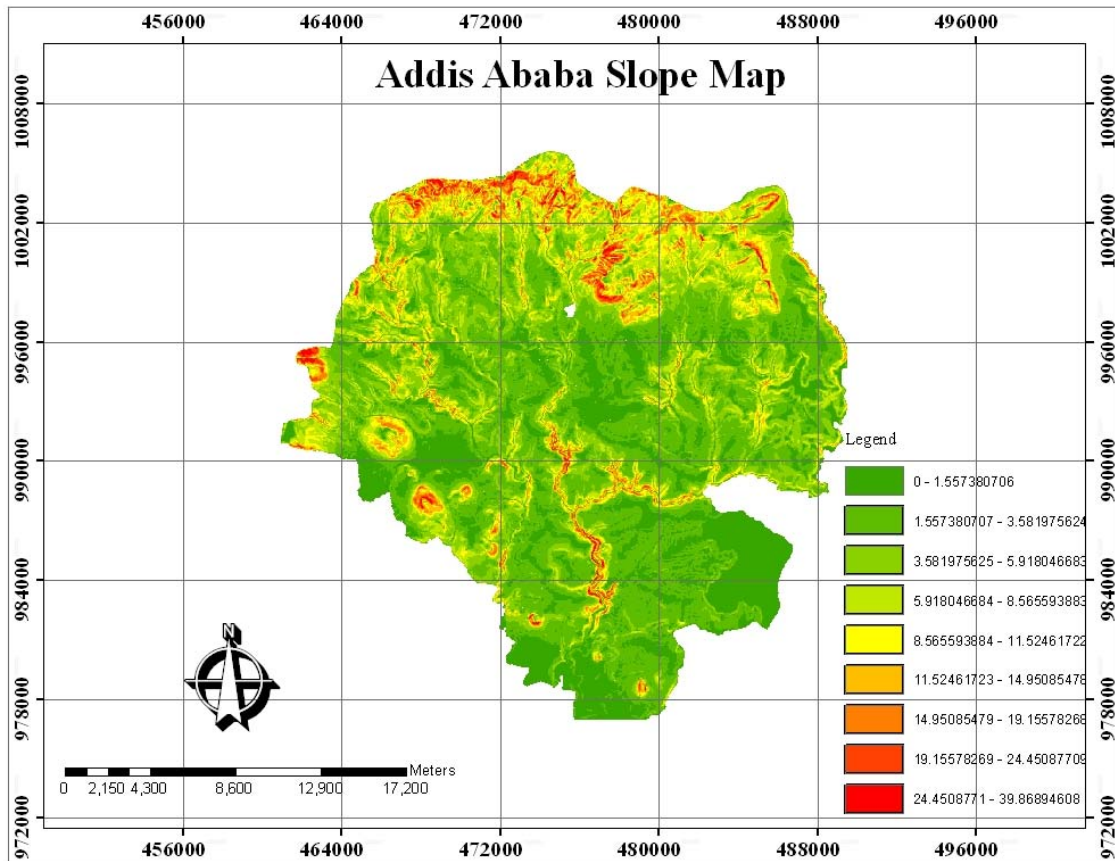


Fig 8.3 Addis Ababa slope map

Slope ranges	Percent	Description
Less than 2°	27.19671	Low
Less than 10°	61.73548	Moderate
Less than 39°	11.0678	High

Table 8.4 summary of Addis Ababa slope

As we see from the above table, the majority areas of Addis are found below 10°. Most steep slope areas are found at the northern parts of the city. Slope values strongly affect urbanization. Housing and road alignments are most favorable in gently sloping areas. Therefore the current trend of the city's expansion is to the south of the city.

Interestingly, as shown in the figure, most of the road networks of the city are found at the northern parts of the city. This is because the city is originally established in the northern part of its current extent. However the current trend by the city's government is to expand laterally to the south and western areas.

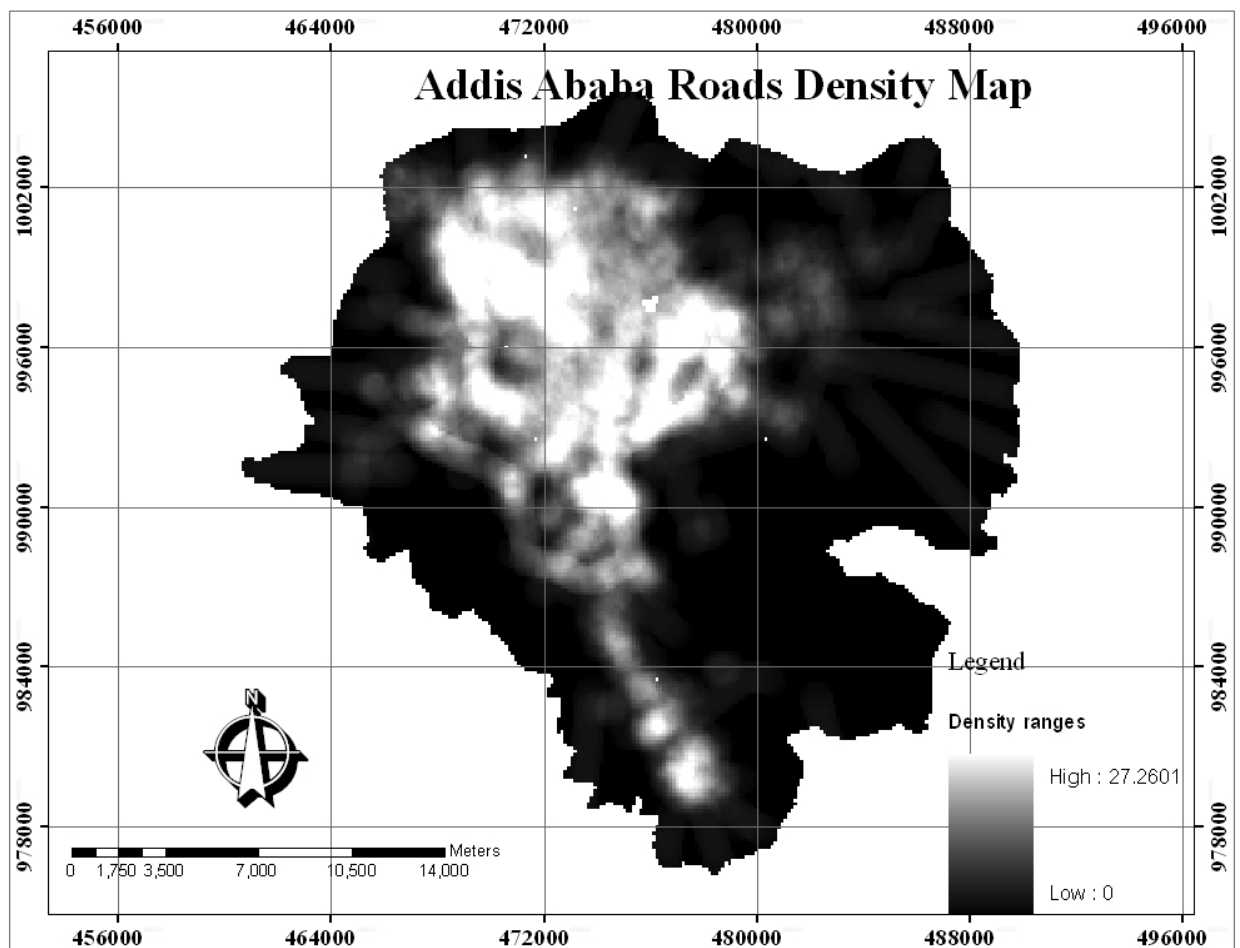


Fig 8.4 road density

Slope condition

Cycling needs gradient of the given road to be low because it is labor intensive activity. Less than 5% is recommended by AASHTO's guideline for bicycle track design manual. When the existing road network is constrained by such slope factor most of the roads in the northern part of the city found unsuitable for cycling. Whereas most of the roads in the central part of the city were found suitable for cycling. For this general evaluation it was taken that tolerable slope range to be less than 10 %.

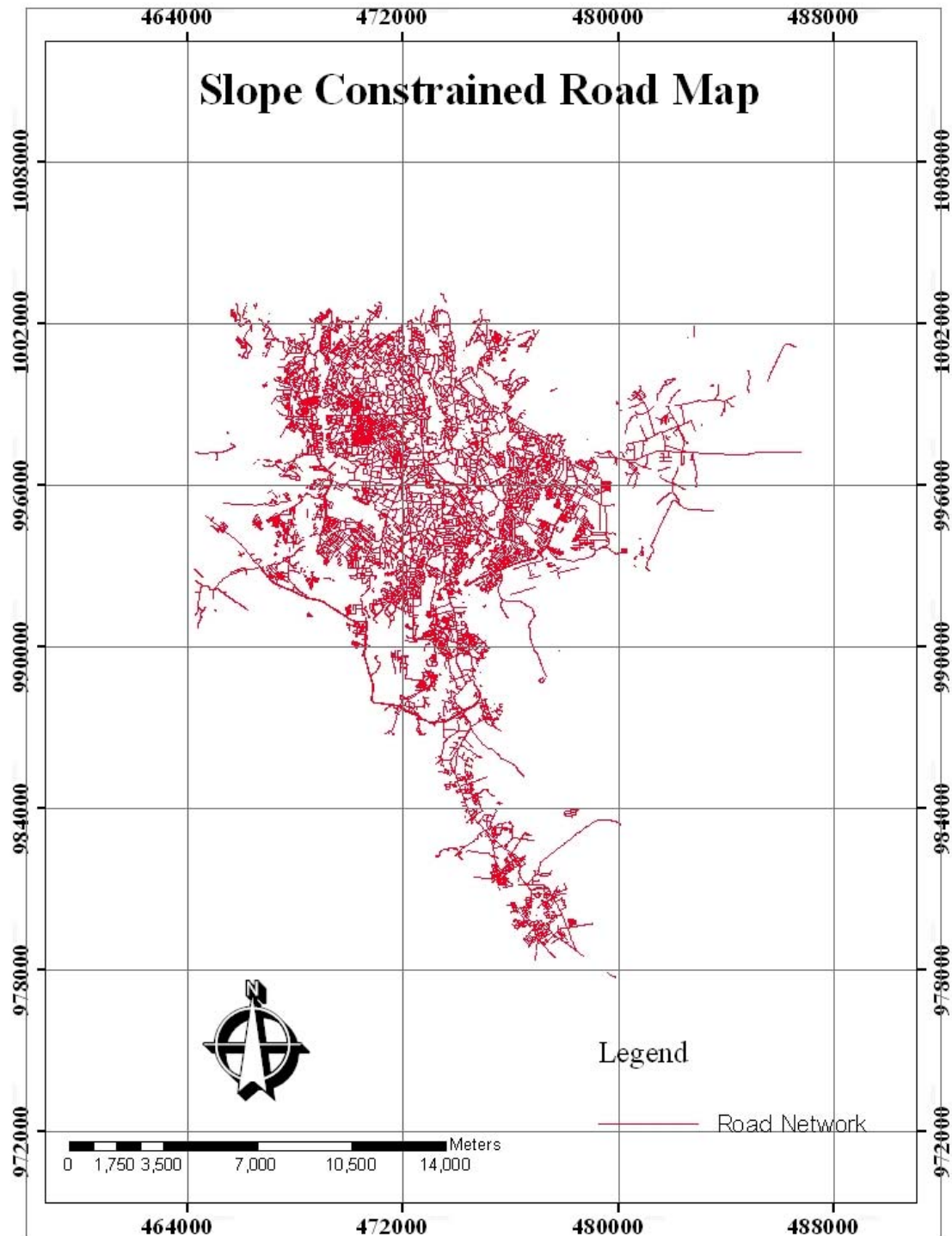


Fig 8.5 slope constrained road map

The above figure shows that about 2.2% of the total road network is removed due to slope factor. Therefore 198 road segments out of the total 9084 segments are excluded.

Surface condition

The quality of roads in the city is very poor. Around 64 % of the roads of the city are unpaved. This could be caused from low level of inventory and financial limitation. The AACRA is moving towards expansion of roads to bring more accessibility. Where as maintenance of the existing roads were not given a serious attention.

Here, only usable street were referenced because information on pavement quality was not available for all streets. The road networks that are surface paved are shown below.

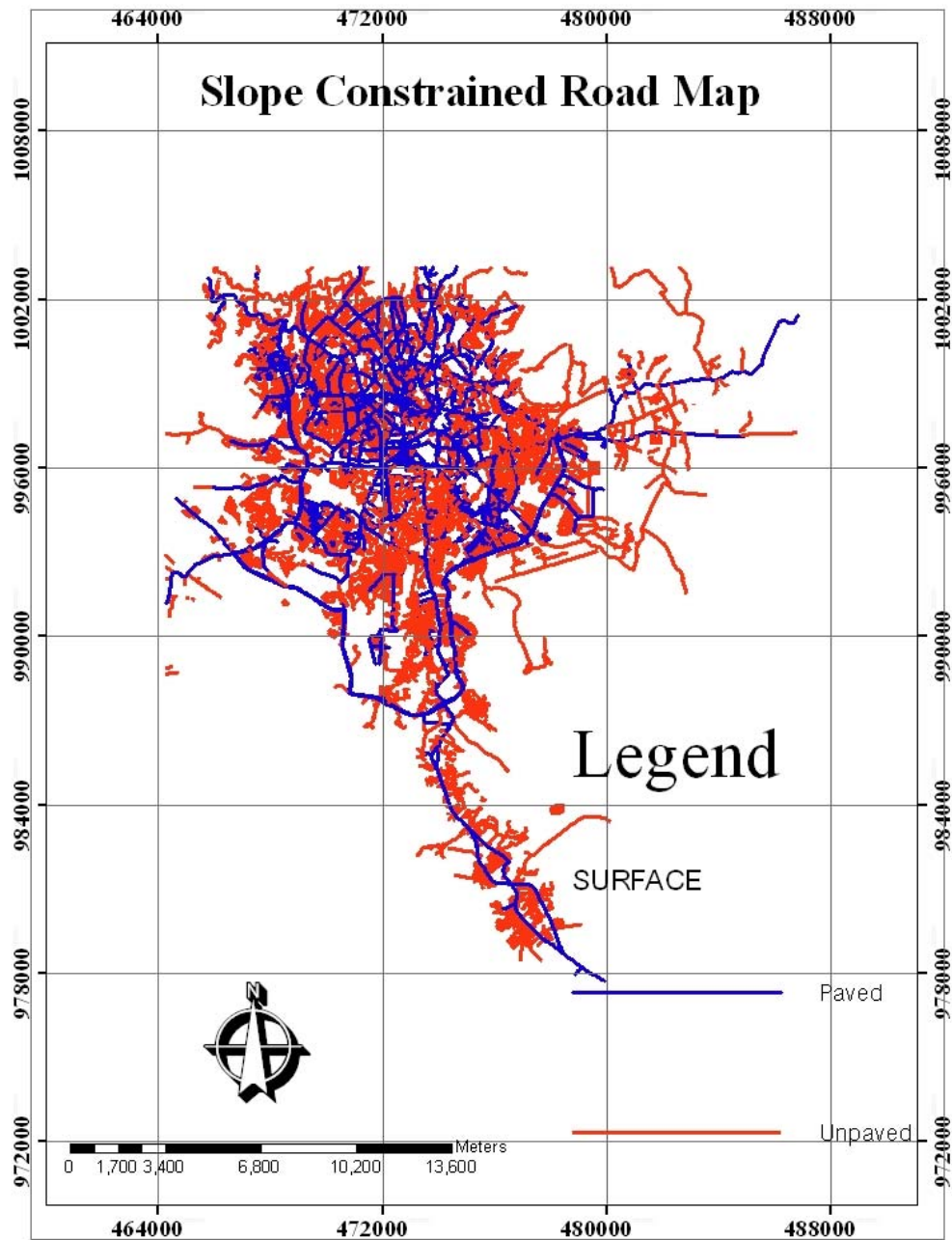


Fig 8.6 road pavement condition

Again by this factor additional 6746 road segments are excluded. The remaining road segments are only 2140 out of the total 9084 road segments of the city. Road surface criteria excluded nearly 63 % of the total roads.

Traffic condition

Traffic load of the roads in Addis is varying widely. High traffic roads are observed in the central part of the city in hierarchy-1 roads. More than 43% of the total traffic loads are found in hierarchy-1 road segments. The least traffic load is observed in roads with hierarchy 4.

HIERARCHY_	Road segments count	Traffic count	Percent
0	6918	0	0
1	524	4544547	43.56271
2	352	2716390	26.03853
3	526	2345512	22.4834
4	773	825747	7.915371

Table 8.4 summary of road traffic

Cycling requires low traffic load for many reasons including accidents and environmental problems induced by motor vehicles. Roads with steep gradient are not desirable for cycling and hence most of hierarchy-1 roads were excluded. Most literatures consider AADT less than 2000 is tolerable for cycling for general purpose route evaluations.

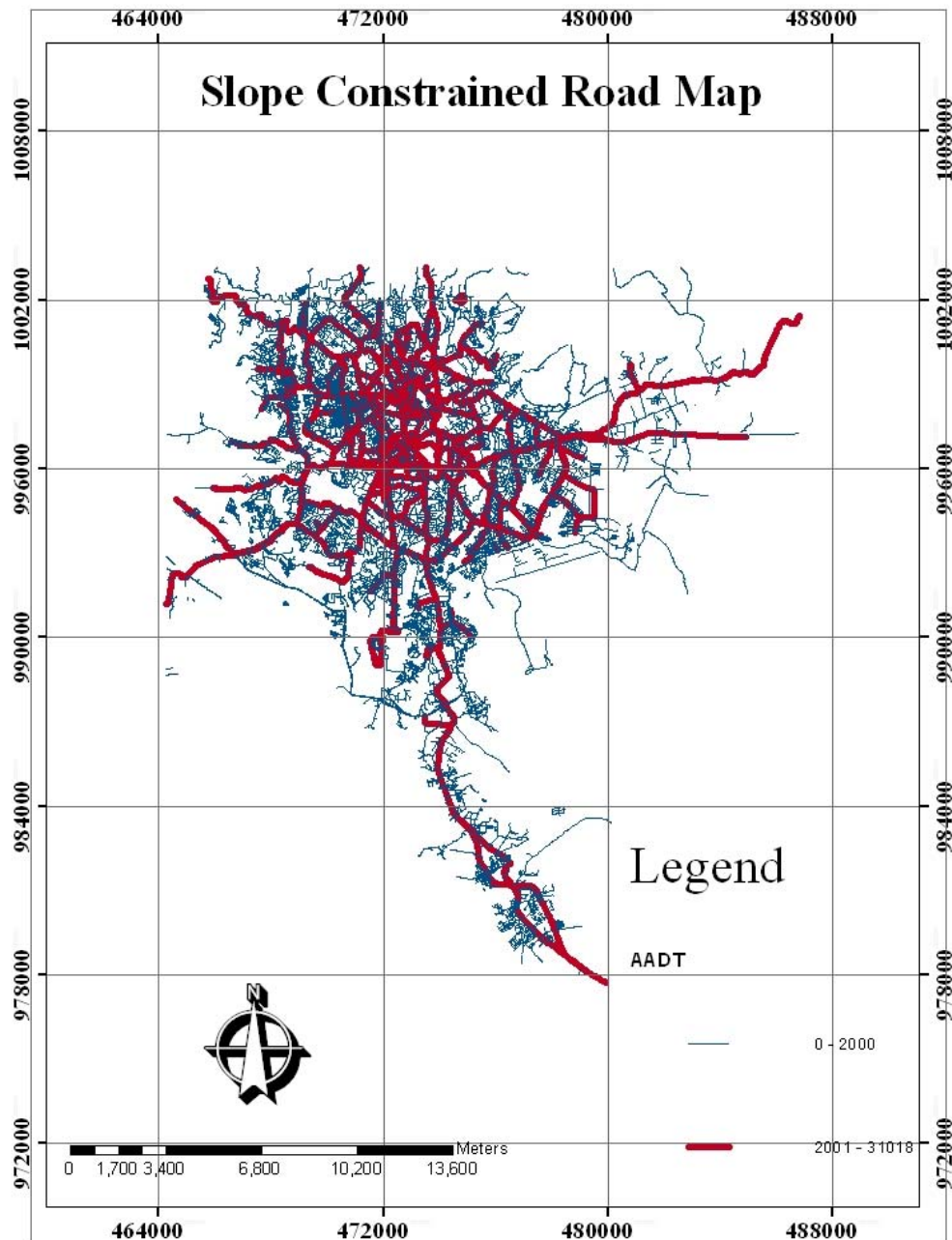


Fig 8.7 road traffic

Additional 1242 road segments are excluded due to traffic load parameter. Finally only 898 road segments are remained from the total roads. The final findings indicated that only 9.88% of the entire road segments in the city are suitable for cycling.

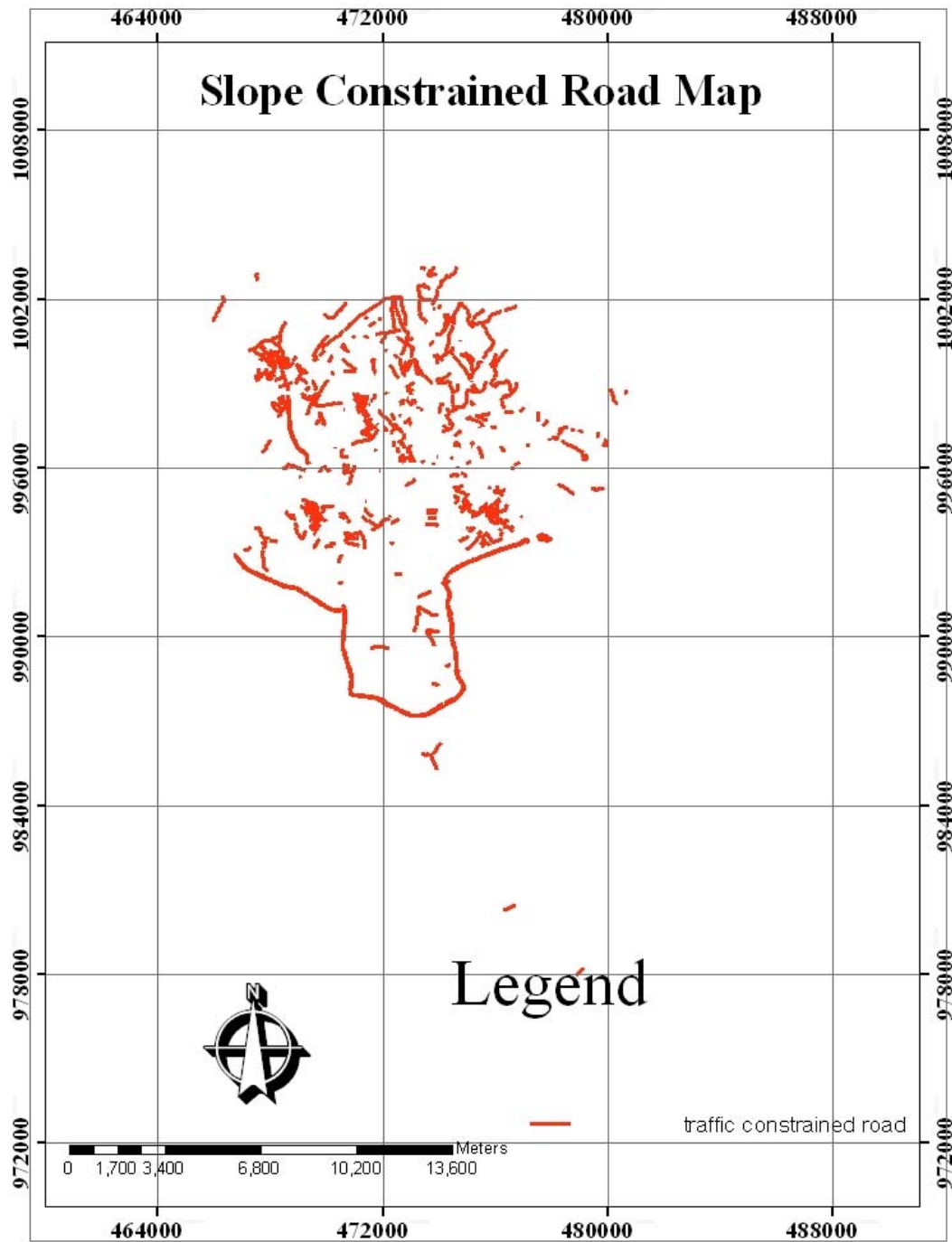


Fig 8.8 traffic constrained road map

Summary of the general evaluation

As discussed earlier the general evaluations of the entire roads were considered important because it can give a general overview for identification of roads for detail investigation. The factors used to select potential routes for cycling were very general. However the second phase of the evaluation was made on the basis of it. From the entire road segments of the city this general evaluation selects only 9.88%. The extraction was summarized as follows:

	Factors			Road segments
	Slope	Traffic	Surface	
Initial segment count				9084
Slope constrained	198			8886
Traffic constrained		1242		2140
Surface constrained			6746	898

By the second phase considering the findings from the general purpose evaluation, further analyses were made to produce faithful result that can possibly be used by commuters. Even though factors used on both cases were similar the levels of detail were very different. In the coming section we will discuss how the detail evaluation of road segments performed and what the result of this analysis looks like.

8.2. Specific discussion

In order to examine the existing roads for their suitability to be used as bicycle route, a specific part of the city- arada sub city- were chosen. Arada sub city is selected among the other ten sub cities with a consideration of high terrain variation, traffic congestion and socioeconomic background. It was very important to introduce diversification of mode in this sub city where there exists people with very different socioeconomic background. It will bring an equitable transport system where all people can satisfy their travel need through use of specific and affordable mode of transport consistent to their background.

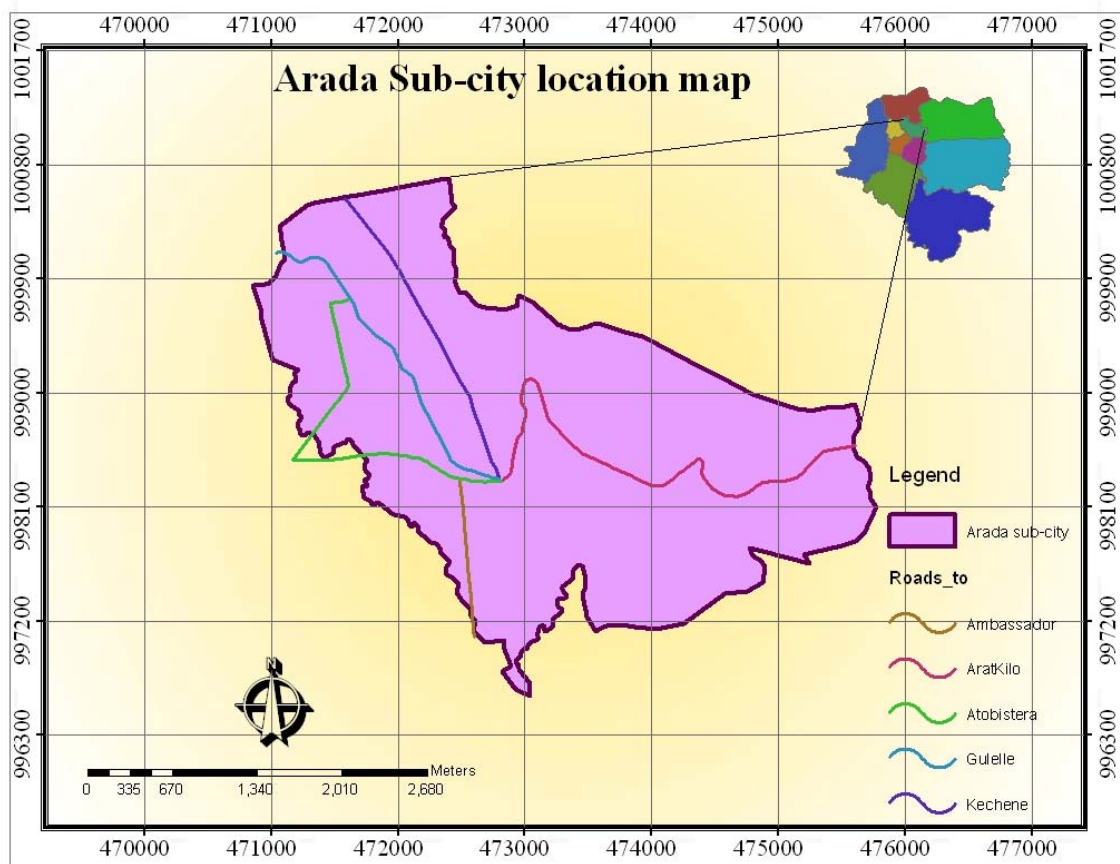
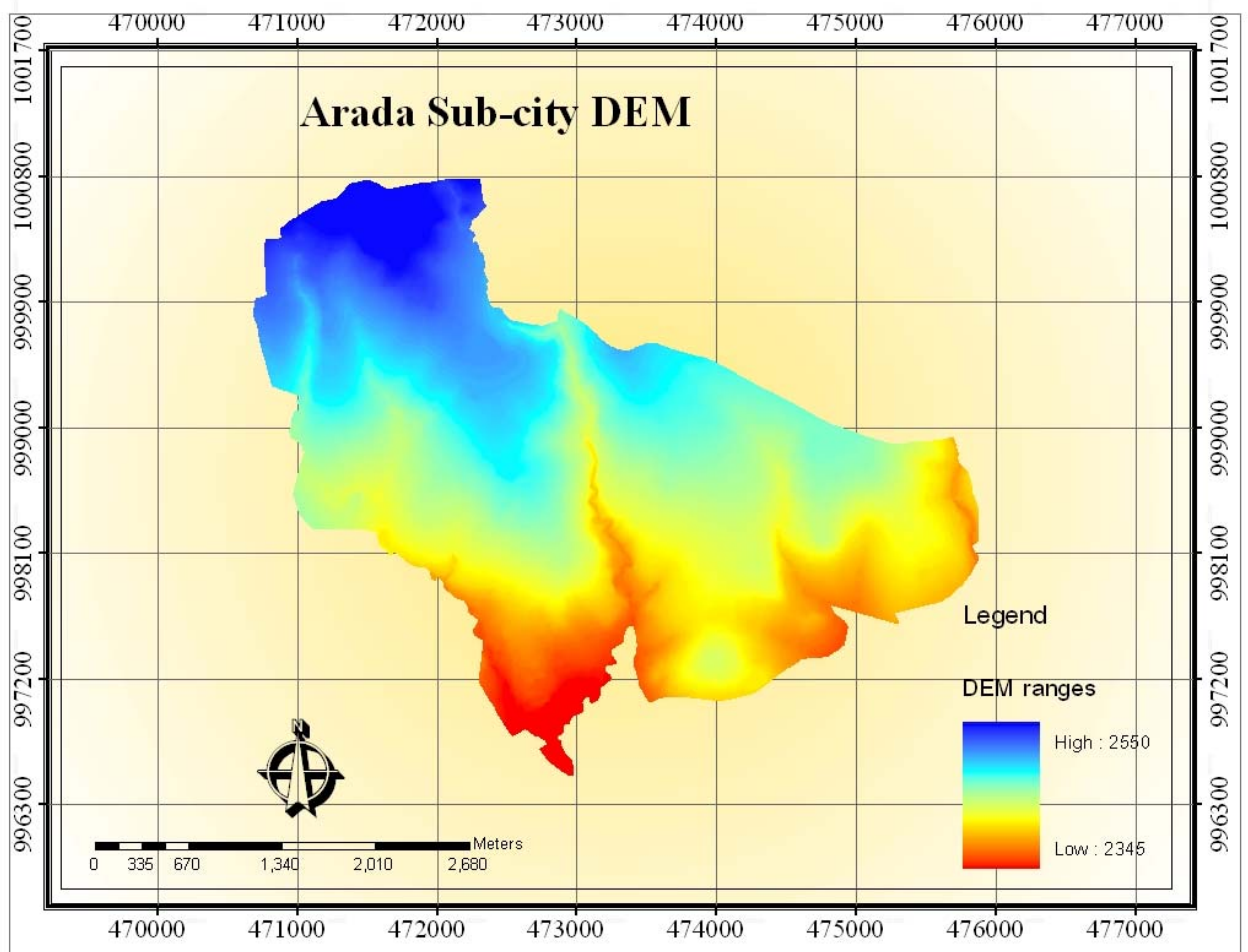


Figure 8.9 study area for specific discussion (*Arada sub-city*)

Gradient

As discussed earlier gradient of roads strongly influence its nomination to serve as cycling route. In this discussion gradient of each road segment was calculated individually in order to find more reliable result that can be used by bicyclists.

The study area's terrain varies between 2345 and 2550 m a.s.l. Most of high elevation areas are found at the northern most parts of the study area. While most of steep slope areas are found following major rivers crossing the study area.



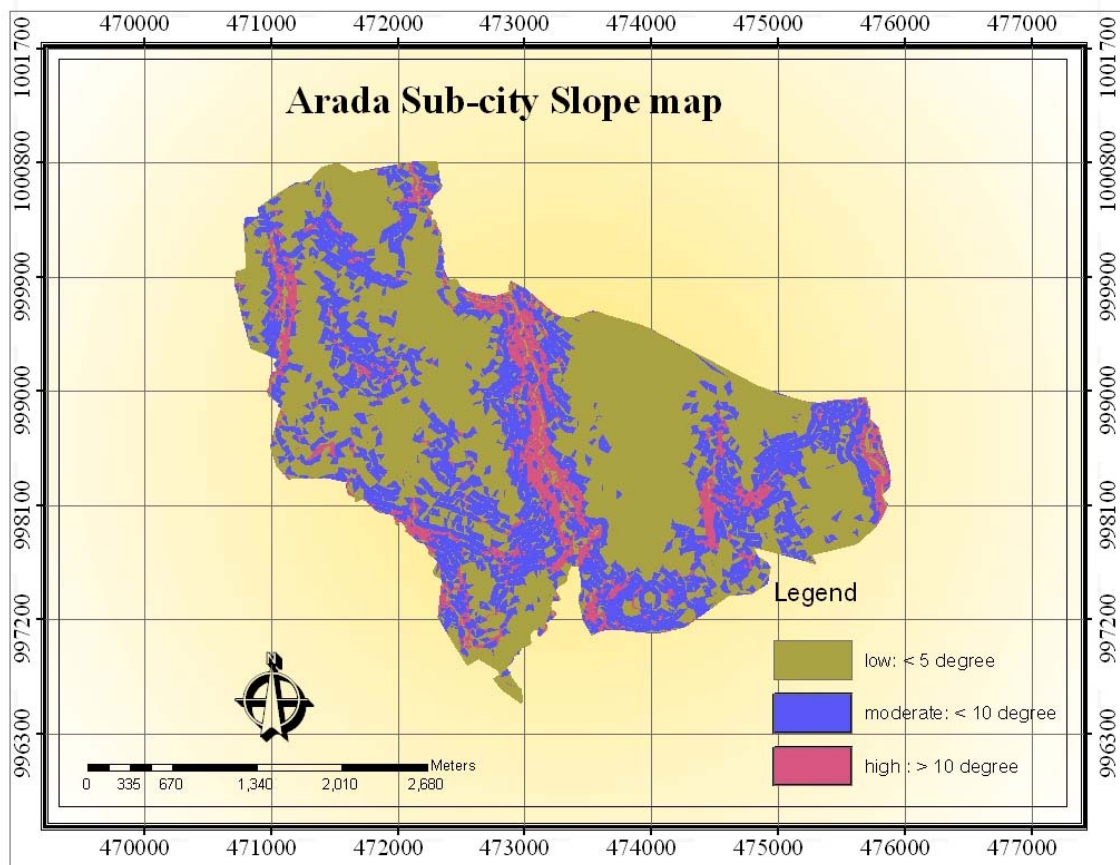


Fig 8.10 arada sub-city DEM and slope map

Using geoprocessing tools in ArcGIS slopes of each segment were derived. In the first place, it was mandatory to find the end nodes of each street segment to calculate the slope. However in the raw data there were no nodal information available for those segments. Therefore it was a must to extract nodes of those streets. And again to find those nodes the real segments should have been converted to straight line because the real networks could potentially give more than those two end nodes. After identifying those end nodes, three-dimensional coordinate information was assigned to those nodes automatically by the geoprocessing tools of ArcGIS. Then using the spatial join function those nodes are joined to the

real network in two phases – one to the Fnode and the other to the Tnode.

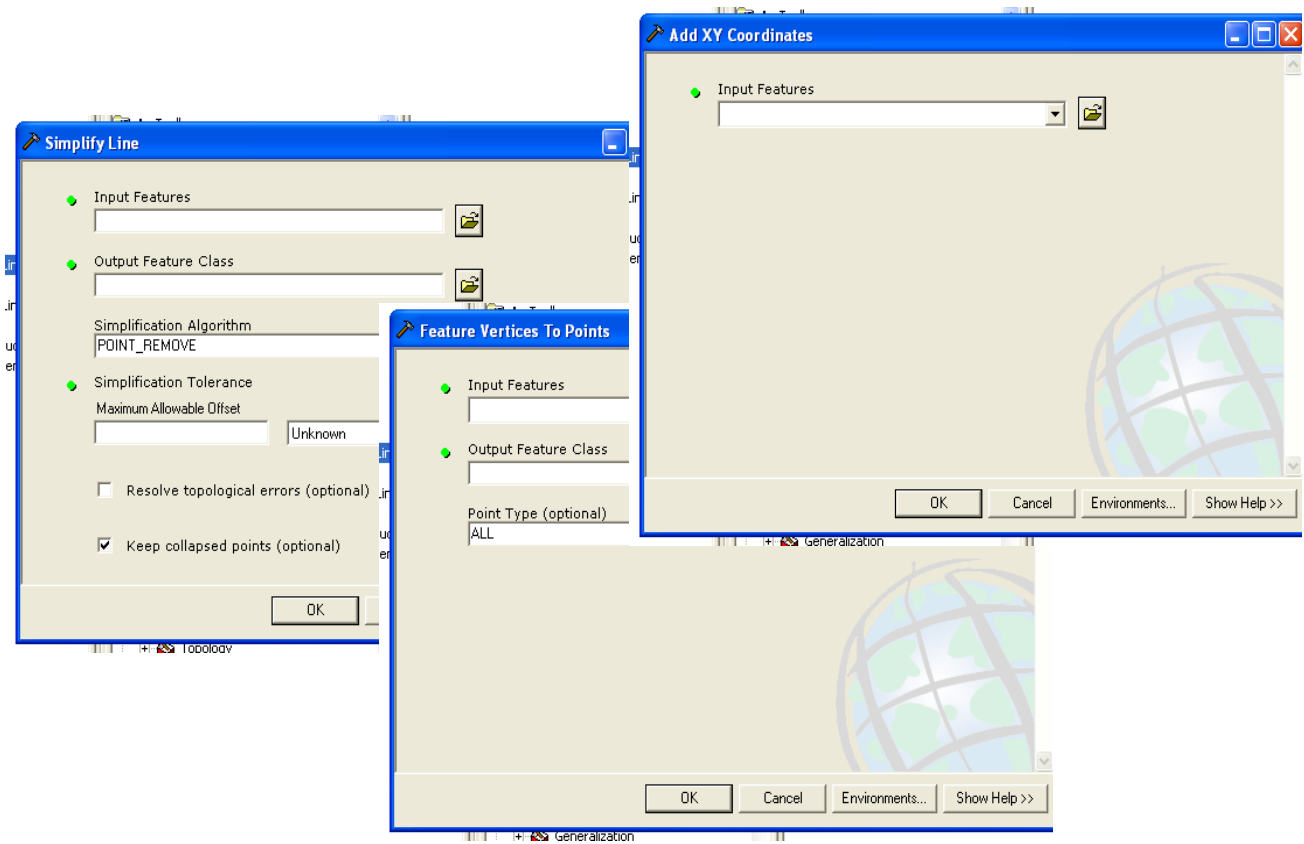


Fig 8.11

data analysis in Arc Toolbox

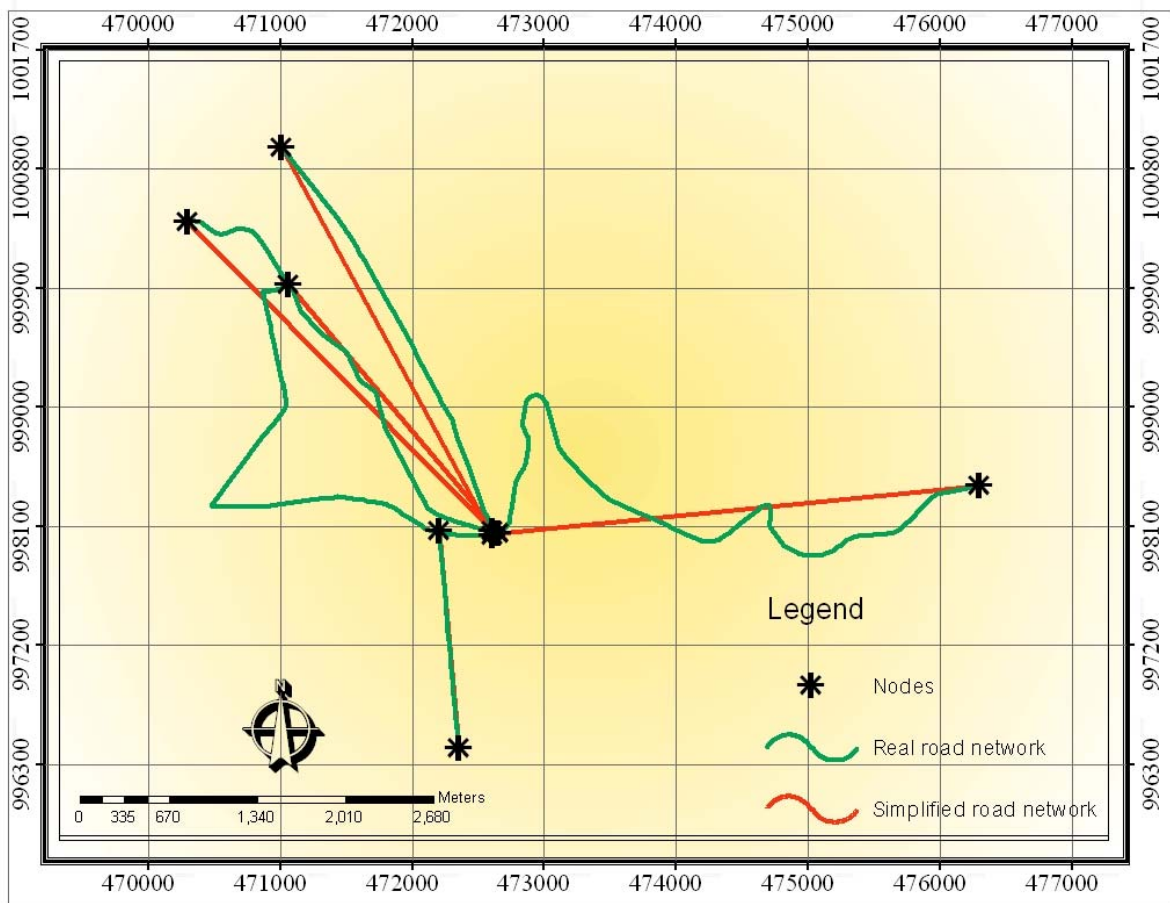


Fig 8.12 *simplified road network and nodes*

Nodes	POINT_X	POINT_Y	POINT_Z
1	472797.75	998298.10	2452.60
2	472797.75	998298.10	2452.60
3	472491.60	998321.01	2446.25
4	472491.60	998321.01	2446.25
5	472797.75	998298.10	2452.60
6	472797.75	998298.10	2452.60
7	475607.36	998582.22	2396.12
8	475607.36	998582.22	2396.12
9	471036.64	1000103.68	2510.92
10	471036.64	1000103.68	2510.92

Table 8.5 *node extraction summary*

As it is shown in the above table there are ten nodes with a full of coordinate information. It was assigned to the five roads as Fnode and Tnode. However in order to classify the nodes in to two equal and consecutive parts as Fnode table and Tnode table MapInfo was used.

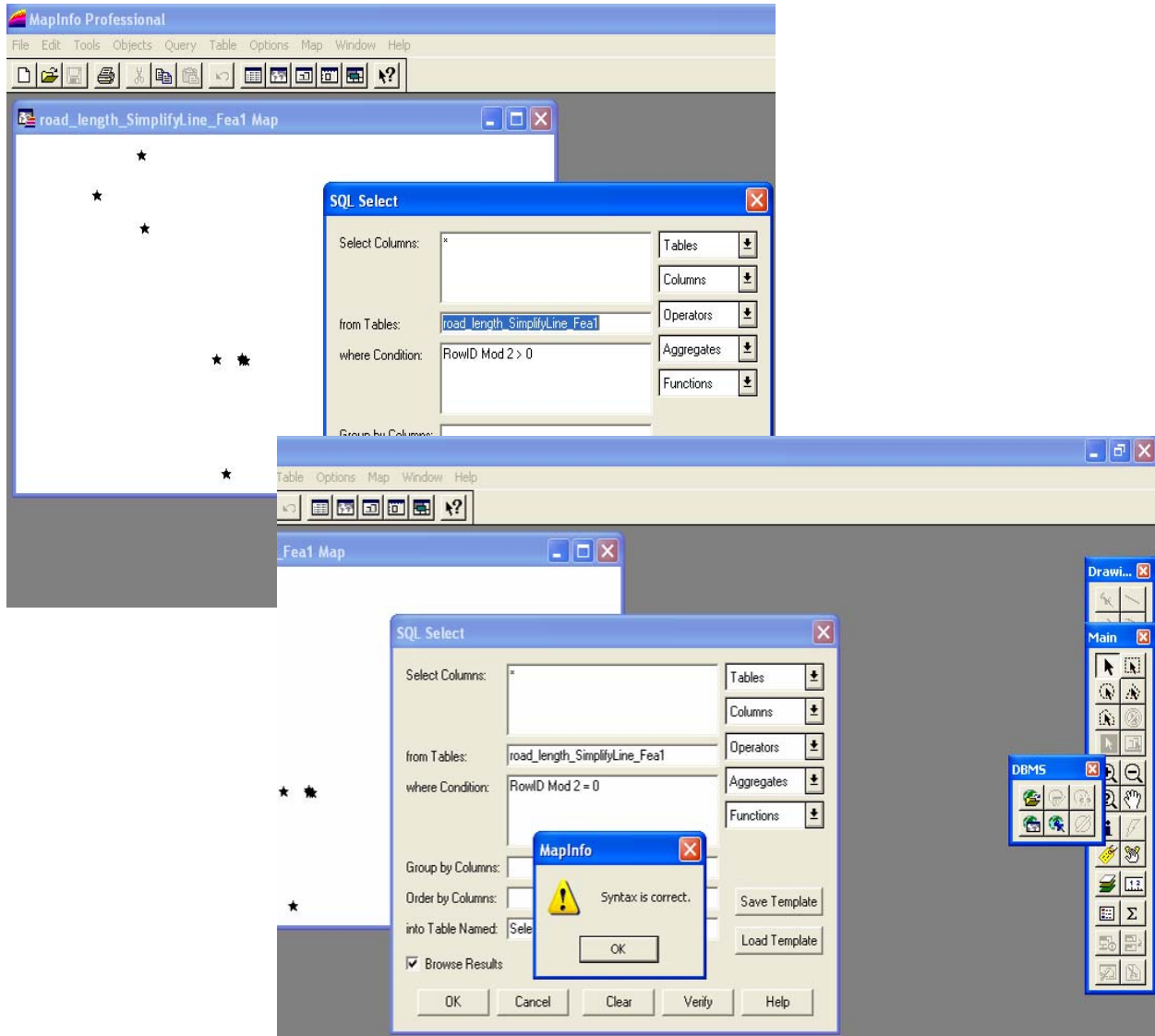


Fig 8.13

data analysis in MapInfo

Finally the slope of each segment is calculated using those nodal information applying the formula:

$$\text{Slope} = \text{Rise} / \text{Run}$$

Where- Rise implies vertical increment or mathematically $Z_f - Z_t$

Run implies horizontal increment or mathematically $X_f - X_t$

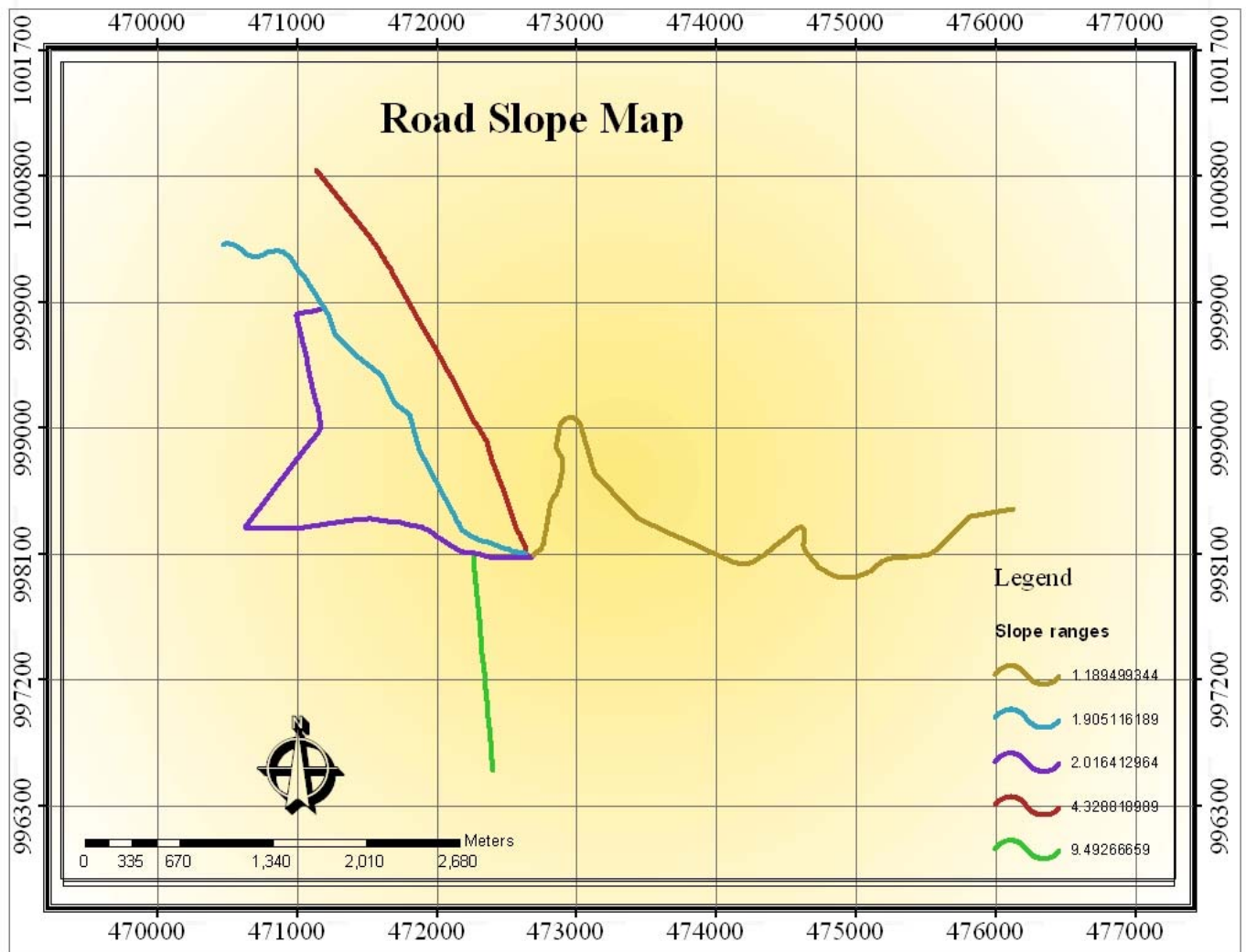


Fig 8.14 slope map

As we see from the above figure roads running to Ambassador are of high slope while that runs to Arat kilo is gentle. Those roads running to Atkilt era, Gullele and Atobis era are found between those two extremes.

After calculating the slope of each street segment it was classified and assigned grade based on the gradient. Roads gradient that fall under 5% are categorized as the best and given grade- 1. While those nearly 10% are categorized as the worst among the candidates and given the grade 3.

STR_IDX	POINT_X	POINT_Y	POINT_Z	POINT_X_1	POINT_Y_1	POINT_Z_1	SLOPE	GRADE
100.00	472797.75	998298.10	2452.60	471579.50	1000535.30	2544.77	4.33	2
21001.00	472491.60	998321.01	2446.25	472599.78	997070.30	2357.16	9.49	3
2019.00	472797.75	998298.10	2452.60	472830.43	998308.51	2453.75	2.02	1
2002.00	475607.36	998582.22	2396.12	472830.43	998308.51	2453.75	1.19	1
110.00	471036.64	1000103.68	2510.92	471620.17	999743.30	2491.52	1.91	1

Table 8.6 summary of slope calculation

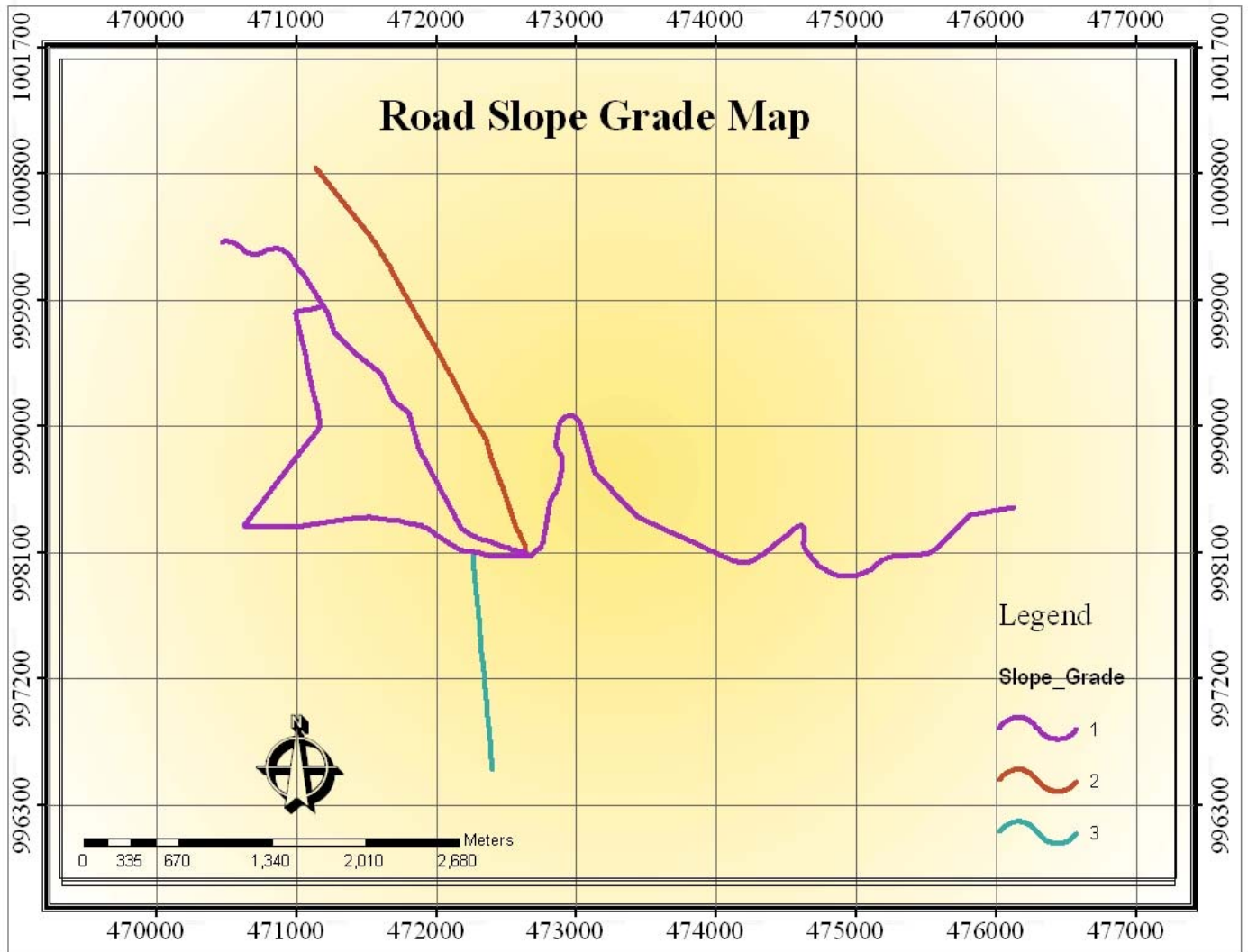


Fig 8. 15 slope grade

The result indicates that the road running to Ambassador is the worst with respect to slope. It has about 9° slope and assigned the poorest grade, grade-3.

Traffic condition

Bicycle friendly route are also greatly influenced by the actual traffic load of the street segment under consideration. In order to classify the given road network according to traffic load, comparison were made between the roads' maximum traffic holding capacity- potential ADT- and the actual traffic load –actual ADT. Finally relative traffic load or traffic density was calculated for the roads using the equation:

$$\text{Traffic density} = \text{Potential ADT} - \text{Actual ADT}$$

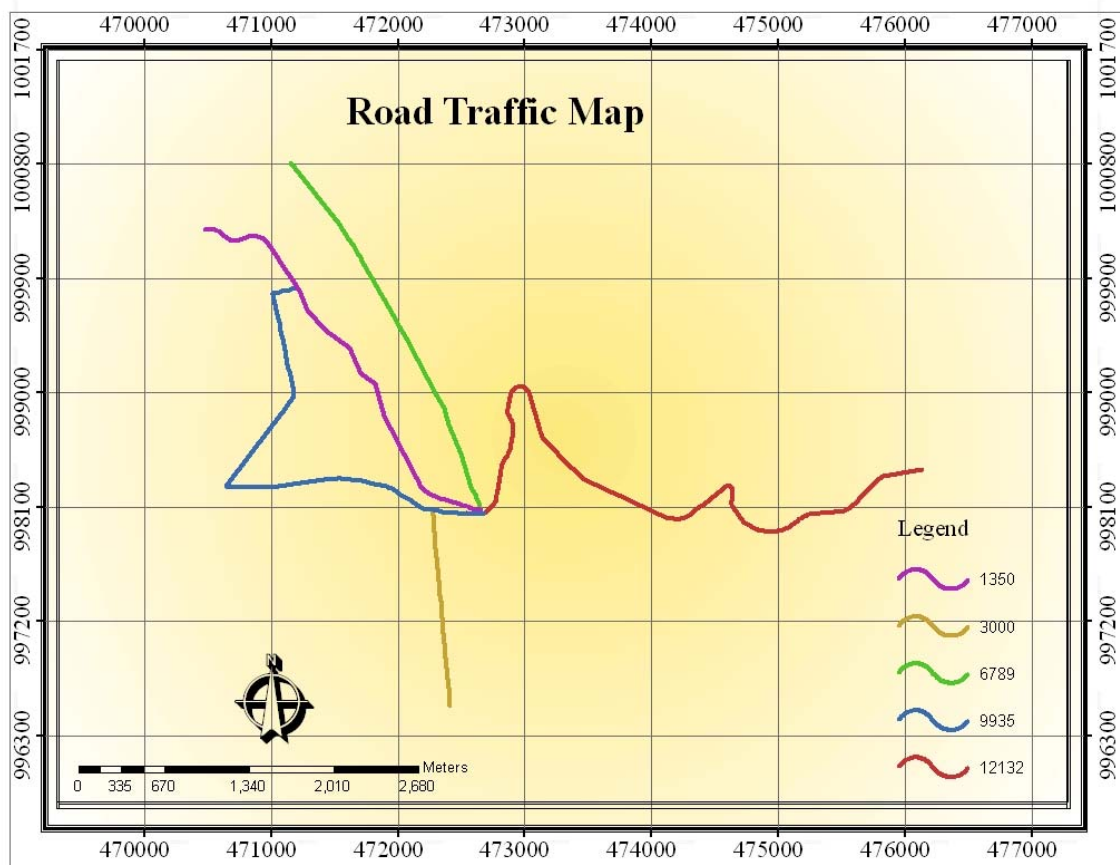


Fig 8.16 traffic distribution map

By subtracting the roads' actual traffic load from that of the maximum traffic holding capacity it is possible to obtain the relative load of each street segment.

Then the resulting relative traffic load –Traffic density of each street segment was categorized. As a result roads with relatively high Traffic density categorized as the worst and given grade 3. While those with low Traffic density as the best and given grade 1.

Figure grade traffic

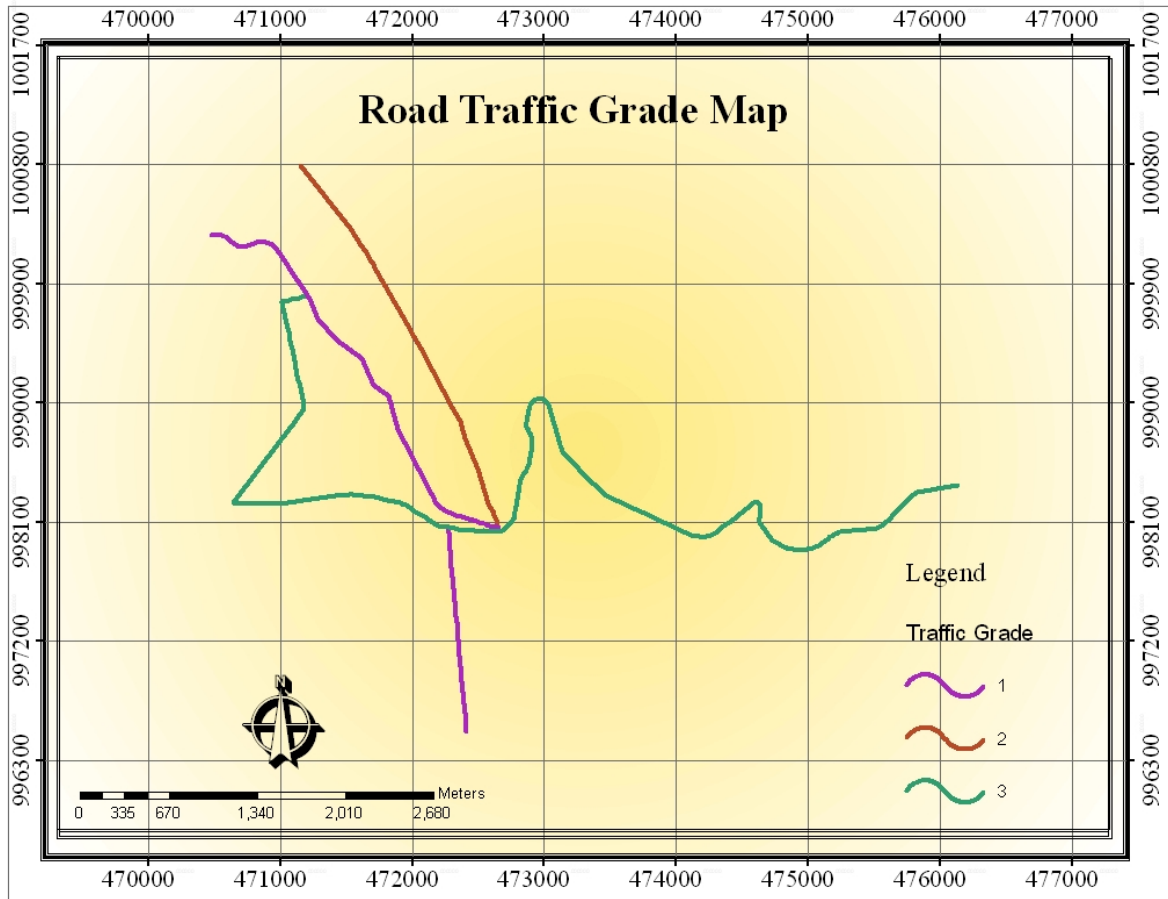


Fig 8.16 traffic grade

As we see from the result road running to Kechene is the worst according to traffic condition and assigned the poorest grade, grade-3. While those roads running to Ambassador and Atobis tera are among the best and given the grade-1. Roads to Gullele and Arat Kilo are in between the extremes.

Surface condition

As already discussed earlier roads' surface condition potentially affect its candidature to be selected as cycling route. In this specific discussion further dimensions are considered. We compared the potential number of cars that can flow at a specific segment at a time with that of the actual lane number assigned by AARCA. Roads' potential to allow numbers of cars passage at a time was calculated as follows:

$$P = (W_r / W_c)$$

Where: P is road's potential to accommodate parallel flow

W_r is width of the road

W_c average width of vehicles

Then the actual lane number assigned by AACRA was multiplied by average width of motor vehicles. By subtracting this result from the potential, net width of the given roads network were obtained. This net width was aspired to serve as potential bicycle paths. Roads with net width more than 2 m are categorized as the best and given grade-1. While roads with net width less than 1.5m categorized as the worst and given grade 3.

STR_IDX	PAV_WIDTH	LANE_NO	PWidth / 3.5	PW_Lane	share_m	grade_surf
100.00000	10.00	2	2.85714	0.85714	2.99999	1
21001.00000	9.40	2	2.68571	0.68571	2.39999	1
2019.00000	9.00	2	2.57143	0.57143	2.00005	2
2002.00000	12.00	4	3.42857	-0.57143	-2.001	3
110.00000	12.00	2	3.42857	1.42857	4.9995	1

Table 8.6 summary of traffic density calculation

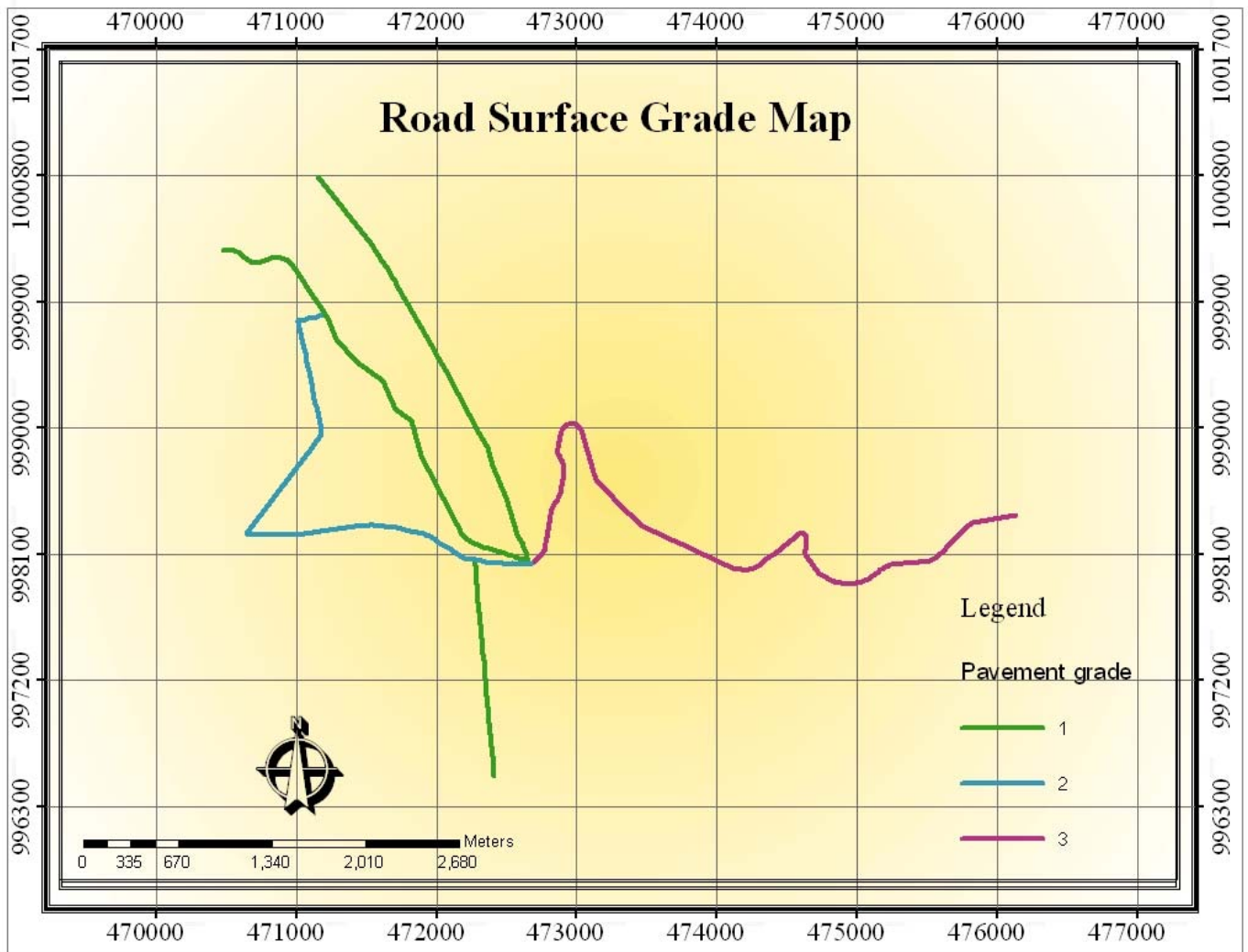


Fig 8.17 pavement surface grade

The shown in fig. 8.17 roads running to Ambassador, Gullele and Atobis tera are suitable for cycling with respect to surface parameters and assigned grade-1. Those roads running to Arat Kilo is among the worst and given grade-3.

Link Impedance

For auto travel, impedance is usually treated as the time it takes to traverse the length of a roadway segment. For each street segment or link the impedance of traveling from point a to point b is calculated by the following formula:

$$I_{ab} = l_{ab}/v * f_{ab}^t * f_{ab}^s * f_{ab}^c$$

Where:

I_{ab} – the impedance of a link from point *a* to point *b*.

l_{ab} – the length of the street segment.

v – The speed of bicycles under ideal conditions; let 15 mph.

f_{ab}^t – the auto traffic factor. Auto traffic generally increases the impedance of cycling. For very light auto traffic, the value of f_{ab}^t is 1; as auto traffic approaches the roadway capacity, the value of f_{ab}^t increases rapidly. The value of f_{ab}^t set to 3 when auto traffic reaches the roadway's capacity.

f_{ab}^s – the link slope factor. Uphill slope increases the impedance. Moderate downhill slope decreases the impedance. Considering the findings in Smith (1975), the values for f_{ab}^s ranging from 3 to 1 according to the slope.

f_{ab}^c – the road surface conditions factor. Here, we reference only usable street (surface paved) width because information on pavement quality was not available for all streets. Streets with net width more than 1.5m given a value of 1. Whereas streets with low net width less than 1.5m given a value of 3.

As shown in the figure 8.18, the road to Atobis tera was found the best among the candidates. While the road to Arat kilo is the worst of all. The following table will summarize the grades assigned by each parameter.

Roads to...	Factors			Result
	Slope	Traffic	Surface	
Ambassador	3	1	1	2
Arat kilo	1	2	3	5
Kechene	1	3	2	4
Atobis tera	1	1	1	1
Gullele	2	2	1	3

Table 8.19 final summary

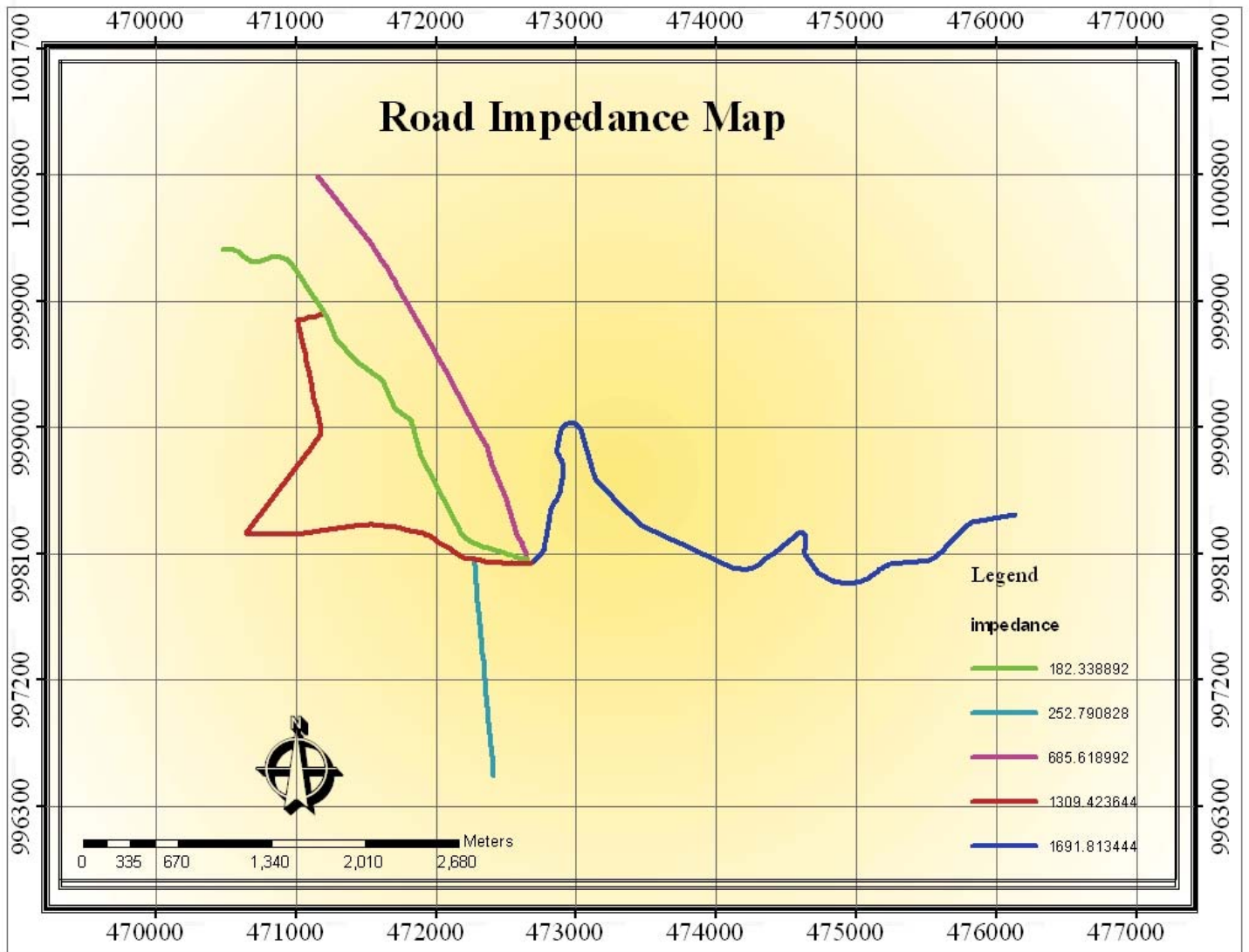


Fig 8.18 impedance map

9. Conclusion and recommendation

Addis Ababa, where various local and international organizations located, has high level of mobility that demands various forms of transportation. Currently the most common form of transportation mechanism is Automobile. This automobile dependency resulted is high level of traffic density, accident problem, and environmental degradation.

In this study an attempt was made to study suitability of cycling as an alternative means of transportation. Concerns about increasing traffic congestion and deteriorating air quality have had to search for alternatives to automobile in many cities. The Bicycle has received growing interest as one of these alternatives because it is emission free, energy efficient, and relatively inexpensive.

In order to do this a GIS-based model that considers slopes, traffic density and pavement surface is used to evaluate roads suitability for cycling. The study was conducted in two steps. The first step is aimed at producing generalized suitability map of cycling. Considering the findings from the first step and applying detail assessments the second step resulted in more faithful suitability map.

By first step the entire roads of the city are evaluated and out of the 9048 street segments of the city only 9% are found to be suitable for cycling. The analysis showed that the factor pavement surface is the most influential to limit the suitability of roads for cycling. Using this factor alone about 65% of the total roads is found to be unsuitable.

As an attempt for detail study, the second step considered only five roads out of the 9048 streets that run to Ambassador, Atobis tera, Arat kilo, Kecheneand Gullele streets of the city. All the roads are selected from Arada sub city where there exists high traffic density and people with different socio-economic background. The detail analysis again considered the same there factors and the results indicated that the route that runs to Gullele found to be the best for cycling. This route has low gradient (steep), calm traffic density and wide 'pavement width'. In contrast, the road that runs to Arat Kilo is found the worst. The effect of traffic density and 'pavement width' greatly influenced its suitability for cycling.

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