

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH AND PLANETARY SCIENCE**

*Addis Ababa
University
(Since 1950)*



**Optimal Routing of Highway in Landslide-Prone Areas
Using Remote Sensing and GIS:
A Case Study on Gohatsion – Dejen Road Project, Ethiopia**



**A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF
ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN
REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM**

**By
Bamlaku Yilikal
May 2015**

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH AND PLANETARY SCIENCE**

**Optimal Routing of Highway in Landslide-Prone Areas
Using Remote Sensing and GIS:
A Case Study on Gohatsion – Dejen Road Project, Ethiopia**

By: Bamlaku Yilikal

Advisor: Fekerte Arega (Ph.D.)

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING**

May 2015

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH AND PLANETARY SCIENCE

Optimal Routing of Highway in Landslide-Prone Areas
Using Remote Sensing and GIS:
A Case Study on Gohatsion – Dejen Road Project, Ethiopia

By: Bamlaku Yilikal

Approved By Examining Board:

Signature

Examiner 1

Examiner 2

Advisor

Fekerte Arega (Ph.D.)

May 2015

DECLARATION

I hereby declare that the thesis entitled “*Optimal Routing of Highway in Landslide-Prone Areas Using Remote Sensing and GIS: A Case of Gohatsion – Dejen Road Project, Ethiopia*”, submitted to the Department of Earth Science, Addis Ababa University, as a part of Master of Science in Remote Sensing and GIS is my own work and, it contains no materials previously published or written by another person and has not been previously submitted elsewhere to any other university or institute for the award of any other degree or diploma.

Bamlaku Yilikal

Addis Ababa

Ethiopia

CERTIFICATE

This is to certify that the thesis entitled “*Optimal Routing of Highway in Landslide-Prone Areas Using Remote Sensing and GIS: A Case of Gohatsion – Dejen Road Project, Ethiopia*” is the original work carried out under my guidance. This is the actual work done by Bamlaku Yilikal for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University.

Dr. Fekerte Arega

Department of Earth Sciences

Addis Ababa University

Addis Ababa

Acknowledgement

First and foremost, my greatest debt of gratitude is owed to my Almighty God for his daily guidance and care throughout my life. *What shall I render to the LORD for all His Bounties toward me? Ps 116:12.*

Secondly, I would like to extend my special gratitude and sincere thanks to my adviser Dr. Fekerte Arega who encouraged and directed me. Her challenges brought this work towards a completion. It is with her supervision that this work came into existence. I am also heartily thanks to my friend Sileshi Degefa for his invaluable support in all aspects of my work without his advice and support, this paper would not have come to an end.

Thirdly, I am very much indebted to my employer Ethiopian Roads Authority for sponsoring the entire period of my study. By covering all the related costs of the study, in this regard, the authority has realized my dreams of accomplishing my Master study.

Furthermore, I would like to thank my beloved families and friends of mine for their consistent encouragement, support and motivation which helped me much to complete the thesis work successfully. Special thanks go to my beloved fiancée, Alem, for her remarkable love throughout the time and unchanged assistance she made through building my inspiration up from the very beginning of the start of the paper until end.

Despite the fact that there are many other individuals to be accredited, I cannot close without expressing my acknowledgement to my best friends. Their consistent support and encouragement helped me overcome setbacks and stay focused on my graduate study. I greatly value their friendship and I deeply appreciate their belief in me.

Table of Contents

Table of Contents

Acknowledgement	i
Table of Contents	i
List of Figures	iii
Lists of Abbreviations	iv
Abstract	v
CHAPTER ONE	1
1. Introduction	1
1.1. Background	1
1.2. Statement of the Problem	3
1.3. Objectives.....	4
1.3.1. General Objective	4
1.3.2. Specific Objectives	4
1.4. Significance of the Study.....	4
1.5. Scope of the Study	5
1.6. Limitation of the Study.....	5
CHAPTER TWO	6
2. Literature Review.....	6
2.1. Road Infrastructural Development in Ethiopia	6
2.2. Route Alignment Selection Practice in Ethiopia	7
2.3. GIS and Remote Sensing in Route Planning.....	9
2.4. Local GIS and Remote Sensing Applications in Highway Route Planning	10
CHAPTER THREE	12
3. Study Area Overview.....	12
3.1. Abay Gorge, a General Description.....	12
3.2. Climatic Condition.....	13
3.3. Vegetation.....	13
3.4. Topography	14
3.5. Hydrology.....	14
3.6. Geology	15

CHAPTER FOUR.....	18
4. Methodology of the Research	18
4.1. Data Collection.....	19
4.2. Pre-Processing and Thematic Data Layer Preparation	19
4.2.1. Digital Elevation Model.....	20
4.2.2. Lithology.....	20
4.2.3. Drainage.....	20
4.2.4. Land use/Land cover.....	20
4.2.5. Landslide Mapping	21
4.3. Data Processing and Analysis for Route Planning.....	22
4.3.1. Generating a Thematic Cost Map	22
4.3.2. Selection of Optimum Route.....	27
CHAPTER FIVE	29
5. Analysis and Discussion	29
5.1. Slope and Aspect.....	29
5.2. Relative Relief	32
5.3. Drainage Character	33
5.4. Land use/Land cover	34
5.5. Lithology.....	36
5.6. Major Landslide Inventory along the Existing Road.....	37
5.7. Landslide Hazard Zonation (LHZ) Analysis Map	39
5.8. Thematic Cost of the Road Corridor	40
5.9. Optimum Route Determination.....	42
CHAPTER SIX.....	45
6. Conclusion and Recommendations	45
6.1. Conclusion.....	45
6.2. Recommendations	47
References.....	48
APPENDICES	51
Appendix 1:.....	51
Appendix 2:.....	54

List of Figures

Figure 2.1 Trends of Road Infrastructure Development in Ethiopia.....	7
Figure 2.2 ERA's Route Selection Procedure flow chart.....	9
Figure3.1 Location Map of the Study Area.....	12
Figure 3.1 Major Lithological units and their cross sections along Gohatsion to Dejen road section of the Blue Nile gorge.....	16
Figure 4.1 Overview of the General Methodology developed for Optimal Route Selection.....	18
Figure 4.2 Methodology developed to generate Land Hazard Zonation.....	22
Table 4.3 Weights and Rates of each thematic layer to generate the cost surface.....	24
Figure 4.4 Schematic Diagram of Thematic Cost Map used in Route Planning.....	26
Figure 4.5Methodology for the generation of Optimal Route Selection.....	27
Figure 5.1 Slope map.....	29
Figure 5.2 Aspect Map.....	31
Figure 5.3 Relative Relief Maps.....	32
Figure 5.4 Drainage Density Map.....	33
Figure 5.5 Land Use/Land Cover Map.....	35
Figure 5.6 Lithology Map.....	36
Figure 5.7 Thematic Cost Surface map of Abay Gorge.....	37
Figure 5.8 Landslide Inventory along the Existing Road.....	39
Figure 5.9Landslide Hazard Zonation of Abay Gorge.....	41
Figure 5.10 Schematic Diagram of Optimal Route Selection Result.....	42
Figure 5.11 Optimal Highway Route of Gohatsion- Dejen Road Project.....	44

Lists of Abbreviations

DEM	Digital Elevation Model
ERDAS	Earth Resource Data Analysis System
ERA	Ethiopian Roads Authority
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic map per
GCPs	Ground Control Points
GIS	Geographical Information System
GPS	Global Positioning System
LHZ	Land Hazard Zonation
RSDP	Road Sector Development Program
SRTM	Shuttle Radar Topography Mission
URRAP	Universal Rural Road Access Program

Abstract

Optimal highway routing is an important part of highway planning activities. The objectives of this study are to present and demonstrate the potential of Remote Sensing and GIS technology on route alignment selection in mountainous regions prone to landslide. The existing road from Gohatsion to Dejen town traverses through areas susceptible to landslide hazards. Due to landslide, some sections of the road have been frequently blocked. On the other hand, the extent of the hazard increased from time to time and becomes more severe during the rainy season. This study was carried out to investigate the potential landslide hazard areas and to select an optimal route connecting Gohatsion to Dejen through areas free from land hazards including landslide, rock fall and debris flow. This study was depended on remote sensing data, ancillary or secondary data and field data. The collected data were used to develop various thematic layers such as landslide distribution, landslide hazard zonation, land use/land cover, drainage density, slope and lithology using Remote Sensing and GIS tools which are vital to generate the optimal route. These thematic data layers were used to produce thematic cost map which is in raster form and provides an estimate cost for route selection. Then, the optimum highway route was selected between Gohatsion and Dejen upon the thematic cost map. This optimum route is shorter than the existing alignment by 9km and avoided the active landslide areas found in the existing road at km ...andwithout missing the existing Abay Bridge.

Keywords: Optimum Highway Route, GIS, Remote Sensing, Landslide, Thematic Cost, Landslide Hazard Zonation

CHAPTER ONE

1. Introduction

1.1. Background

Route alignment planning for a new highway on the regional level constitutes a complicated planning process which involves the consideration and analysis of various data sets. In developing countries in particular, where this process is still implemented by using traditional or manual systems, a number of problems and challenges are encountered (Manoj and Paul, 2004). In most cases the required data are not available due to the long process of institutions owing the data. If the data sets are made available, their format another problem because they usually come from different sources in different formats. Such formats are mostly old paper maps in different coordinate systems, tables or reports. In few cases, various digital data in different formats are also available. The integration of such data sets is always a difficult, but important task towards the choice of the optimal route. The development of alternative routes for a potential road and the evaluation of socio-economic and environmental impacts of such alternatives represent further technical challenges. To overcome these deficiencies, the use of Geospatial technologies is crucial to manage the variety of data sets from different sources, to offer multi-criteria analysis tools required for the planning process.

Nowadays Geospatial technologies are widely used in civil engineering applications. Transportation and highway engineering most often rely on spatial variables, including environmental, topography, built-up areas, and geology. Such criteria are taken into consideration in the selection of route location and the design of highway alignment processes that are usually perceived as rather complicated. Therefore, this complexity motivated highway engineers to give more attention to GIS applications in route location and highway alignment,

due to their ability to consider many spatial variables simultaneously in solving optimization tasks with spatially distributed linear objects such as roads, railways and pipelines (Imtiaz A. *et. al.*, 2012).

Analyzing variants of planning routes of transport is necessary to solve whole typical tasks. It is related to an evaluation in detail of physiographic factor, landscape, engineering-geological and others requirements for the investigation area. It also includes determining the length of the route, calculation of intersections with rivers, roads and railways which are considered as mountain relief complexities. Consideration of the road construction costs, which depends on underlying geology and land covers (rocks, marshland, artificial features etc.), require detailed spatial multi-criteria analysis.

An existing GIS spatial analysis capability gives possibility of operative evaluation. It also gives a capability to each part of investigation area for whole complex of factors. Modern GIS software allow to automate a complex operations such as intersection with different linear and polygonal objects, estimation of transport costs during construction and operational service of route, calculation of an integrated construction cost etc.

The necessity of GIS and Remote Sensing applications in planning variants of routing of highways has attracted road developers in various countries. The proposed highway route should satisfy all requirements such as technical/engineering, financial and environmental parameters.

1.2. Statement of the Problem

The conventional route planning has exclusively been based on topographical gradient and curvature. The highway planner usual practice involves manually marking segments of permissible gradients for route alignment on small scale topographical maps. Such approach is tedious, and thus may not be feasible when a variety of other factors such as landslides, geology and land use/land cover are also considered (Saha *et.al*, 2005). With the availability of data from remote sensing/satellites, it has become possible to efficaciously collect and analyze synoptic spatial data, such as geology, structural features, land use/land cover, drainage, settlements, etc. Besides, advanced Geographic Information System (GIS) computational techniques offer numerous advantages in multi-geodata handling for integrated geo-environmental studies.

The terrain in Abay Gorge is highly susceptible to landslides, mainly owing to its complex geological setting combined with contemporary crustal movements, high relief and heavy rainfall (JICA, 2013). Due to general ruggedness of the terrain and steep slopes, roads provide the only way of transportation and connectivity in the area. Invariably, in the rainy seasons, some sections of the roads are blocked due to landslides, thereby disconnecting the road for a significant duration of time. Every year, a huge amount of money is spent for Gohatsion - Dejen Road maintenance. The Ethiopian Roads Authority (ERA) the representative of the federal government in the road sector assigns emergency crew particularly during the rainy season in order to solve traffic interruption problems temporarily. Regardless of the deployed emergency crew there are casualty, fatality and injuries, property damage caused by car accidents due to landslide and rock fall. In addition ERA has hired international consultant to study the cause of landslide and take countermeasures on the subject road. In spite of these efforts the problem still lingers. Therefore, it is crucial to forge long-lasting mechanism by selecting a new route along less land hazards susceptible area using the modern tools of Remote Sensing and GIS. The main aim of this paper

is to present the potential of remote sensing–GIS technology to devise an automatic and intelligent approach for route planning in mountainous regions that are prone to landslides using Gohatsion - Dejen as a case study.

1.3. Objectives

1.3.1. General Objective

The main objectives of this study are to demonstrate the application of Remote Sensing and GIS technology on route alignment planning phase of road in mountainous regions that are prone to landslides and to provide road developers a workable procedures that exhaustively integrate all the necessary parameters.

1.3.2. Specific Objectives

- ❖ To identify the necessary parameters for route alignment planning process
- ❖ To prepare thematic cost map by integrating the identified parameters using GIS and Remote Sensing.
- ❖ To generate optimal and feasible route between Gohatsion and Dejen in the Abay gorge based on the thematic cost map using GIS and Remote Sensing tools.

1.4. Significance of the Study

This study will be used as a clue and stepping stone for highway route planers, and scholars who are interested to study the application of geospatial technologies specifically GIS and Remote Sensing on highway planning on areas susceptible to different potential hazards. It will also avoid unnecessary maintenance cost of the Ethiopian Roads Authority for Gohatsion - Dejen Road Project which emanated from the landslide.

1.5. Scope of the Study

However route planning process involves several engineering factors, such as quantity survey, material test, detail geological investigation, etc., in this study, it was tried to show the preliminary route alignment planning process from a geospatial perspective. This involves zonation of landslide hazard, mechanism to avoid land hazard zone and generate the feasible route.

1.6. Limitation of the Study

This research was based on the physical observation, secondary data and field observation with technical persons to locate the landslide prone areas. It would be good to use landslide measuring instruments like extensimeter and soil data. In addition it is expensive to obtain high resolution remote sensing data.

CHAPTER TWO

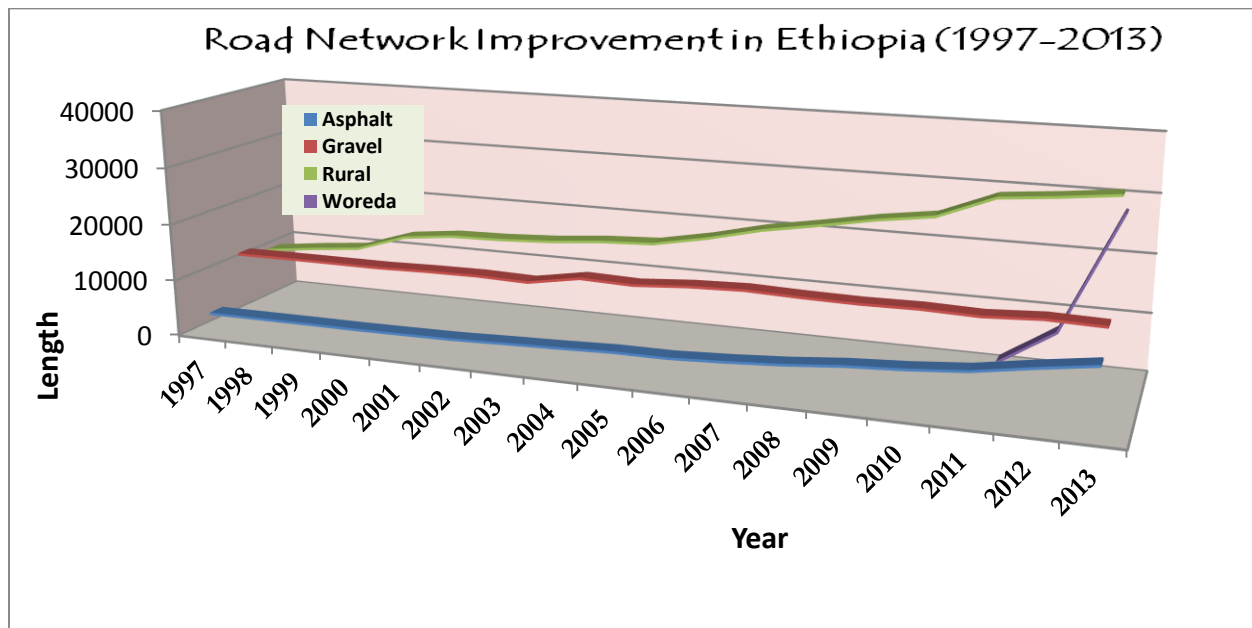
2. Literature Review

2.1. Road Infrastructural Development in Ethiopia

Roads are vital to a country's economic development. The high quality road network directly boosts the economy by reducing journey times and costs, immensely contribute to the development of the country (Shiferaw *et.al.* 2012). The actual construction process will have the added effect of stimulating the construction market. Ethiopia is strongly dependent on road infrastructure for its freight and public transport services. The country has been landlocked since the secession of Eritrea in 1993 and most of Ethiopia's international trade has since been channeled through the smaller and more expensive port of Djibouti. There are practically no railways except for the rundown single-track connecting Addis Ababa and Djibouti that began service in 1901, and only a few of the rivers are navigable due to the country's mountainous terrain.

The current Ethiopian government made the road sector one of its priority areas and implemented Four Road Sector Development Programs (RSDPs) since 1997. The total cost of the RSDP during the 16 years was about US\$ 142.1 Billion birr (ERA, 2013). The total road network expanded from 26,550 km in 1997 to 81,629 km in 2013. Among the major activities of the RSDP include 26,273 km was on federal roads, 27,728 km was on regional roads construction and maintenance and 27,628 km was on URRAP roads (ERA, 2013).

Figure 2.1 Trends of Road Infrastructure Development in Ethiopia. (ERA, 2013)



2.2. Route Alignment Selection Practice in Ethiopia

Highway route selection is a complicated planning process which involves the consideration, analysis and evaluation of socio-economic, engineering/technical and environmental impacts of different alternatives. The parameters which should be considered during route selection includes; the approximate construction costs, alignment and profile studies, typical section development, preliminary designs for geometric layout, drainage, right-of-way and utilities, location of interchanges, grade separations and intersections, preliminary bridge designs at critical locations, hazard evaluations, and other supplemental studies (Shannon, 1996).

The identification of the nodal points, that is the start and end point of the route to be studied are determined for political, economic or social values through a letter from the regional administration. Ethiopian Roads Authority (ERA) usually marks the points on small scale road map and continues the conventional method of manual route selection process based on the request. Mostly the recommendation posted from either a local consultant. The organization

implements the manual system to perform some of these tasks. The choice of a feasible corridor of a new highway is mostly based on the topography of the land. Economic and geological data are often not adequately considered and sometimes considered visually based on the perception of the individual who do the reconnaissance on the selected route.

The Ethiopian Road Authority applies different criteria for the preliminary selection of new road projects that are proposed by regional states. As would be expected, priority in road placement is given to areas with high economic potential and surplus food production. ERA also takes into account population distribution as well as regional equity in economic development. Road projects that pass the preliminary selection will go through feasibility studies which would help ERA refine its selection of projects and the proposed budget. Despite having a set of criteria for road placement, it is not clear what specific variables ERA uses to operational them. For instance, it is not clear how exactly economic potentials of different geographic locations are assessed or how regional inequality in economic development is evaluated. There is also lack of clarity about the process and criteria by which regional states prioritize their road projects before they submit to ERA (Shiferaw *et al.* 2012).

Road infrastructural planning is concerned with preparing and supporting decision about the development of the road network system in the country. The development of road transport in a nation has several issues either related with the economic point of view or opening access to the most remote areas. According to the Ethiopian Roads Authority (ERA) route selection manual, the engineering, environmental and economic parameters are given due attention.

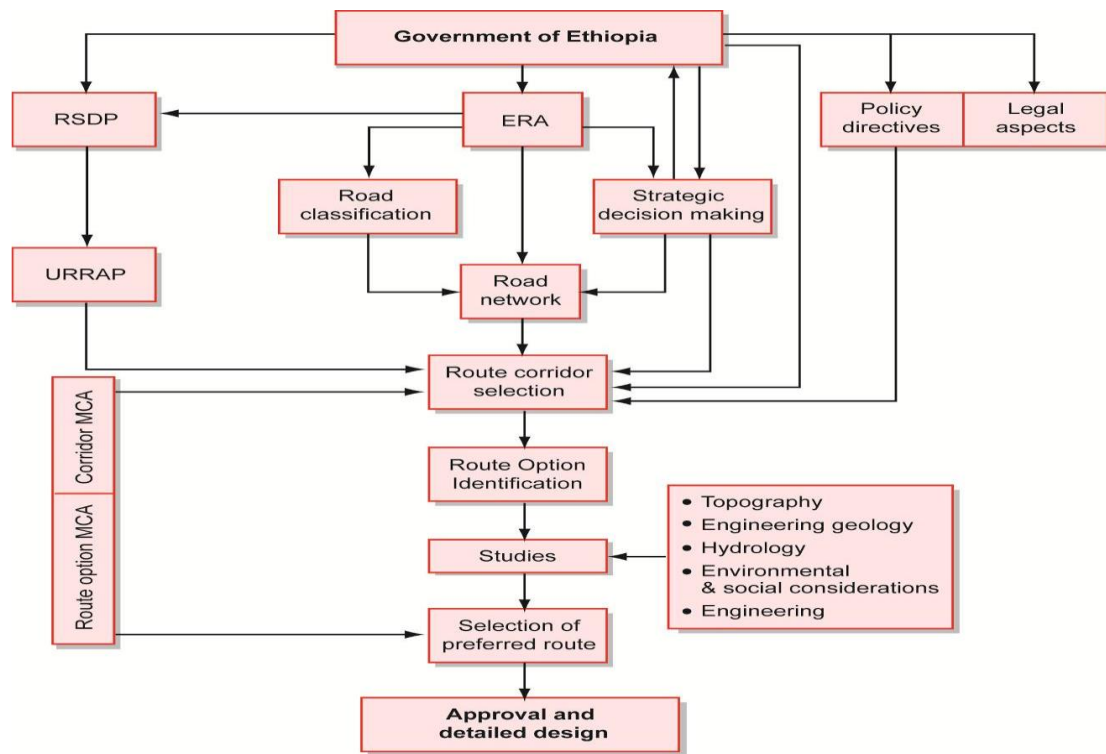


Figure 2.2 ERA's Route Selection Procedure flow chart (ERA, 2012)

2.3. GIS and Remote Sensing in Route Planning

Geospatial technologies have a significant role in highway route planning, some of the tools which are vital to conduct route alternatives selection are; surveying instruments, satellite images, topographic maps, remote sensing software, and GIS can be mentioned. Geographic Information System (GIS) can help to capture, store, analyze, and display geographical information based on its location character and link it with transportation planning variables. GIS is particularly useful in transportation since it is an effective way to integrate the information needed to support many criteria for transportation planning, evaluation, and analysis (Alexandre and B. Gonçalves, 2010).

GIS play a main role in highway planning. It is useful to address complex tasks in planning, analysis, evaluation, design, construction, and maintenance of different types of engineering

activities. In addition, it provides database management for extending human memory, spatial analysis for rigorous computation, and map display for visualization of large amounts of information about transportation and highway road networks (Yang *et.al.* 2003).

Determining the best route through an area is one of the oldest spatial problems. This problem has recently been solved effectively using GIS and Remote Sensing technologies. During the last decade, a few attempts have been made to automate the route planning process using geospatial technologies (Saha *et.al.*, 2005). A number of researches have already been performed in highway route design using GIS and high resolution remote sensing image, even though the methodology is still in an exploratory stage. In this context, physical, environmental, political, social, economic and legal processes was considered and implemented for highway routing determination. Multiple factors were considered using GIS techniques for highway, railway, and pipe routing determination

2.4. Local GIS and Remote Sensing Applications in Highway Route Planning

There are a limited number of studies regarding use of GIS in transportation planning in Ethiopia. The one which can be mentioned as a pioneer study on the application of GIS and Remote Sensing on highway route selection was done by Fekerte and Muse (2006). The objective of the study was to introduce the application of remote sensing datasets and utilization of GIS geo-processing techniques to highway route selection and present the resulting routes of a GIS analysis based on available data. Various engineering factors as well as environmental constraints that influence the cost of construction, economic benefits, environmental compatibility and future liability of the proposed road project were considered in the route selection analysis. Among the engineering constraints are length of the road, slope/gradient of the terrain, water bodies (wetlands, rivers, streams and lakes), soil types, lithology & geologic

structures (faults, lineaments and escarpments) etc. Of the environmental constraints are land use/land cover which includes settlement areas (cities/towns/villages), distance from existing roads and railway and others constraint etc. Finally the researchers selected two optimum alternate route alignments between Addis Ababa and Nazareth using different parameters and weight in accordance with their expected influence. The study also shown the potentially worthy of applying geospatial technologies in highway route selections, particularly in reducing time, effort in the field and hence cost of the reconnaissance stage. In addition the method provides decision makers with better quality of information and an opportunity to examine & evaluate various constraints cumulatively and interactively.

The other study was done by Yohannes (2005). The researcher explored and evaluated the potential use of GIS, in current practice of route alignment planning in Ethiopian Roads Authority in comparison to the scientific and technological approach. The researcher found that problems are encountered on some of the started project to which the manual method of route alignment planning has been deployed. The study underpinned most of the problem was derived from lack of modernized tool to visualize the consequence of the selected route. To reduce this and similar problems it recommended the authority to establish the technological input of GIS in ERA and adopt an integrated spatial decision-making approach for route alignment selection within the GIS framework.

CHAPTER THREE

3. Study Area Overview

3.1. Abay Gorge, a General Description

The study area is located in Oromia and Amhara Regional states between the towns of Gohatsion and Dejen, lies within the Abay basin. It is characterized by rugged topography having a maximum elevation of around 2400m *a.s.l.* and a minimum elevation value of around 1000m *a.s.l.* The present regional physiographical setting of the study area is a result of various processes. Besides, the uplifting which is believed to be responsible for the formation of the deep canyon, erosional leveling, weathering and mass wasting have played a major role in creating the present landform (Almaz *et.al.*,1994).

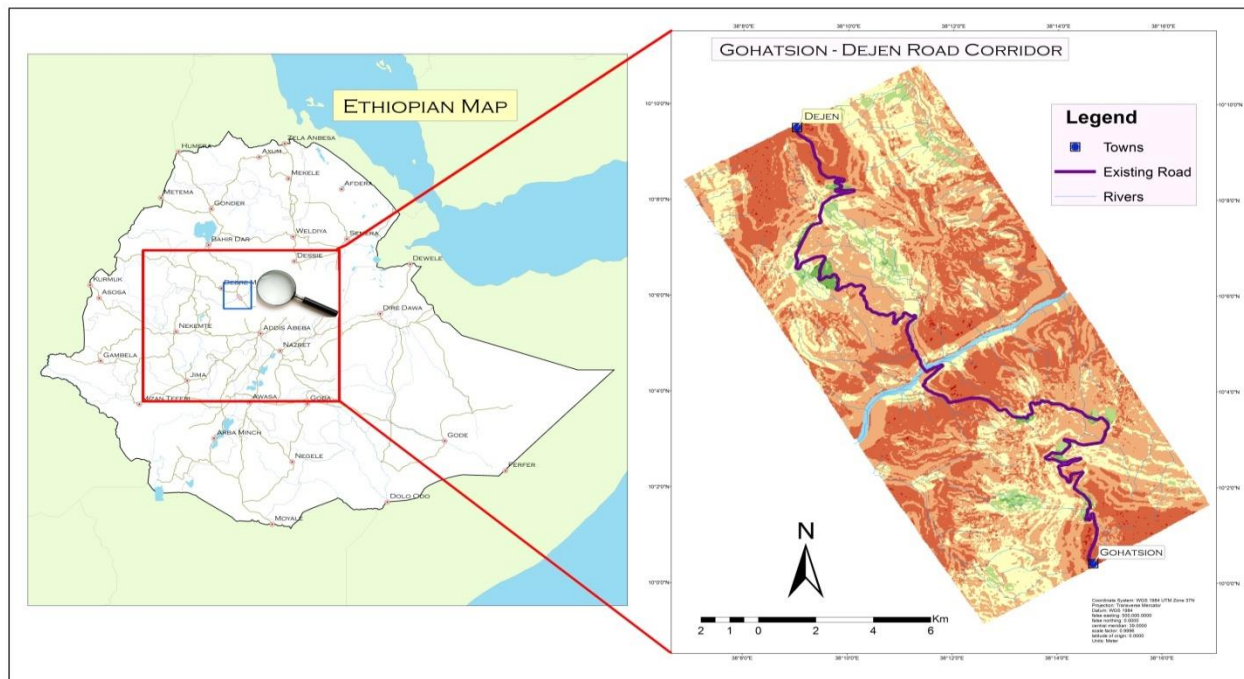


Figure3.1 Location Map of the Study Area

According to Lulseged (2009), the basin owes its distinctive shape to the various rock layers on the valley walls, with each responding to erosion in a different way. Hard, erosion-resistant rocks

such as basalt, sandstone and limestone formed vertical cliffs. By contrast, soft layers like marl, shale and mudstone gave rise to gentle slopes. The slight asymmetrical appearance of the basin in many areas is a result of the variation in the response of slopes to river incision and local depositional effects.

3.2. Climatic Condition

The climate of the project area as a whole is highly dependent on elevation. At the time when the basin top receives much rain, areas near the river channel remain dry. Day time average temperature also varies inversely with elevation, increasing from 25⁰c at the top part of the basin to around 40⁰c down at the river channel in a dry period. The average temperature in the study area falls in the range between 15⁰c - 35⁰c. However, in some months the temperature reaches up to 40⁰c in the basal gorge area. In many parts of Ethiopia, the rainy and cool season starts in June and ends in September and the dry and warm period is from October to May. Project area has got two rainy seasons. June to September is the major one and is the long rainy reason, but small rains occur from February - April too. During these rainy periods heavy intermittent rains, lasting from a few minutes to several hours are common. Heavy rain falls that initiate landslides have been reported in the past. The mean annual rainfall generally ranges between 1200-1600mm within the gorge and up to 2300 mm on the plateau. But generally annual rainfall falls between 900 - 1400 mm (Lulseged, 1999).

3.3. Vegetation

Like any parts of the country, vegetation along the Project road areas has been severely destroyed owing to various reasons as population increment and thus this resources base has degraded considerably from over exploitation of this limited forest resources. The original vegetation has been significantly disturbed due to the expansion of subsistence level agricultural

practices that predominate in the area. Low vegetation cover characterizes the project road vicinities, mostly desert bushes & short grasses with sporadic growth of acacia, which is denser at the sides of the river basin. On the plateau sections of the road vegetation cover is significantly affected through human interference (decades of clearings, cultivation and other activities).

3.4. Topography

The project area has got relatively adverse topographic conditions. The topography of the area is generally mountainous/Escarpment. The rugged topography sets terrain limitation in this area. Hence the existing road is characterised by steep cut and fills (steep gradient slopes) & series of twists & switch back curves with short tangents. The Altitude at the town of Gohatsion is about 2536m above sea level, which descends to the Abay Gorge (1060m *a.s.l.*) and again climbs up to Dejen town, which are about 2449m above sea level. The Elevation different is considerable, which is about 1400m with in 20km i.e. 70m rise and fall within each km & an average slope gradient of about 7%. The topography has contributed much to the Engineering geological problems in the area and deterioration of the road.

3.5. Hydrology

The project area can be called rich in water resources (both surface & underground). Drainage density is high, with the stream pattern mainly dendrite and deep-seated straight channels. Being dominated by the Abay River there are also four rivers namely Muga, Guha, Dembeza and Adawedeb rivers. Only Abay is perennial. Peak runoff for all rivers is between July and September, which is the major rainy season of the area.

The pervious character of the underlying material results in a considerable percolation of water through the sedimentary strata & hence many springs are apparent in the area. The hydro geological circulation in this area is through fractures and faults in both the overburden and the

bedrock and the weathering in the basaltic bedrock is also expected to be due to the circulation of water in the fissures and fractures (Mesfin *et.al.*, 1994). In several locations, the water table is observed to be high enough that water was seen from cut slopes and flowing to the side drains. Water's contribution to the geo-engineering problems of the area is significant.

3.6. Geology

The sedimentary & volcanic rocks in the Abay Gorge are formed within Mesozoic & Cenozoic time respectively. The nature of lithology, fossils dispersion and sedimentary structures are due to the complexity of depositional environments, such as coastal, fluvial, lacustrine, and partially arid lagoon. But the basalt is from fissure flow magma (EIGS, 1974). The study area lies in one of the Mesozoic sedimentary basins of the northwestern plateau of the country (Russo *et.al.*, 1994). The basin contains approximately 1400m thick section of Mesozoic sedimentary rocks unconformable overlying Neoproterozoic basement rocks and unconformable overlain by Early Late Oligocene and Quaternary volcanic rocks (Gani *et.al.* 2009). The geology of the study area has been studied by different authors. The major lithological units exposed in the area and their brief explanation is given below as studied by Lulseged (2000).

Basalt: this rock covers the top flat highlands on both sides of the valley. It is characterized by the presence of well-developed columnar joints which makes it susceptible to detachment and falling apart in to blocks and boulders.

Limestone: this rock is directly underlies the basaltic unit and it is on top of the shale unit. It comprises thin bedded to massive beds of limestone. It is also called Antalo limestone. It is of Middle – Late Jurassic age on the basis of Callovian to Kimmeridgian benthic foraminifers and macro faunas.

Gypsum and Shale: the gypsum unit is sandwiched between two shale lithounits. This unit is comprised with two sets of well-developed joint sets. It is also intercalated with thinly bedded shale layers.

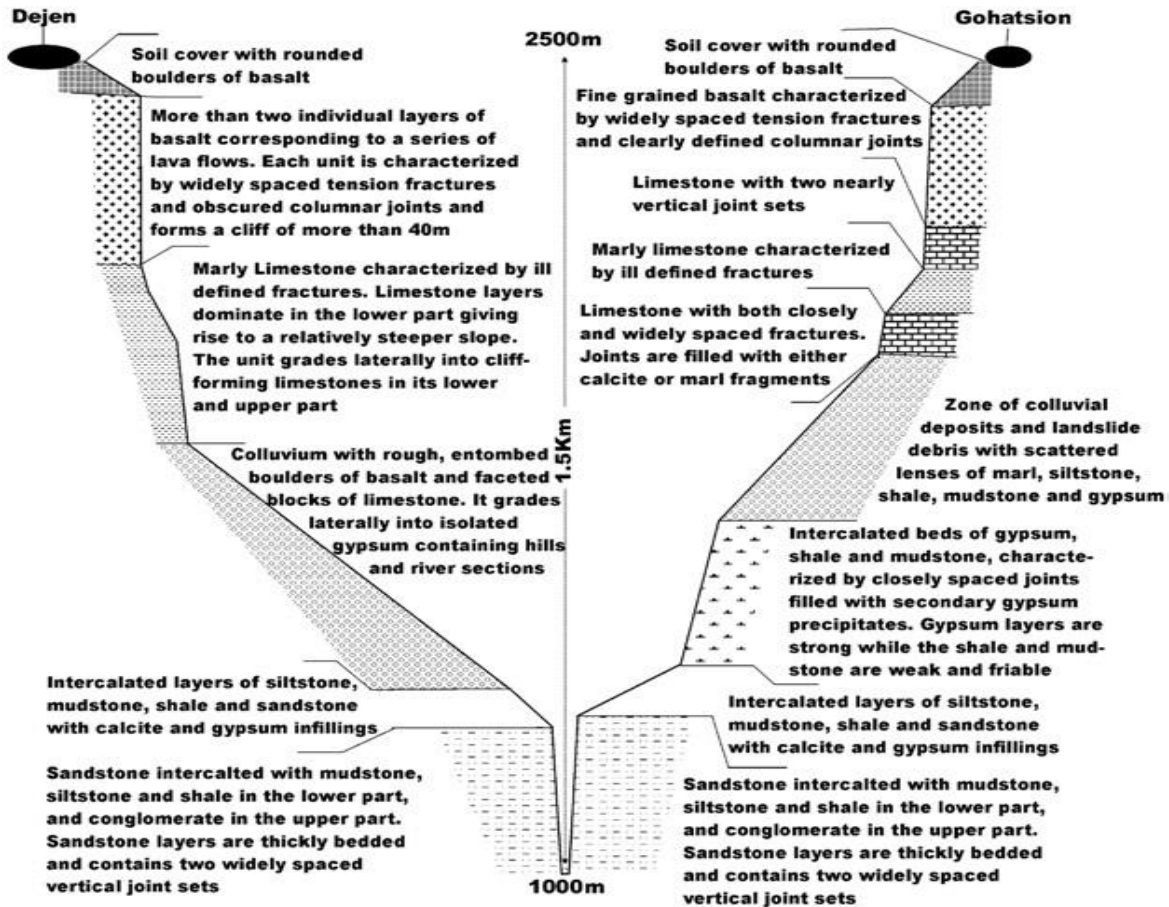


Figure 3.1 Major Lithological units and their cross sections along Gohatsion to Dejen road

section of the Blue Nile gorge (Lulseged, 2000)

Sandstone: - it is also called Adigrat sandstone and it is considered to be Triassic–Early Jurassic in age based on some biostratigraphy data and comparison with adjacent areas providing fossil ages. The unit is found unconformable overlying Neoproterozoic basement rocks.

Siltstone: - the silt stone unit is composed of silt/clay particles cemented together. It is found intercalated with shale, mudstone and sandstone with calcite and/or gypsum veins in places

which indicates a change of the depositional environment. It is mostly yellowish green to brownish in color. It is highly consolidated and partly alternating, which is thickly laminated and cross-bedded. It is characterized by weak and friable layers. It is horizontally bedded with closely spaced minor vertical joints.

CHAPTER FOUR

4. Methodology of the Research

The general methodology of the study which is adopted to select the optimum highway route along the Abay gorge shown below includes a collection of vital data from different agencies and organization where it's available. Some of the data basic to the study are: topographic maps, geological maps, remote sensing data, etc. Remote sensing data was primarily used for generating various thematic data layers. A topographic map was used to prepare a base map. Published and field data on geology, structure, landslides, land use/land cover and Ground Control Points (GCPs) were collected and integrated with remote sensing data.

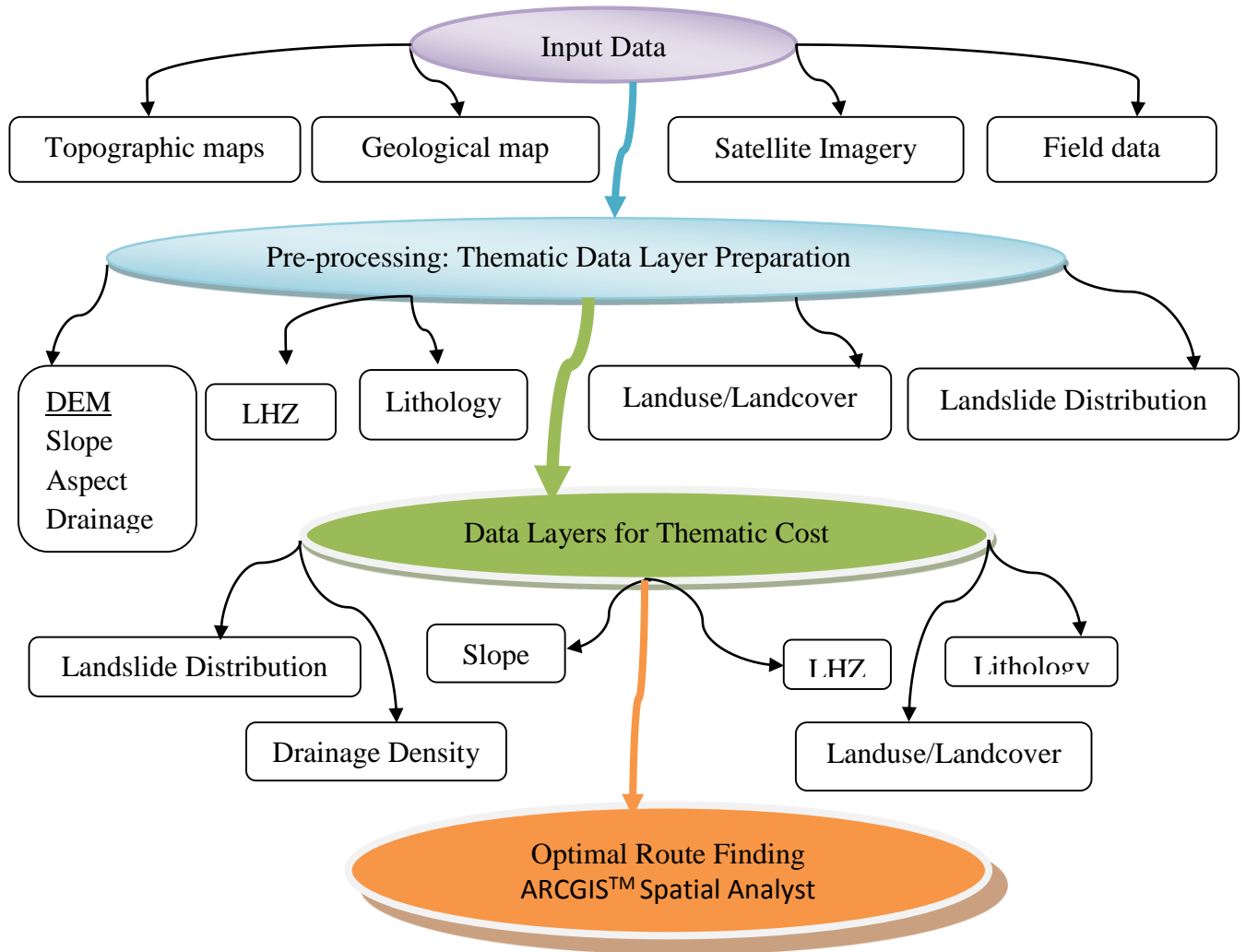


Figure 4.1 Overview of the General Methodology developed for Optimal Route Selection

Pre-processing of remote sensing data was carried out for removal of common radiometric and geometric distortions. A landslide hazard zonation (LHZ) map was prepared using various factors of thematic data layers. A concept of thematic cost map for route development and maintenance was developed, and various thematic data layers were integrated in a GIS environment to generate a 'thematic cost' map. Subsequently, Spatial Analyst Algorithm was adopted and implemented for least-cost route selection. Various software packages (ERDAS Imagine 9.2, IDRIS and Arc GIS) were used for data processing.

4.1. Data Collection

The study has depended on three main types of data: (1) remote sensing data, (2) ancillary or secondary data and (3) field data. The remote sensing data was used for mapping of landuse/landcover. The remote sensing images were geometrically corrected and accurately registered with topographic map using a large number of well distributed GCPs. The ancillary data, namely topographical and geological maps, and road design parameters were collected from various sources. A large amount of information extracted from the topographic maps, e.g. contours and point elevations, drainage network, roads, etc. A geological map was used to collect information on lithology and structural features.

Field data are very important in any remote sensing-GIS study. Sufficient field data were also collected to obtain information on existing landslide distribution and to collect training and testing data samples for landuse/landcover classification and distribution.

4.2. Pre-Processing and Thematic Data Layer Preparation

The most important and primary task done to finalize this study is generating different thematic data layers. A number of thematic data layers, i.e. Digital Elevation Model (DEM), lithology,

landuse/landcover, drainage density, landslide distribution and landslide hazard zonation (LHZ), and slope have been generated using remote sensing-GIS techniques.

4.2.1. Digital Elevation Model

A digital elevation model (DEM) is a basic component in GIS analysis. In this study, the conventional topographic map digitization technique was implemented to generate the DEM. Contours from the topographic map were digitized, raster, and interpolated to generate the DEM. Various DEM based derivatives, such as slope, relative relief and aspect, were produced.

4.2.2. Lithology

The regional geological map was used as the basic input. The rock groups and formations were reclassified in to sub litho units. The geological map was digitized and co-registered with other thematic layers.

4.2.3. Drainage

A drainage map was generated by digitizing the drainage lines from the topographical maps and was subsequently used for generating drainage density maps. The drainage density map was used as an input for the generation of LHZ map, and to estimate the rough cost of bridge construction, if required, during route planning.

4.2.4. Land use/Land cover

Satellite Image data are particularly very useful in mapping land use/land cover of mountainous regions. In such a terrain of the Abay gorge, classification of remote sensing data encounters many problems due to different factors. Therefore, Pre-processing of remote sensing data was carried out for removal of common radiometric and geometric distortions. Finally, a supervised

classification method was adopted. A number of classes were mapped, viz. bush and shrub lands, farm land, barren land, and water bodies.

4.2.5. Landslide Mapping

In this study, particular emphasis was given to existing landslides along the existing road corridor and landslide hazard zonation and their impact on route planning.

4.2.5.1. Mapping of Existing Landslides

In high-altitude mountainous regions, landslides occur at distant and remote places which are inaccessible; therefore this study gave high emphasis on landslides which are stretched along the road corridor and accessible to collect data on physical presence. The identification and recognition of landslides were carried out based on the data collected directly from field.

4.2.5.2. Landslide Hazard Zonation (LHZ)

Landslide hazard zonation deals with segmenting an area into near-homogeneous domains and ranking these according to degrees of potential landslide hazard (Varnes, 1984). For many years, remote sensing-GIS techniques have been used for LHZ mapping. The approach followed (figure 4.2) in this study is based on the empirical relationship between landslide activity and causative factors, viz. lithology, relative relief, slope, aspect, landcover and drainage density were generated and used as inputs for LHZ mapping. Inherent causative factors depending upon their influence in causing slope instability were given rates/weights. Different classes within each causative factor were also given weights according to their significance in causing instability. The information on existing landslide sites collected during the field visits and interpreted from the satellite data was also incorporated to arrive at a more accurate weighted score for each causative factor and their respective sub classes. This formed the basis for giving weight to each parameter and defining their relative significance in inducing landslides. These weighted factor

maps were overlaid using multivariate criteria analysis to prepare a landslide hazard zonation (LHZ) map for Abay gorge.

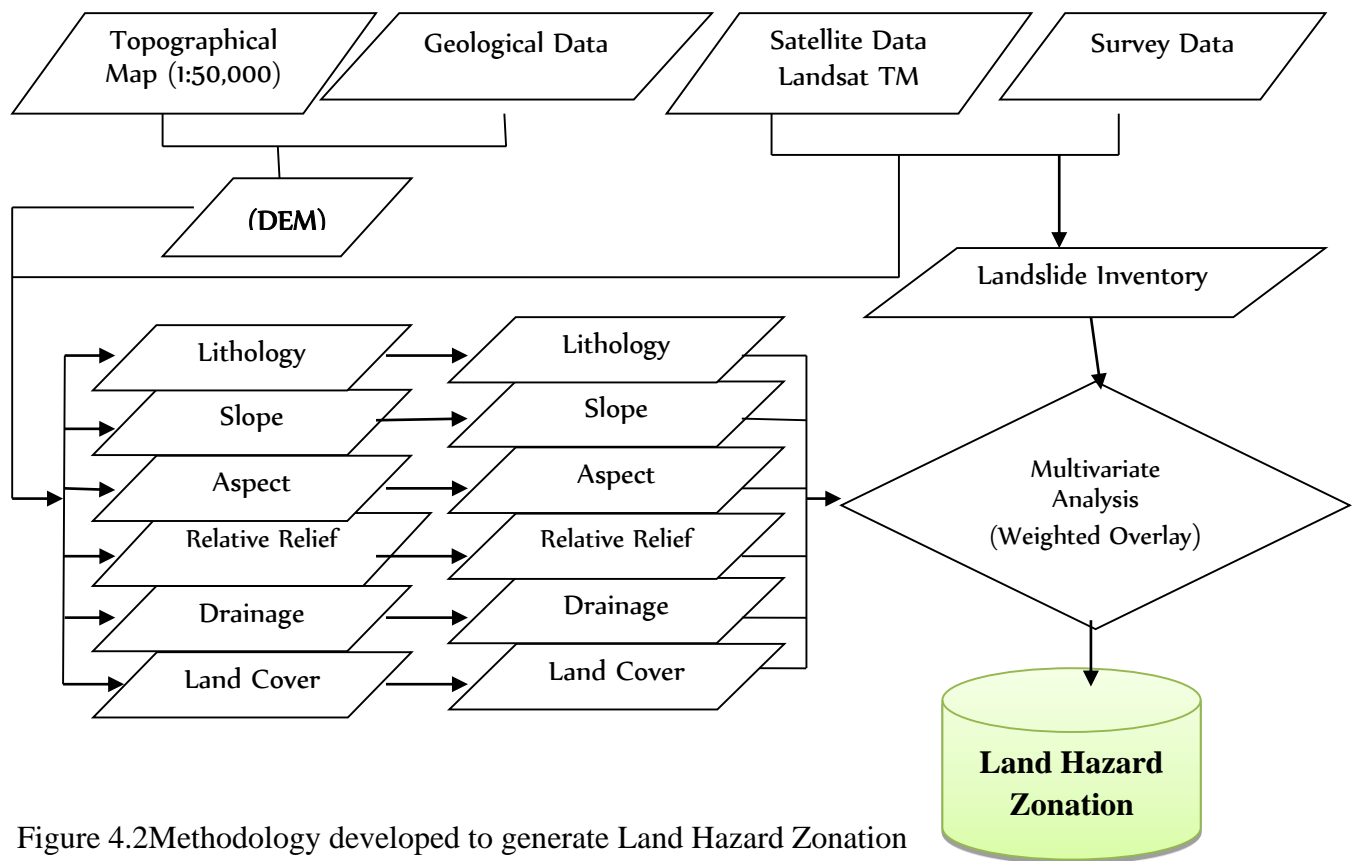


Figure 4.2 Methodology developed to generate Land Hazard Zonation

4.3. Data Processing and Analysis for Route Planning

The planning of optimum highway route alignment, which has less probability to land hazards i.e.; rock fall, debris flow and landslide...etc. and also having minimal construction and maintenance cost can be done using the following two route planning procedures.

4.3.1. Generating a Thematic Cost Map

Areas which are prone to different land hazards such as; landslide, earthquake, rock fall...etc. is affected by high cost of road development and maintenance. Therefore, several geo-environmental factors (i.e.; existing landslides, potential of a new landslide occurrence/LHZ,

excavation and cut-and-fill works, etc.) should be considered to generate the thematic cost surface of the area where, the route will be aligned. The spatial variation of these factors can be represented in terms of raster data layers, which can be integrated in GIS environment to arrive at a cumulative data layer, here called the ‘thematic cost map’. The thematic cost map is a raster map where value at each pixel gives the estimated relative cost of passing through the pixel.

4.3.1.1. Thematic Cost Concept and Computation

Highway route planning, development and maintenance activity is highly depend on different cost factors, the most important factors in this study are landslide distribution, landslide hazard zonation, landuse/landcover, lithology, slope, and drainage density. The thematic cost map is a raster map, where the value at each pixel gives the estimated relative cost of route development and maintenance through the pixel. The cost is cumulative, having inputs from various data layers.

The data layers, landslide distribution (size), landslide hazard zonation, drainage density, landuse/landcover, slope and lithology are of diverse types consisting of measurements at different scales, such as categorical, ordinal and ratio type data. In order to integrate this variety of data, an ordinal weighting rating is used, and to arrive at a cumulative data layer, the concept of thematic cost is developed. Therefore, a weighting rating system in the range of 0 to 9 was used, with zero signifying the minimum cost and 9 implying the highest cost. For example, the landslide distribution thematic data layer was assigned the highest weight of 9, followed by LHZ weight of 8. The weighting rating values were based on a comparative study of various thematic data layers and discussions with experts working in the area of highway engineering. Thematic layers weights and rates used in this implementation are outlined below (Table 4.1).

Table 4.1 Weights and Rates of each thematic layer to generate the cost surface

Thematic Map	% Influence (Weight)	Rate
Existing landslide	22	
No Landslide		0
<200		6
>200		7
>300		8
>400		9
Landslide Hazard	21	
Low		2
Medium		3
High		8
Very high		9
Slope	20	
Flat		2
Rolling		4
Mountainous		9
Escarpment		9
Lithology	14	
Sandstone & Siltstone		4
Gypsum & Limestone		5
Basaltic Rock		8
Colluvial deposit & Alluvial fan		9
Drainage Density	13	
Low		1
Medium		4
High		6
Very high		8
Land use/land cover	10	
Shrub		5
Water		6
Farm land		7
bare land		5

Landslide Distribution: is considered here that landslide occurrence is the most important parameter in road planning in a mountainous terrain, as landslides lead to recurring problems, such as blockades, disruptions, civic miseries, etc., and greatly increase the cost of highway maintenance. Therefore, the highest weight of 9 was given to landslide occurrence. There is no

doubt that it may be ideal to avoid landslide areas altogether during road planning. However, if the landslides are small in size, it may be possible to apply slope-stabilization measures for the route to pass through these. Keeping this aspect in view, rating values were assigned according to the size of the landslides in the region.

Landslide Hazard Zonation: The LHZ map is considered here as the second most important parameter (weight=8) influencing the thematic cost of road development and maintenance. Each pixel in the landslide hazard zonation map prepared earlier carries a value that represents the potential of the landslide hazard. Landslide hazard zones were rated in increasing order according to the severity of the hazard (table 4.1).

Land use/land cover: are required to estimate the cost of land acquisition during route planning. Further, the road construction over landslide debris may accentuate the problem of slope instability. Hence, Barren areas are relatively favorable for route planning due to the fact that such areas are not productive and which is under government control, involve no compensation cost and are devoid of environmental problems like cutting of trees. Sparsely forest or shrub areas seem to be the most suitable for road construction. These areas are relatively stable, and may have minimal environmental problems and susceptibility to landslide.

Lithology: was considered mainly from the nature and stability of the rock susceptible to landslide and from the point of view of costs of blasting, excavation, cut-and-fill works, and stability etc.

Drainage Density: The drainage density map was used here to consider the cost of a possible bridge construction and to analyze the probability of landslide occurrence in the area. Generally, the cost of route development and maintenance increases with increasing drainage density, and also the probability of landslide occurrence increases. Therefore, higher ratings were assigned to higher drainage density areas and the pixels without any channel or low density have been

assigned a zero value.

4.3.1.2. Thematic Cost Map Generation

For each thematic data layer, there is a weight factor. The classes within each thematic data layer carry a rating, which is used as ‘attribute data’. A large number of methodologies are available to find the interrelation among the weights and to accumulate various data layers. For simplicity, the thematic cost map is computed here as:

$$\text{Thematic Cost} = \sum \text{Weight} \times \text{Thematic Data Layer (attribute)} \quad (1)$$

Hence, in this case,

$$\text{Thematic Cost} = [9 \times \text{LD} + 8 \times \text{LHZ} + 7 \times \text{SL} + 5 \times \text{LI} + 4 \times \text{DD} + 3 \times \text{LULC}] \quad (2)$$

Where LD is the landslide distribution, LHZ is the landslide hazard zonation, SL is the slope of the area, DD is the drainage density, LULC is the land use/land cover, and LI is the lithology.

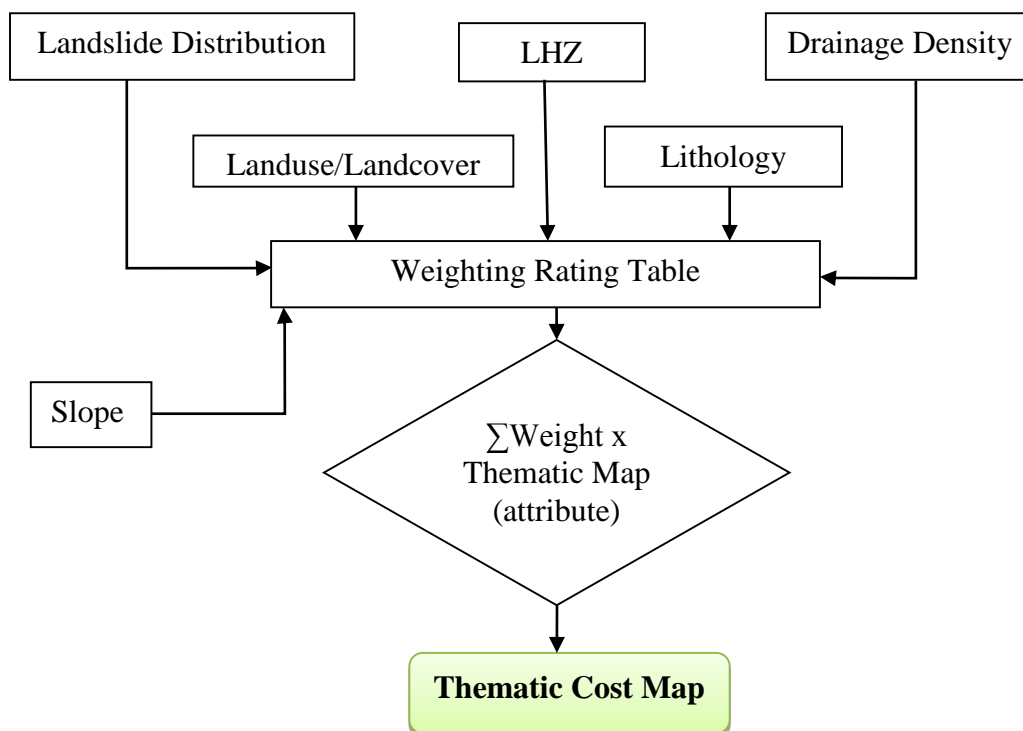


Figure 4.3 Schematic Diagram of Thematic Cost Map used in Route Planning.

4.3.2. Selection of Optimum Route

As the route alignment covers a certain distance, it passes through pixels, and their successive grid pixel cost values will accumulate to give the total cost. This final step involves finding the least-cost route for Gohatsion – Dejen road project. The procedure helps select an optimal route that is supposed to be the best, as it tries to avoid major landslides and passes through low thematic cost zones, thereby reducing overall road development and maintenance costs. Figure 4.4 shows the route planning steps adopted in this study.

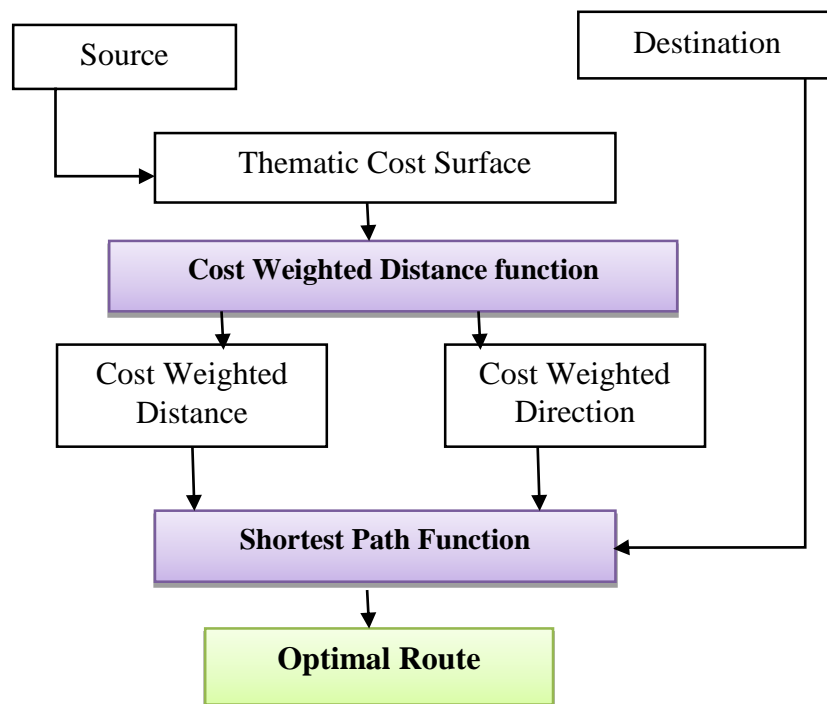


Figure 4.4 Methodology for the generation of the Optimal Route Selection.

After the thematic cost surface map generated, it is almost ready to find the shortest path from the source. Cost weighted distance has already performed, creating a distance dataset and a direction dataset using the source point. However it is necessary to decide on, and then create, the destination point for the road. Hence this requires the creation of destination point on the Gohatsion to Dejen which is used in the calculation of shortest path to the highway. The shortest

path is calculated using the function “shortest path” in the Spatial Analyst. Specifying the destination point as input along with the distance and direction theme, calculates the optimal path through which Highway has to run. It represents the least cost path, least cost meaning avoiding landslide and steep slopes and on land use types considered to be least costly for constructing the Highway from source to destination.

CHAPTER FIVE

5. Analysis and Discussion

5.1. Slope and Aspect

Slope and aspect are the most important triggering factors that determine the hazardousness of an area. The slope degree refers to the rate of change in elevation over distance with lower the slope value representing flatter terrain and higher values representing steeper terrain. In the current study, According to ERAs standard the slope angle is divided into four classes, i.e. gentle slope (0° - 2°), rolling slope (2° - 14°), mountainous slope (14° - 37°) and escapement ($>37^{\circ}$). The gentle slopes (below 2°) form is only 2% of total area of the road corridor and such slopes are found either along the river's course or on ridge tops of the gorge.

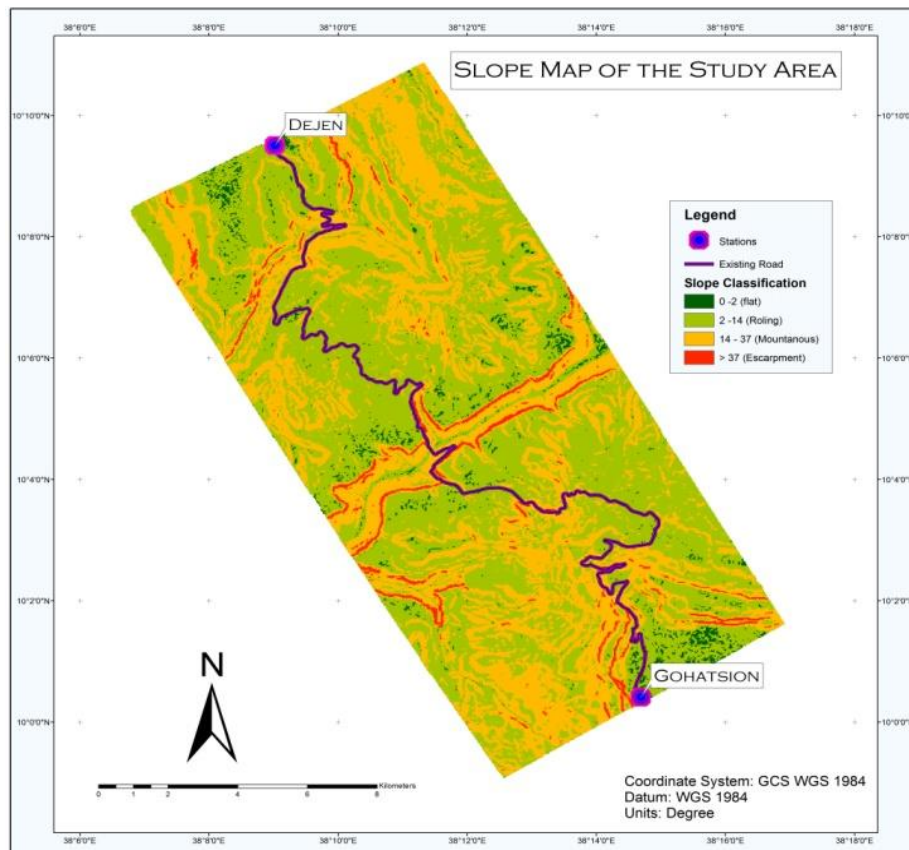


Figure 5.1 Slope map

The moderately steep or rolling and steep slopes or mountainous accounts almost 55% and 40% of the total area of the road corridor respectively, the remaining 3% of the total area possesses very steep to precipitous (above 37°) slopes. The highest landslide densities occur in a class along rolling and mountainous slope areas and the density and distribution of the landslide decreases along areas having a slope of 2° and below and areas having greater than 37° (figure 5.1).

The steepest slope involves deep cutting during the construction. This aggravates the existing landslide problems for two reasons. The cut surface promotes the percolation of water which ultimately lubricates and increase the load, this aggravates the sliding. The second is vibration during construction and maintenance. Vibration during maintenance accelerates detaching of the loose materials and cracking at the weak points.

During the operational stage of road heavy truck stay long on road due to the steepness of the slope. Particularly during the wet season the road becomes slippery. As a result truck and trailers move slowly which aggravates the sliding problems. The riding quality immensely reduced. The main cause for the highest slide density along the road is due to the heavy truck. Therefore, in the course of optimal route selection it was tried to avoid the steep slope.

Aspect defines the down slope direction of the maximum rate of change or the direction of steepest slope in x-y plane. The influence of aspect on the occurrence of landslides can be direct or indirect. Direct, because the aspect influences the amount of water absorbed by soil or evaporated. Indirect, because a correlation could be found between other landslide factors and the aspect\factor (i.e. land covers, in particular regarding the presence of vegetation, geological structures ...etc.). Thus, the high correlation of landslides with the aspect factor can depend on the particular geological structure that could be investigated. The aspect distribution in the study

area has an even distribution as all eight directions (figure 5.2). The aspect has significance in understanding the slope stability.

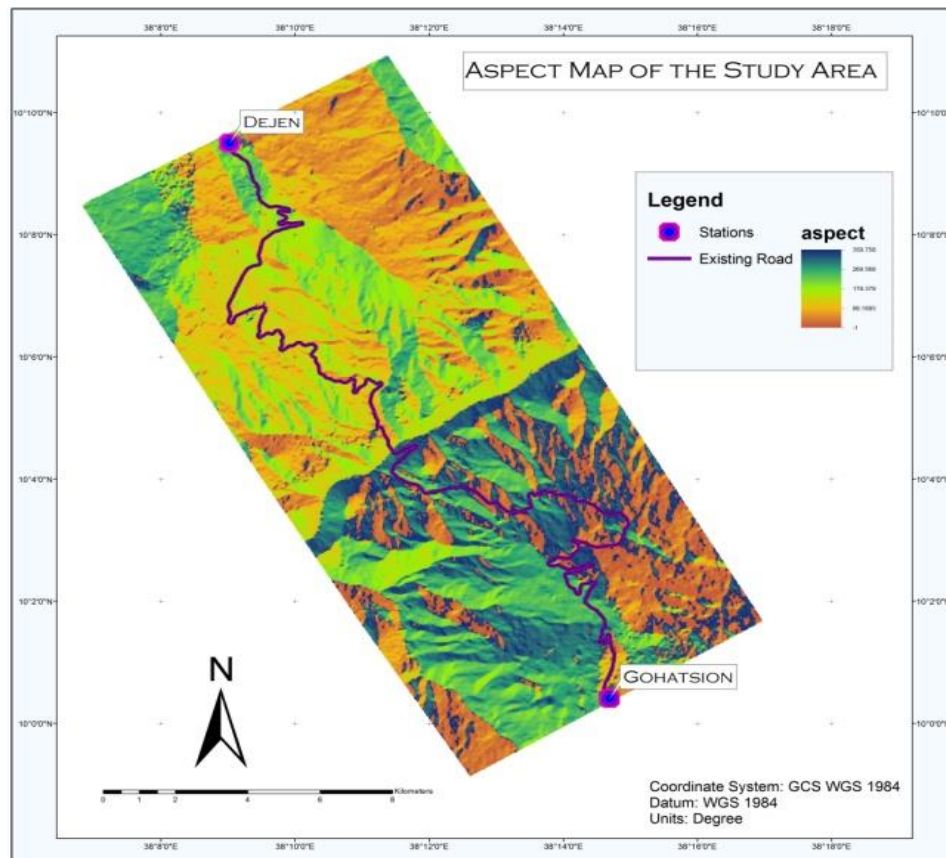


Figure 5.2 Aspect Map

Aspects mainly influence evapo-transpiration and vegetation cover which ultimately play role on the frequency of the landslide. The windward has high vegetation which anchors loose materials by root while the leeward has less vegetation. On the other hand too dense vegetation increases percolation and increases the bulk weight which aggravates the sliding problem. This is not the case in Abay Gorge which has very scarce vegetation influenced by anthropogenic factor (cleared for fire wood and construction).

5.2. Relative Relief

The area possesses high relative or local relief which refers to the difference between the highest and the lowest altitude in an area. The higher values indicate rapid rise in altitude and presence of faults, lower relief signifies mature topography. A determinant of morphological character of an area, relative relief has noteworthy alliance with landslide by acting as a triggering factor. As a risk agent, relative relief plays a decisive role in the vulnerability of settlements, transport network and land. In the Abay gorge, there is wide variation in relative relief ranging from low (998m *a.s.l.*) to very high (2536m *a.s.l.*), which is presented in (figure 5.3).

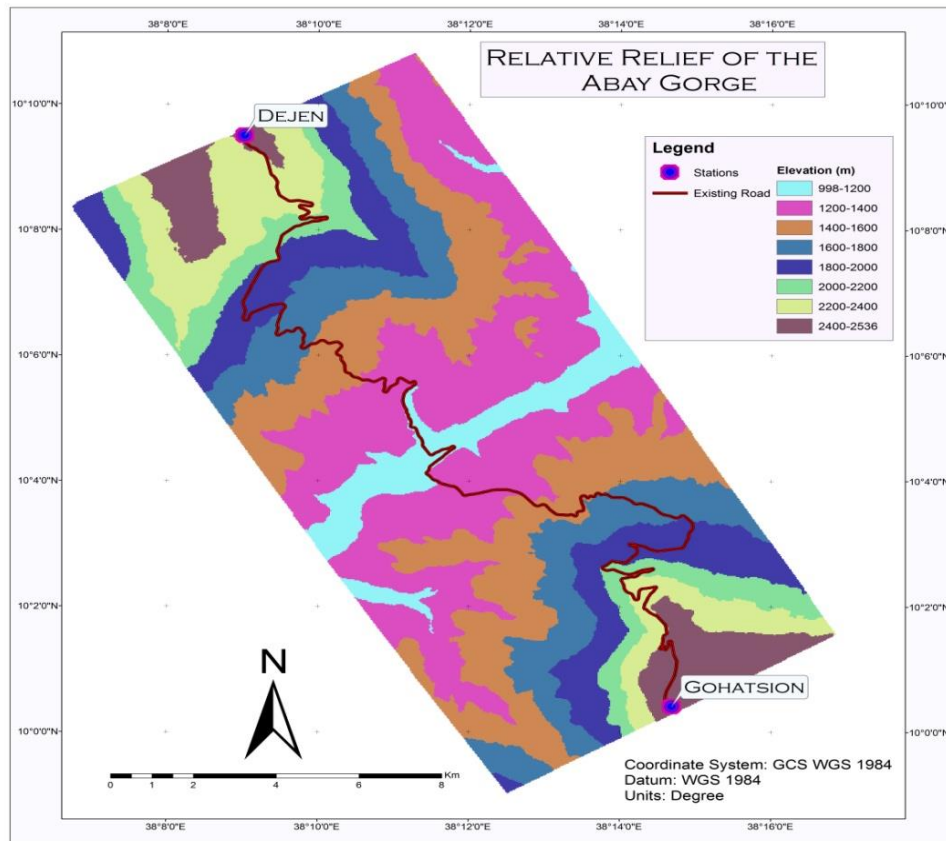


Figure 5.3 Relative Relief Maps

About 22% of the total area of the gorge has an elevation of 2000m and above. While the remaining 68% falls in the range between 998 – 2000m. Only few part (< 6%) of the study area have relative relief values <1000 m. High relative relief values lie in almost the whole portion of

the gorge. Higher relief values are more significant in causing landslides and causes of high cost for highway construction and maintenance.

5.3. Drainage Character

The drainage patterns in the area are an outcome of long time interaction between the geological structure, topography and slope. The overall drainage reflects early stage of dendrite pattern with visible traces of parallel dendrite and trellis patterns in between. A mathematical expression of drainage morphometric of an area is drainage density which is a measure of the length of stream channel per unit area of drainage basin.

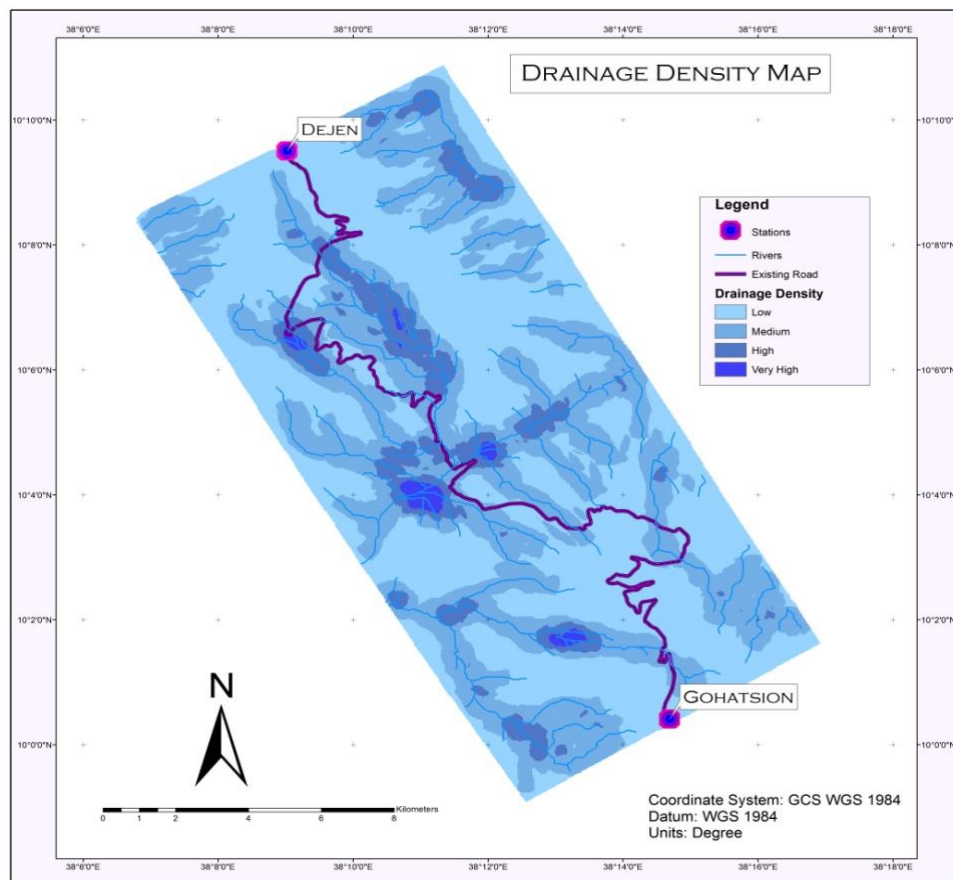


Figure 5.4 Drainage Density Map

The measurement of drainage density is useful in determining landscape dissection and runoff potential. Higher values denote higher degree of dissection of land, as well as indicate the higher probability of slope failure and the higher the cost of highway route construction.

The drainage density in the study area (figure 5.4) can be grouped in the range of low (below 1.0 km²) to very high (above 3.0 km²). About half of the total area has low density mostly comprising of mountain tops, major ranges and ridges. The valley floors of all the major streams have high to very high drainage density. Such areas account for only 9% of total area of the road corridor of Abay gorge. In mountainous regions drainage density provides an indirect measure of groundwater conditions, which have an important role to play in landslide activity (Yoseph, 2010). This is because, the higher the drainage density, the denser the stream network, and surface flow accumulates to the nearest stream very quickly. This phenomenon reduces the amount of infiltration, and ultimately sustains the soil strength as its initial condition. The drainage density is the mirror reflection of ground water which means the higher the drainage density the higher the ground water. The ground water is one of the factors for sliding. That means areas with higher drainage density are susceptible for sliding.

5.4. Land use/Land cover

Land use/land cover analysis reflects relationships between land use, disaster risk and vulnerability to disaster events. The land use/ land c over analysis for this study was made based upon the satellite image of LANDSAT TM (2009) and field data. Prominent four classes of land cover were identified in the study area, i.e. farmlands, barren surface, shrub, and water bodies. The maximum likelihood classification (MLC) algorithm which is the most accurate classifier was used. From the land use / land cover map (figure5.5) of the study area, farm area is seen to lie in the upper part of the gorge. The farm area is the most fragile class, which means human interference has bearing effect on the occurrences of landslides as compared to other classes. The

farm area covers about 53% of the study area. The class under barren land has area coverage of about 33 percent of the total area. This is followed by shrub, covering about 13 percent of the total area. The least coverage (water bodies) accounts 0.5 percent of the total area.

Land use is one of the key factors responsible for the occurrence of landslides, since the Abay gorge is found in landslides prone area, it's mandatory to use the land use/land cover as a more prominent parameter to study the landslide hazard and highway route selection. Land use changes like replacement of forest and shrub lands to agricultural land, road and other infrastructure is an important factor in triggering landslides. This implies that land use in study area under direct human influence has very high intensity to landslide. This can be particularly seen along the road corridor of the Abay gorge. From analysis it is found on the study areas shows that major active landslides occur in farm and barren land.

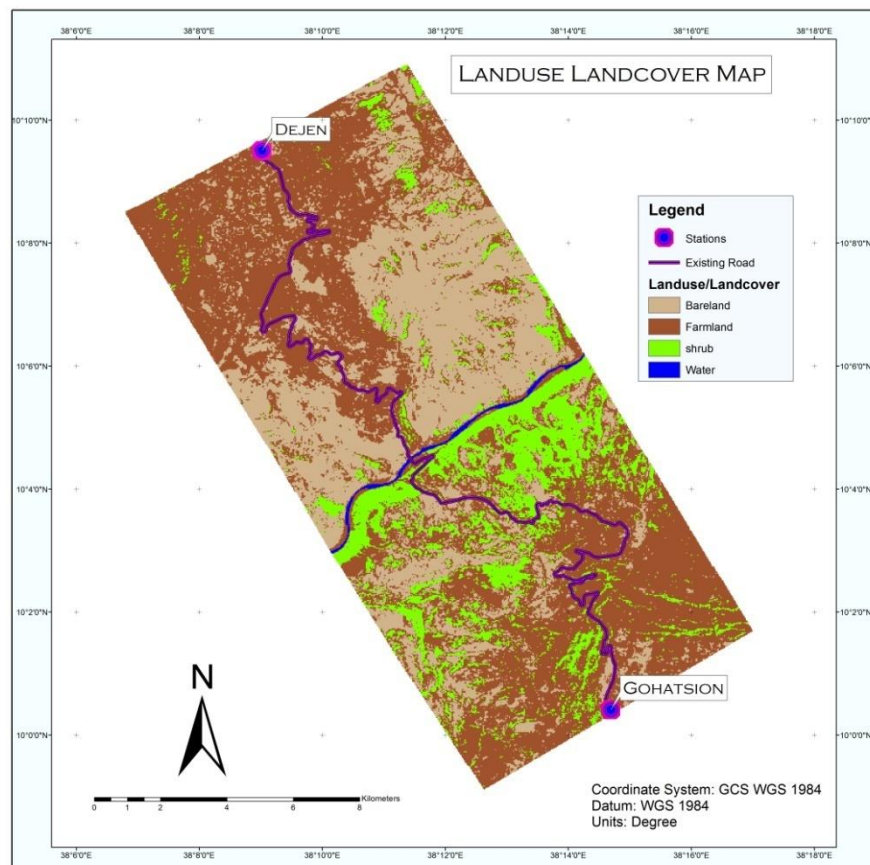


Figure 5.5 Land use/Land cover Map

Land use land cover governs the hydrologic condition of the study area through altering natural drainage pattern, limits the predictability of infiltration Vs runoff, erosion and sliding. As the myriad portion of land use of the study area is a farm land the farmers traditionally alter the drainage pattern in order to reduce erosion. But little emphasis is given to reduce the speed and force of runoff. The runoff from different farm plot come together and become huge to create gully and trigger sliding. The absence of conservation measures on the farm plot to counteract miss management is very minimal.

5.5. Lithology

It is widely recognized that geology greatly influences the occurrence of landslides, because lithological and structural variations often lead to a difference in the strength and permeability of rocks and soils and also Lithology is one of the important factors for landslide susceptibility mapping (Lulseged *et. al.*, 2004). The study area consists of 7 types of rock formations and these litho-units reclassified into four groups based on their landslide susceptibility potential, which is shown on figure5.6. Analysis shows that landslides are mainly observed in different magnitude of different lithology units, i.e. on the Colluvial deposit (30.38%), Alluvial fan (20.45%), Basaltic rock (17.26%), and the rest are in the limestone with siltstone and shale.

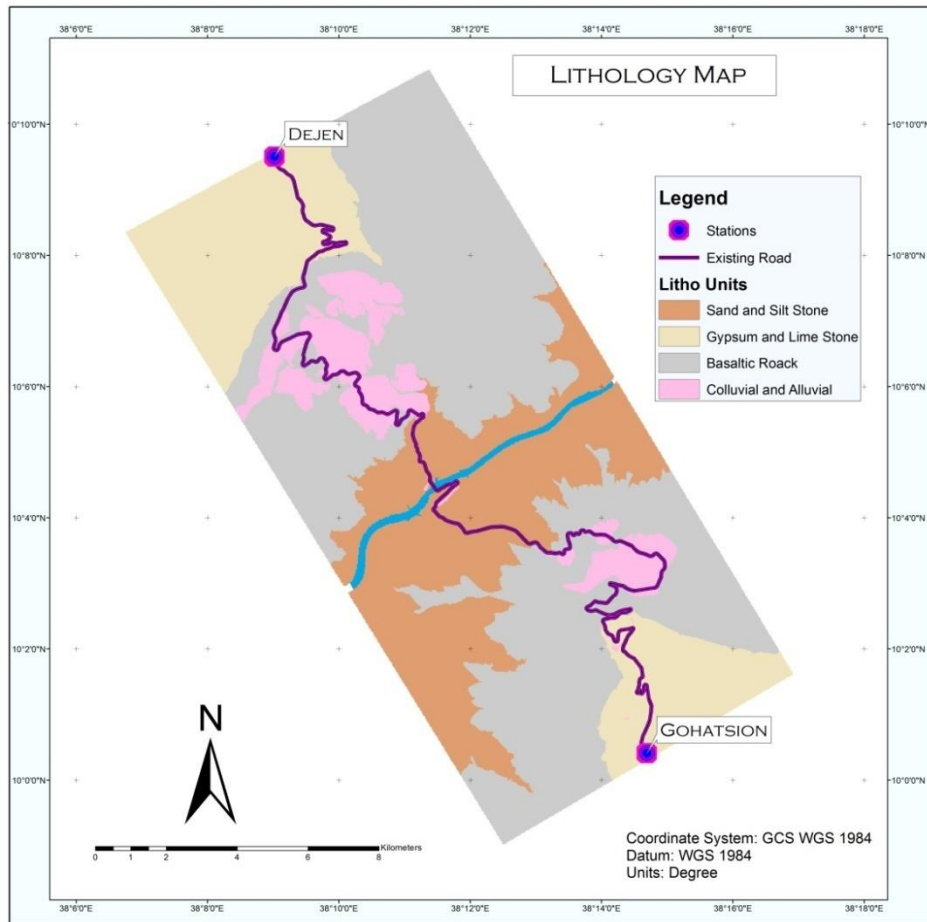


Figure 5.6 Lithology Map

5.6. Major Landslide Inventory along the Existing Road

The identification and mapping of existing landslides is a prerequisite for performing statistical analysis of the relation between the distribution of landslides and its influencing parameters as well as to select an optimal route which is free from landslide hazard. The reliability and accuracy of the landslide inventory map also influence the success of applied methodology. Since it is not possible to reach all places to locate every landslide in mountainous regions such as in the Abay gorge, the identification is dependent on the distinctness of those landforms as visible from the survey done on the field and unpublished landslide inventory map of the area. A total of 255 landslides of various dimensions have been identified in the area using both field

data and different unpublished land hazard maps. From figure 5.7 it can be observed that landslides are densely located in the vicinity of the highways.

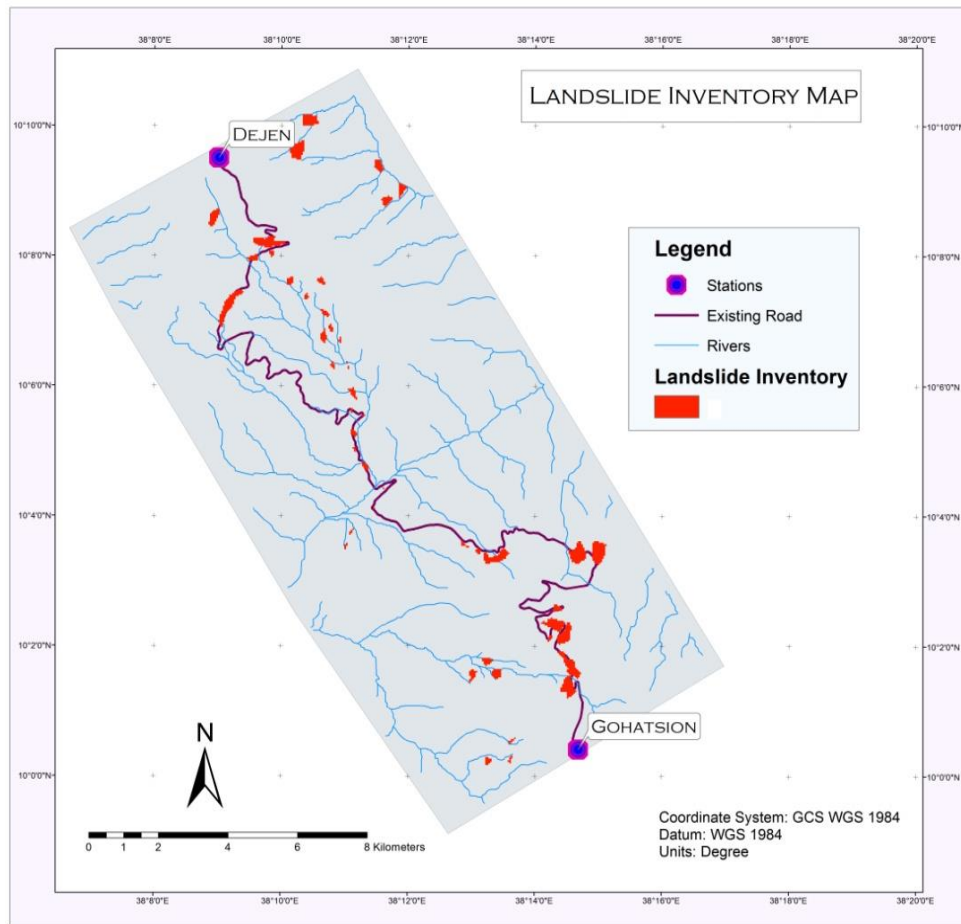


Figure 5.7 Landslide Inventory along the Existing Road

Accordingly, Over 255 land hazards were mapped within the corridor area between Gohatsion and Dejen road in the Abay gorge. Of this large number of hazards, only 11 are the relatively large, deep, slower-moving types of landslides that typically cause damage to roadways. In contrast, small, shallow, rapidly-moving debris flows are very abundant along the Gohatsion – Dejen highway corridor of Abay gorge. Hazards related to debris flow deposits on the roadway surface can typically be cleaned up by maintenance personnel and its damage is not that much great. These hazards are concentrated in the few areas where debris flows may impact the roadway surface.

Consider the case that the entire major and minor landslide and the associated debris flow track is unsuitable for route location and therefore must be avoided. For such a situation, the entire zone can be assigned a high value in the thematic cost layer. The source and destination points (Gohatsion and Dejen) towns have been found at nearly the same elevation (approximately on 2500m *a.s.l.*) on either side of the set of major and minor landslides.

5.7. Landslide Hazard Zonation (LHZ) Analysis Map

Several thematic digital data sets were integrated for such analysis under GIS environment to find out the cumulative landslide hazard map. These include an inventory of landslides, slope angles, drainage density, high local relief and geological map of the area, high resolution digital elevation data, and suitable high-resolution RS data. The outcome of the overlay, integration and analysis was the production of hazard risk map (figure 5.8).

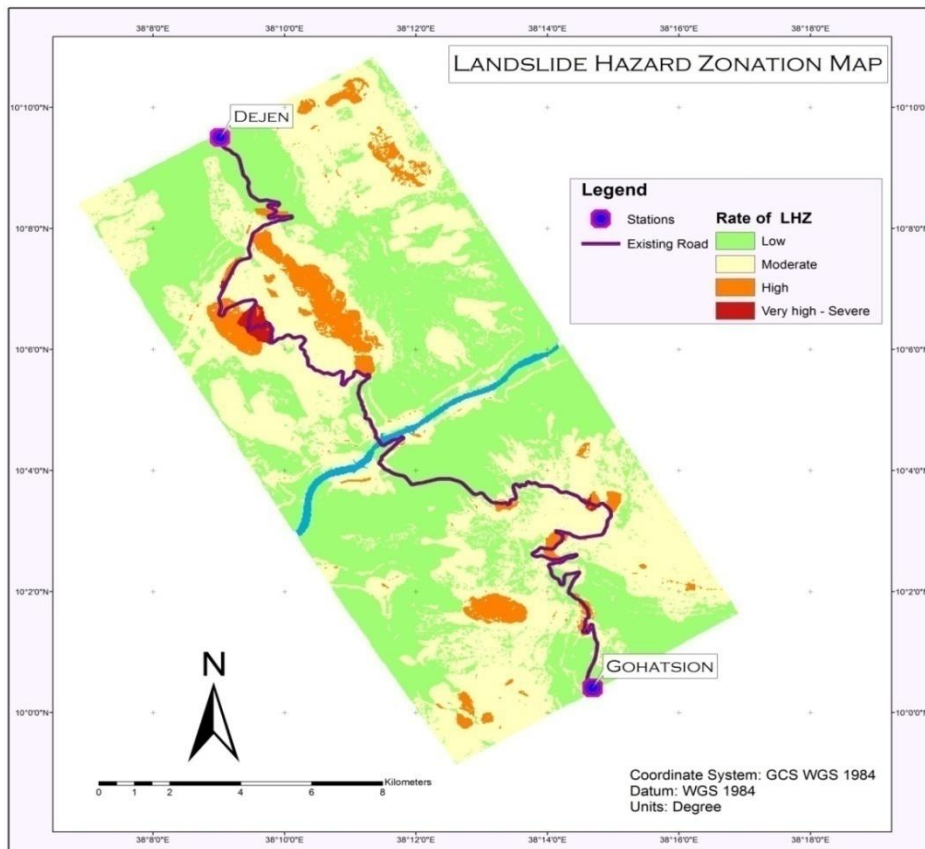


Figure 5.8 Landslide Hazard Zonation of Abay Gorge

The analysis shows that almost entire district is prone to landslide risk of varying magnitude. Over 52 percent area is liable to moderate to severe landslide risk and within this about 6 percent has high to severe risk while about 46 percent of the total area has moderate risk of landslide occurrence. Such areas are located and distributed in the steep slope part of the gorge, along the existing highway road (Gohatsion - Dejen) Areas having high drainage density fall in the category of high to severe landslide hazard potential. The remaining about 48 percent area of the road corridor has low to moderate risk of landslides. These include the valley floors mainly of the valley along the river Abay and adjoining areas, and high altitude areas of land surface. Very small area (0.42%) constituting river channel/streams is devoid of landslide risk.

The susceptibility to landslides is inherent in the natural characteristics of the landscape and there is a definite relationship between landslide occurrence and the geophysical setup of the area. The high slope angles, drainage density, high local relief and geological structure produce suitable conditions for landslide occurrence (Lulseged, 2000). The rainfall during the summer season is also invariably the immediate triggering factor. In addition, anthropogenic activities such as infrastructure and agriculture aggravate the problem. The intensification of human activities, encroachment on vulnerable land and rampant expansion of mining (gypsum resource extraction) and roads adds to landslide vulnerability. It is pertinent to note that landslide activity is largely confined to the vicinity of roads and this is substantiated by field visits and previous studies. The present study demonstrates high degree of hazardousness of the Abay gorge.

5.8. Thematic Cost of the Road Corridor

The thematic cost surface gives a high weight for areas of existing and active landslide, Landslide hazard, areas of steep slope and higher relative relief and high drainage density areas. The stack of grid based maps were calibrated to a common suitability scale of 1 best through 9 worst situation to generate cumulative cost of the study area and finding the optimal route of the

road between Gohatsion and Dejen towns. In turn, a weighted average of the calibrated map layers is used to derive a Discrete Cost Surface containing an overall relative suitability value at each grid location. Note that the weighting in the study area strongly favors avoiding locations within/near to the active and susceptible areas of landslide and very steep slope and escarpment gradients.

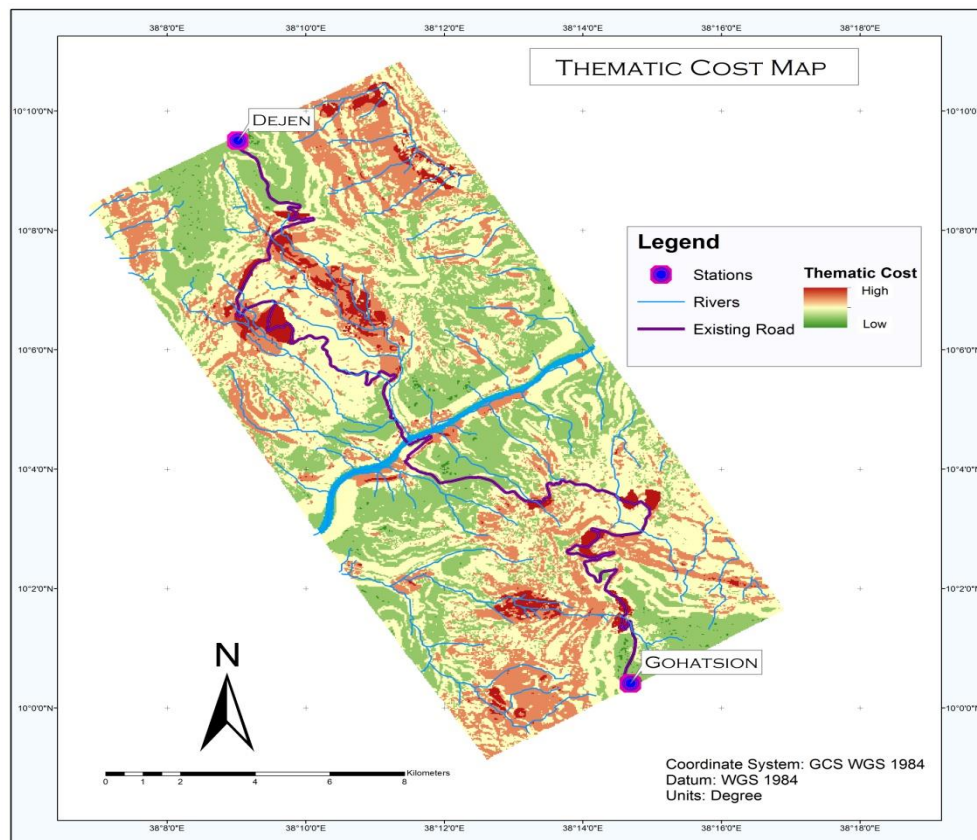


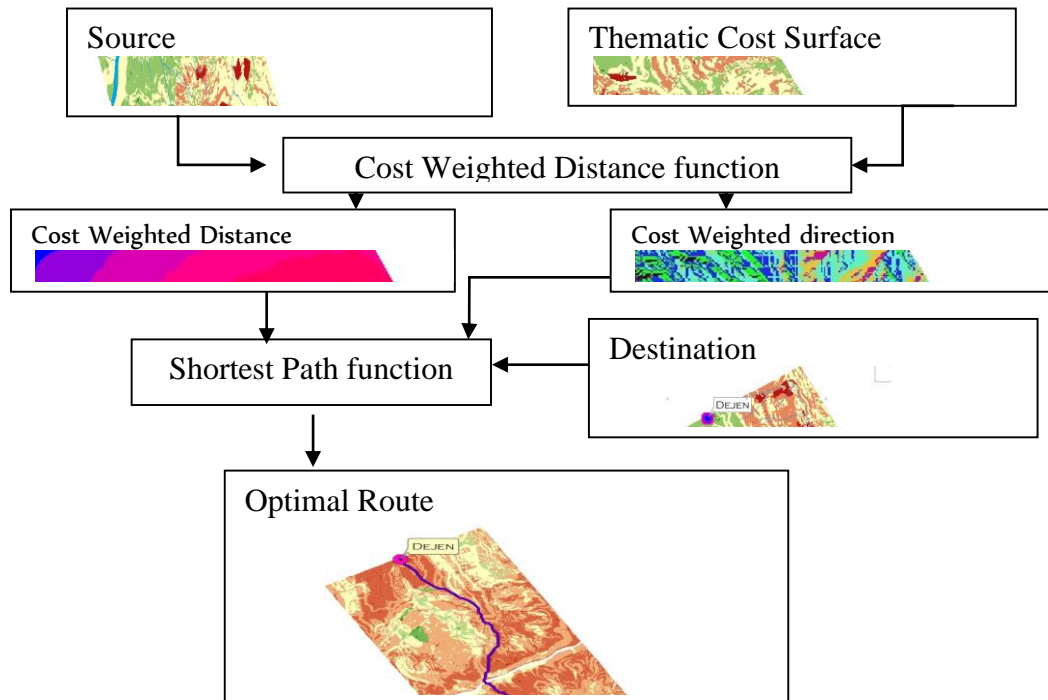
Figure 5.9 Thematic Cost Surface Map of Abay Gorge

The result after analysis is a map showing the different colored regions classified from very good to bad portion of land representing the suitability for selecting the road path as in (figure, 5.9). The green areas were assigned very good, light yellow areas assigned good, orange areas were assigned bad, and brown areas were assigned too bad. From the resulted weighted overlay map it could be decided to choose the optimum road path by carefully trying to design the path to pass through the colored areas that are indicated by good avoiding the bad one.

5.9. Optimum Route Determination

Ranges of parameters were considered to develop thematic costs for the selection and evaluation of optimal route alignment between Gohatsion and Dejen towns. The main parameters which were considered in this study are; landslide, terrain, geology, land use/land cover, and elevation were accumulated to generate the cost surface. The parameters were selected and weighted based on Route Section Manual (ERA, 2012) and also based on the scope of the study, which is selecting highway route relatively free from landslide hazard. Accordingly, the first step of defining the discrete cost surface map is the most critical as it establishes the relative goodness for locating a highway at any grid cell in a project area. It imparts expert judgment in calibrating and weighting several routing criteria maps. The remaining steps, however, are mechanical (deterministic) and require no user interaction or expertise and done by using Spatial Analyst of ArcGIS software, the optimal route alignment of the study area was selected. The process of selecting optimal route in landslide prone area is shown in Figure below.

Figure 5.10 Schematic Diagram of Optimal Route Selection Result



The development of the optimum route option was further determined by the predefined starting and ending control points (objective of the road project connecting Gohatsion and Dejen towns found in the opposite sides of the Abay gorge). The existing highway route path, which passes through active and susceptible landslide areas, has a total length of 40 km. While, the new route alignment which is selected using GIS and Remote Sensing in this study has a total length of 31km and far away from both active and susceptible land hazard areas.

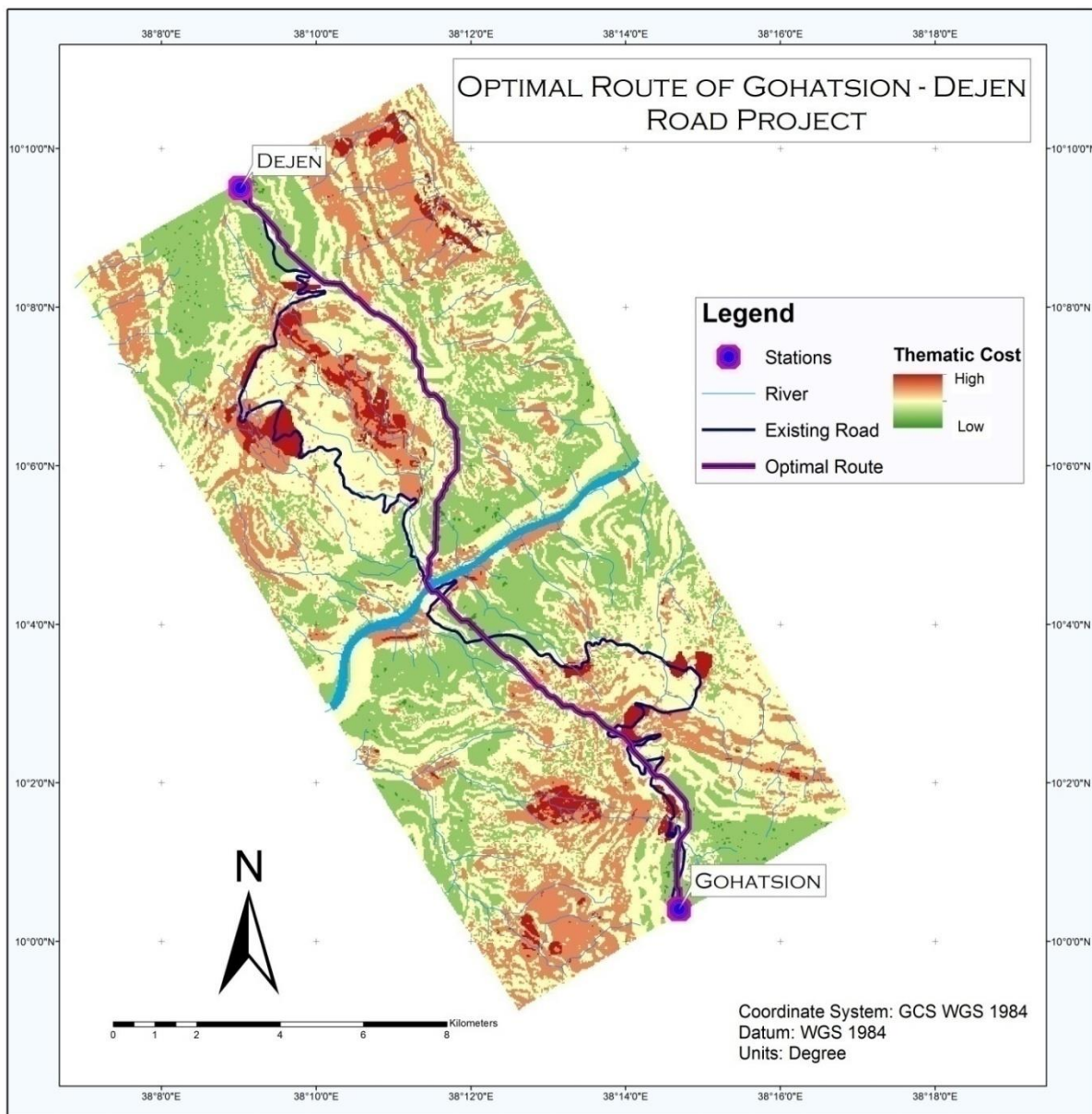


Figure 5.11 Optimal Highway Route of Gohatsion- Dejen Road Project

The new alignment developed in this study is restricted to pass through the newly constructed Abay Bridge. This is deliberately made to reduce construction cost of bridge which is very high. Results indicate that the route which was designed applying GIS method is more environmentally effective and cheaper than traditional one. This showed a potential saving of the cost used for reconnaissance survey and other activities done manually and the optimal alignment can be obtained by applying digital or automatic route selection process. The described system of multi-criteria analysis has universal applicability. It can be used for route determination of any optimizations such as roads, irrigation drying channels, power lines and railways. In addition to its technical benefits optimum routing using tools indicated in this study reduces loss of life and property due to the landslide. Accidents are inexorably increasing close to landslide active areas. On the subject road a number of car accidents were recorded. Most of the accidents are due to rutting, cracking, potholes created due to the sliding nature of the area. It also ameliorate the maintenance cost particularly costs in the form of emergency. The Government of Ethiopia has hired international consultant to mitigate the problem on the existing route. Efforts have been made but not accompanied with the expected results. Therefore, planning the route using the tools indicated here substantially minimize costs associated to alleviate the problem.

CHAPTER SIX

6. Conclusion and Recommendations

6.1. Conclusion

The main goal of this study was to show the competence of geospatial technologies specially GIS and Remote Sensing on road route alignment planning on mountainous or rugged terrain areas which are prone to landslide or any land hazards. Gohatsion – Dejen road traverses Abay Gorge a landslide-prone area was chosen to show the potential and application of GIS and Remote Sensing on the preliminary road route planning process. Within this corridor, landslides have been an ongoing problem for decades. In order to evaluate and avoid the relative hazards of the landslides on this road, a lot of activities have done by Ethiopian Roads Authority (ERA), however the problem is still persist. In the GIS and Remote Sensing based methodology, it is possible to integrate and analyze various parameters related to road development and maintenance at the same time. The concept of thematic cost could help the purpose. In the manual method, it is difficult to consider a large number of parameters at the same time to conduct a purposeful analysis.

The raster based map analysis of GIS provides a wealth of capabilities for incorporating terrain and other artificial information surrounding linear infrastructure. The thematic Costs used to generate the optimal route of the road corridor were resulting from considering; the existing and active landslides, potential landslide or land hazard zonation (LHZ), terrain or slope, lithology, land use/land cover, and drainage of the study area.

The existing road path which passes through an active landslide, debris flow, and rock falls has a total length of 40km from Gohatsion to Dejen. The new route which is selected in this study by using the developed methodology considering the above thematic layers has a total length of

31km and passes through areas which are relatively free from land hazards. This proposed optimal route provides land hazard free, risk free, free from environmental pollution, and also the shortest distance for movement of vehicle traveling from Gohatsion to Dejen. Results indicate that the route which was designed applying GIS and Remote Sensing method in mountainous and land hazard prone area is more environmentally effective, safer and cost-effective route. Applying Geospatial technologies could also be used for route determination for irrigation, drainage channels, power lines and railways.

6.2. Recommendations

The cost of road construction in Ethiopia is inexorably increasing. Selecting the feasible route and quality of road design immensely determine the cost of construction as well as that of maintenance. Currently in Ethiopia, Route section is made manually without considering all fundamental parameters. Lack of multi-criteria analysis during route selection triggers safety problems, diminishes the quality and durability of the road and ultimately raises the cost of construction and maintenance. Furthermore, it invite for complains from road users and nearby community. The application of GIS and RS for optimum routing of Gohatsion - Dejen Road Project in this study showed promising result which avoid landslide hotspots and reduce the total length of the road. Therefore, the Ethiopian Roads Authority, the regional road agencies and organization with similar work process like Railway Corporation needs to consider GIS and RS for route planning. Design consultant, supervision consultant and individual experts vastly benefit from the tools and methods followed in this study to increase efficiency while reducing cost and time.

References

- Saha A. K., M. K. Arora, R. P. Gupta, M. L. Viridi and E. Csaplovics, 2005. GIS-based route planning in landslide-prone areas. *International Journal of Geographical Information Science* Vol. 19, No. 10, pp. 1149–1175
- Admasu Shiferaw, Mans Soderbom, Eyerusalem Siba and Getnet Alemu, 2012. *Road Infrastructure and Enterprise Development in Ethiopia*. International Growth Center London School of Economics and Political Science 4th Floor, Tower Two Houghton Street London WC2A 2AE United Kingdom.
- Alexandre B. Gonçalves, 2010. An extension of GIS-based least-cost path modeling to the location of wide paths, *International Journal of Geographical Information Science*, 24:7, 983-996
- AlmazeGezahegn and TadesseDessie (1994). Report on Engineering Geophysical Investigation of the Blue Nile basin for rerouting of the main road. Ethiopian Institute of Geological Survey, Addis Ababa.
- Carrara, A., Cardinali, M., Guzzetti, F., and Reichenbach, P., 1995. GIS technology in mapping landslide hazard, *geographical Information Systems in Assessing Natural Hazards.*, Dordrecht: Kluwer Academic Publishers, p. 135-176.
- Ethiopian Institute of Geological Survey, 1974. Engineering Geophysical investigation of the Gohatsion to Degen re-route. EIGS, Ethiopia.
- Ethiopian Roads Authority Route Selection Manual, 2012. Addis Ababa, Ethiopia.
- Ethiopian Roads Authority, 2013. Road Sector Development Program. Addis Ababa, Ethiopia
- Fekerte Arega and Muse Belew, 2006. GIS and Remote Sensing in Highway Route Selection: Case of Addis Ababa Nazareth Expressway Alignment. Addis Ababa, Ethiopia.

- Gani, N. D.S., Abdelsalam, M. G., Gera, S., Gani, M. R. 2009. Stratigraphic and structural evolution of the Blue Nile Basin, Northwestern Ethiopian Plateau. *Geol. J.* 44, 30–56.
- Intiaz A., AbdNasir B., Khamaruzaman B., Mir Aftab H. T., Shabir H. and Munirah R.,2012. Computer Application in Routing of Road using Least-Cost Path Analysis in Hillside Development. *Research Journal of Environmental and Earth Sciences, University TeknologiPetronas, Malaysia* 4(10): 907-911
- Japan International Cooperation Agency, 2012. Landslide Survey Report, Report for the Gohatsion Dejen Road Project. Addis Ababa, Ethiopia.
- Japan International Cooperation Agency, 2013. Immediate Countermeasures against Landslide and Confirmatory Survey, Report for the Gohatsion Dejen Road Project. Addis Ababa, Ethiopia.
- Lulseged Ayalew, 1999. The Effect of Seasonal Rainfall on Landslides in the Highlands of Ethiopia. *Bull Engineering Geology Env.* 58, 9-19.
- Lulseged Ayalew, 2000. Factors affecting slope stability in the Blue Nile basin. In: Bromhead, E., Dixon, N., Ibsen, M. (Eds.), *Landslides: In Research, Theory and Practice*. Thomas Telford, Cardiff, Wales, pp. 101– 106.
- Lulseged Ayalew and Yamagishi, H. 2004. Slope failures in the Blue Nile basin, as seen from landscape evolution perspective. *Geomorphology* 57, 95-116.
- Lulseged, Dietmar Moeller and Gerhard Reik, 2009. *Geotechnical Aspects and Stability of Road Cuts in the Blue Nile Basin, Ethiopia*. Geotech GeolEng Springer Science and Business Media B.V.
- Manoj K. Jha and Paul Schonfeld, 2004. A highway alignment optimization model using geographic information systems. *Transportation Research Part A* 38, Published by Elsevier Ltd.

- Varnes, D. J. 1984. Landslide Hazard Zonation: a review of principles and practice. United Nations International, Paris, A report.
- Westen, C. J., 1993. Application of Geographic Information Systems to landslide hazard zonation: Itc Publication, v. 15, p. 245.
- Yohannes Fissea, 2005. Institutional Consideration and Evaluation of GIS as a Decision Support Tool for Route Alignment Planning: the Ethiopian Case. Unpublished TRITA LWR Master Thesis, Stockholm.
- Yoseph, E. 2010. Landslide Assessment in Blue Nile Gorge, Central Ethiopia. Unpublished Msc thesis. Gent University, Belgium.
- Zhongzhen Yang and Tao Feng, 2003. Optimizing Highway Alignment in Road Network. Proceedings of the Eastern Asia Society for Transportation Studies, Vol.4.

APPENDICES

Appendix 1:

GPS Points Collected for Land use/Land cover mapping of the Abay Gorge on March, 2013

Latitude	Longitude	Altitude	Landcover
10.008556	38.246565	2432.144043	Shurb
10.043122	38.234553	2048.85083	Shurb
10.043206	38.234275	2067.370605	Shurb
10.043385	38.233861	2066.884766	Shurb
10.043339	38.23379	2070.706299	Shurb
10.043269	38.233719	2074.499268	Shurb
10.043269	38.233719	2074.195312	Shurb
10.043152	38.233765	2078.751221	Shurb
10.043269	38.233614	2076.208496	Shurb
10.043339	38.233621	2073.773682	Shurb
10.043345	38.233559	2073.147217	Busheland
10.043343	38.23356	2073.231934	Busheland
10.04344	38.233633	2068.683838	Busheland
10.0435	38.233542	2066.331299	Busheland
10.043541	38.233532	2065.550781	Busheland
10.043608	38.233473	2063.763184	Busheland
10.043706	38.233414	2060.601562	Busheland
10.043865	38.23239	2057.731201	Busheland
10.043887	38.232467	2060.155518	Busheland
10.046712	38.235755	1970.755249	Farm Land
10.046754	38.235534	1970.421387	Farm Land
10.046795	38.235306	1970.230835	Farm Land
10.046989	38.235307	1969.751831	Farm Land
10.047187	38.235385	1970.976196	Farm Land
10.047359	38.235505	1969.551147	Farm Land
10.047511	38.235602	1970.200562	Farm Land
10.047729	38.235841	1969.780396	Farm Land
10.047606	38.236099	1968.027222	Farm Land
10.047467	38.236277	1966.007935	Farm Land
10.047337	38.23638	1966.8573	Farm Land
10.048624	38.237762	1953.780029	Farm Land

Latitude	Longitude	Altitude	Landcover
10.048791	38.238053	1952.427734	Farm Land
10.049718	38.23768	1948.184448	Farm Land
10.049792	38.237244	1949.213013	Farm Land
10.050815	38.236023	1932.314087	Farm Land
10.050943	38.236187	1932.588257	Farm Land
10.04943	38.245213	1895.73877	Farm Land
10.059069	38.219706	1511.702759	Bare Land
10.059149	38.219542	1513.586426	Bare Land
10.059245	38.219391	1516.074585	Bare Land
10.059205	38.219286	1519.81189	Bare Land
10.059115	38.219343	1521.858887	Bare Land
10.059048	38.219429	1521.370728	Bare Land
10.059015	38.219522	1522.8302	Bare Land
10.059011	38.219521	1521.803589	Bare Land
10.059303	38.219187	1517.809937	Bare Land
10.071992	38.192583	1194.596802	Bare Land
10.07209	38.192568	1192.825562	Bare Land
10.116982	38.151866	1948.631226	Farm Land
10.114601	38.151048	1895.399536	Farm Land
10.114247	38.150934	1893.256348	Farm Land
10.11347	38.151227	1888.931885	Farm Land
10.113134	38.151313	1887.557495	Farm Land
10.110171	38.151879	1863.309326	Farm Land
10.114128	38.156752	1838.226685	Farm Land
10.114184	38.156955	1837.553467	Farm Land
10.113926	38.156605	1838.198975	Farm Land
10.113838	38.156466	1839.107056	Farm Land
10.114003	38.156579	1837.937744	Farm Land
10.1043	38.171193	1568.586426	Bareland
10.104257	38.171118	1568.575195	Bareland
10.10416	38.17115	1568.603394	Bareland
10.104122	38.171199	1568.582031	Bareland
10.10406	38.171275	1568.709595	Bareland
10.104108	38.171367	1567.913574	Bareland
10.104202	38.171423	1567.074829	Bareland
10.104261	38.171392	1566.226196	Bareland
10.104295	38.171426	1564.693604	Bareland

Latitude	Longitude	Altitude	Landcover
10.104284	38.171467	1564.342529	Bareland
10.104301	38.171515	1564.194092	Bareland
10.104325	38.171573	1563.477173	Bareland
10.104347	38.171674	1560.934326	Bareland
10.093915	38.188922	1306.434692	Bareland
10.093916	38.188923	1306.436646	Bareland
10.09386	38.189017	1301.357666	Bareland
10.093729	38.189032	1299.606567	Bareland
10.093704	38.189112	1297.182007	Bareland
10.077428	38.190488	1126.114624	Bareland
10.077843	38.190846	1123.902832	Shurb
10.078044	38.191055	1122.790649	Shurb
10.077943	38.191103	1121.141357	Shurb
10.078778	38.190626	1125.959351	Shurb
10.078958	38.190618	1127.799561	Shurb
10.078993	38.190471	1129.632568	Shurb
10.079049	38.190349	1130.141846	Shurb

Appendix 2:

All Photographs shown below were taken during a field visit to the gorge on March, 2013

