Mapping Landslide Hazard and Risk Assessment Using GIS-Based Analytical Hierarchy Process and Weighted Linear Combination Methods in Gimbi Town, Western Ethiopia

By

Birhanu Tadesa Edosa

A Thesis Submitted to

The Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's

In Geomatics Engineering (Specialization in Geoinformatics Engineering)

Office of Graduate Studies (OPS)

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Advisor: Daniel Alemayehu (PhD)

Co-Advisor: Roba Gemechu (PhD)

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Board of Examiners Approval

We, the undersigned, members of the Board of Examiners of the final open defense by Birhanu Tadesa Edosa have read and evaluated his thesis entitled: Mapping Landslide Hazard and Risk Assessment Using GIS-Based Analytical Hierarchy Process and Weighted Linear Combination Methods in Gimbi Town, Western Ethiopia and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Geoinformatics Engineering.

____________________	____________________	____________________
Advisor	Signature	Date
____________________	____________________	____________________
Co-Advisor	Signature	Date
____________________	____________________	____________________
Chairperson	Signature	Date
____________________	____________________	____________________
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External Examiner	Signature	Date

DECLARATION

I, Birhanu Tadesa Edosa hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university and all sources of material used for this thesis have been properly acknowledged.

Candidate:

Name: BIRHANU TADESA EDOSA

Signature: ________________

This MSc Thesis has been submitted for examination with our approval as thesis advisor/co-advisor.

Advisor

Name: ____

Signature: ______________________________

Date of submission: ________________________________

Co-Advisor

Name: ____

Signature: ______________________________

Date of submission: ________________________________

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy process
ANN	Artificial Neural Networks
ASFDAAC	Alaska Satellite Facility Distributed Active Archive Center
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CADD	Computer-Aided Design and Drafting
CSA	Central Stastical Agency
EMA	Ethiopia Map Agency
EMA	Ethiopian Meteorological Agency
ERDAS	Earth Resource Data Analysis System
FAO	Food and Agriculture Organization
GDEMV2	Global Digital Elevation Model Version two
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
IDW	Inverse Distance Weighted
LI	Landslide Inventories
LRM	Landslide Risk Map
LSM	Landslide Susceptible Map
LULC	Land use Land cover
MADA	Multi-attribute evaluation or Multi-Attribute Decision Analysis
MCE	Multi Criteria Evaluation
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi Criteria Decision Making
MWR	Ministry of Water Resource
NASA	National Aeronautics and Space Administration
NDVI	Normalized Different Vegetation Index
NGO	Non-Government Organizations
NMA	National Meteorological Agency
OLI	Operational Land Imager
OUI	Oromia Urban Institute
OWWDSE	Oromia Water Works Design and Supervision Enterprise

QRA	Quantitatively Risk Analysis
RS	Remote Sensing
SD	Standard Deviations
TIRS	Thermal Infrared Sensor
USGS	United State of Geodetic Survey
VM	Vulnerability Map of element at risk
WLC	Weighted Linear Combination

LIST OF ANNEX

ABSTRACT

In the present study, semi quantitative landslide hazard zonation and risk assessment for Gimbi Town (western Ethiopia) was carried out, and the environmental effects of landslides on further urban development were evaluated using geospatial techniques. For this purpose, four different group of data were used, namely: landslide inventories for validating final result, environmental factors like slope, aspect, lithology, soil type, elevation/topography, land use, Normalized Difference Vegetation Index and lineaments were used for landslide susceptibility map, triggering factors like rainfall was used for landslide hazard zonation, and element at risk like roads and settlement or built up area were used to map vulnerable at risk. Data of these factors were obtained from digital elevation model, satellite image (landsat8), secondary map, and field observation mapping. Nineteen event- based landslides inventories in the study area were also collected through field survey. Landslide hazard was produced from Landslide Susceptibility Map and rainfall map. Finally, landslide risk map was prepared from the integration of landslide hazard map and vulnerability map of elements at risk. In this study two Geographical Information System (GIS) based Multi-Criteria Decision Analysis techniques like (1) Analytical Hierarchy process (AHP) was used to calculate the weights of associated criteria map layers and (2) weighted linear combination (WLC) was used to produce landslide hazard and risk map in a GIS environment. The results shows that 10.38%(4.83km^2) of the study area falls in very high hazard, 29.22% (13.6 km^2) in high hazard, 32.73%(15.24km^2) in moderate hazard, 21.5% (10.01km^2)in low hazard, and the remaining 6.17%(2.87 km^2) in very low hazard zones, as well as 2.59%(1.2 km^2) of the area falls in very high risk, 17.31% (11.77 km^2) in high risk, 25.37%(11.77 km^2) in moderate risk, 35.09%(16.28 km^2) in low risk, and the remaining 19.64%(9.11 km^2) in very low risk. Validation of landslide hazard zonation map with event based landslides showed that 89.5% of the landslides inventories points fall within moderate to very high hazard zones. Whereas validation of landslide risk zonation map with event based landslides showed that 68.4% of these landslides fall in moderate to very high risk zones. The verification procedure proved that the produced landslide hazard and risk maps are important for land use management and planning in the study area. Thus, the landslide hazard and risk maps, that are produced in this study, will be useful to provide an important information about the locations of landslide prone areas and the levels of hazard and risk for land use planers and engineers so that they can implement suitable remedial measures for landslide disaster risk reduction and management.

Keywords; MCDA, GIS, Landslide, Hazard, Risk, Gimbi Town

CHAPTER I
INTRODUCTION

1.1 Background

Landslides and landslide-generated ground failures are among the most costly and damaging natural hazards in many of the hilly and mountainous terrains of both developed and developing countries in the world. Landslides are considered to be one of the most dangerous natural hazards due to the fact that they cause human casualties and extensive damages of infrastructure and property worldwide (Kouli et al., 2009). Furthermore, landslide have occurred when a rock has been disintegrated and decomposed by the process of weathering and when the weathered and rain soaked material is sliding down due to gravity (Rai et al., 2014). Likewise Sarkar and Kanungo (2004), stated that landslides are one of the destructive geological processes which cause not only enormous damage to roads, bridges, and houses but also lead to loss of life. Hence, there is a need for landslide hazard and risk mapping for identification of potential landslide areas and the potential for causing an undesirable consequence.

According to Girma et al., (2015), landslides have been a frequent problem in most parts of the Ethiopian highlands particularly in the north, south and western parts of the country and parts of the Ethiopian Rift escarpments. Gimbi Town is located in the western parts of Ethiopia which is 441Km from Addis Ababa. In this Town, slope instabilities and landslide problem are frequently observed, especially in the area of Gotira, Gaba Malifu, Badessa Makko and Laga Gaba**.** As Ali et al.,(2017) was discussed, the hilly and mountainous terrains of the highlands of Gimbi Town which are characterized by variable topographical, the local drainage gullies and streams tends to be swampy ,geological, hydrological (surface and groundwater) and land use conditions, are frequently affected by rainfall-triggered slope failures. They also stated that, the main cause of landslide in Gimbi town are geomorphology (i.e. topography & steep slopes), geology, climate (rainfall & temperature), erosion processes, rocks and soil types. Landslides often occur on steep slopes following heavy rainfall (Awange and Kiema, 2013).

According to Kouli et al., (2009), Landslide hazard map depicts areas prone to landslides by integrating the causal and triggering factors of the landslides with data concerning the past distribution of slope failures. In this study the input data requirements for mapping landslide hazard and risk are categorized into four groups i.e. landslide inventory data, environmental factors, triggering factors and elements at risk. The hazard and risk maps have usually incorporated the estimated frequency of landsliding in a qualitative sense rather than quantitatively (Fell et al., 2008). A hazard has a potential to become a risk only on the condition that exposed and vulnerable elements exist in the potentially affected area, including people, structures and infrastructures (Corominas and Mavrouli, 2011). In this study highly vulnerability of element at risk due to hazard are human settlement and road transportation. Landslide susceptibility and hazard is different, the term hazard including the likelihood of the occurrence of a landslide where triggering variables are considered, while the susceptibility map does not includes the triggering variables (Ramli et al., 2010).

A GIS model can be used to combine a set of input maps or factors using a function to produce an output map (Fell et al., 2008). The function can take many forms including linear regression, multiple regression, and conditional analysis and discriminate analysis etc. Geographic Information Systems (GIS) is a tool for collecting, storing, retrieving, transforming, manipulating, and displaying spatially distributed data, and therefore it is frequently used in distributed deterministic modeling. GIS-based MCDA provides a collection of powerful techniques and procedures for dealing with decision-making problems and for designing, evaluating, and prioritizing possible alternative courses of action (Feizizadeh et al., 2014). Nowadays, the development of GIS has enhanced the capabilities for the research of landslides susceptibility (Kouli et al., 2009). Moreover, Remote sensing (RS) techniques are widely used in landslide susceptibility assessment in both the generation of landslide parameters or thematic layers and the production of landslide inventory maps. Generally, landslide hazard and risk assessment is quantitative or qualitative, according to the use of: analytical procedures supported by computer simulation; weighted indicators, expert judgment and field survey; combination of the above two procedures (Corominas and Mavrouli, 2011).

According to Corominas and Mavrouli (2011), the methods of mapping landslide hazard and risk will vary based up on the quality of the input data and the complexity of the analyses performed as well as the mapping resolution in which landslide zoning can be performed at a preliminary, intermediate and advanced levels. The preliminary level of zoning is associated to methods for which susceptibility, hazard and risk are assessed based on heuristic procedures (or Knowledge driven methods). In knowledge driven methods, several techniques can be used such as Boolean overlay, Fuzzy logic, multi-class overlay and Spatial Multi-Criteria Evaluation, Analytic Hierarchy Process (AHP) (Corominas and Mavrouli, 2011). However, three main approaches are mentioned for mapping landslide hazard and risk assessment (Kouli et al., 2009) i.e. qualitative, semi-quantitative and quantitative methods. Qualitative methods that use weighting and rating procedures are known as semi-quantitative methods. These methods include Analytical Hierarchy Process (AHP) and the weighted linear combination (WLC). Landslide Susceptibility Map (LSM) requires a multi-criteria approach with high levels of accuracy and reliability so that the resulting maps are relevant in decision making and for the design of disaster management plans (Feizizadeh et al., 2014). In this study, AHP and WLC methods (semi-quantitative methods) were used to generate landslide hazard and risk maps in GIS environment.

1.2 Statement of the problem

Gimbi Town is found in the western highlands of Ethiopia which is highly affected by landslide hazards causing calamities. In the northern, western, and southern highlands of Ethiopia, the resulting damage due to landslides has been increasing due to various natural and manmade factors (Girma et al., 2015).

Plate 1.1 Landslide photos in the study area.

From the field observations in the study area, landslides in the hills of Gimbi Town is an ongoing problem in every rainy season where the mass of soil is detached from its original location and moves down the hills thereby causing loss of public properties and disturbance of dweller's livelihood. The main causes of landslide in the study area is an intense rainfall which promotes slope movements of rapid and shallow soil slips that occurred at different times with slower and deeper landsliding. According to Ali et al. (2017), the main causes of landslides in Gimbi are geomorphology (topography & steep slopes), geology, climate (rainfall & temperature), erosion processes, rocks and soil types. In addition, calamities from landslide hazards in the study area have increased due to urbanization in landslide-prone areas, continued deforestation, increased precipitation caused by changing climatic conditions and land excavations for engineering construction. From plate 1.1, landslides of different types have occurred in Town which pose a serious damage in the houses, environment and roads.

Although, Ali et al. (2017) conducted a study on the causes of landslides in Gimbi town but there is no study so far who attempted to model the landslide hazard and risk in the town. The current study is important in that it will provide information about landslide prone areas. This can serve as a basic information for geotechnical engineers, land use and urban planners who are concerned for the town expansion and effective land management for a safer society. Hence, this study will provide the most valuable analysis in an efficient and economical way so as to reduce the future damage in properties, infrastructures and loss of lives as a result of landslides. Hence, Geospatial techniques were used to assess and evaluate landslide hazard and risk in order to carry out the issue the issue of landslide disaster into the attention of the academia, local community, decision makers, to concerned organizations that will help for the sustainable development of Gimbi Town.

1.3 Research Questions

1. Which factors are relevant for landslide hazard and risk mapping?
2. How to map landslide hazard and risk of Gimbi Town?

1.4 Significance of the study

This This study is significant for land use planners, urban planners and civil engineers, different scholars or researchers who are interested in this field, NGO's and government organizations that are working on town expansion and infrastructure development of Gimbi Town.

- **Land use/Urban planners and Civil engineers:** They will obtain useful spatial information about landslide prone and safe areas before deciding on land use regulations, land use planning, land use development, master plan expansion and engineering construction
- **Researchers/Scholars**: they will consult the finding of the current study as baseline information for their consecutive study in the area.
- **NGO's and Government Organizations**: they will be accessed spatial information about hazardous and vulnerable area in order to give attention and provide the appropriate decision for considering the possibility of the development with or without any stabilization or protective measures.

1.5 Objectives of the Study

1.5 1. General Objectives

The general objective of this study is to prepare the landslide hazard and risk maps of Gimbi Town by integrating landslide inventory, environmental factors, rainfall and elements at risk using geospatial techniques.

1.5 2. Specific Objectives

- To identify relevant factors for mapping landslide susceptibility, hazard and risk.
- To produce standardized susceptibility map and vulnerability map of elements at risk.
- To prepare the event based landslide inventory points of the study.
- To prepare the landslide hazard and risk maps of Gimbi Town.

1.6 Scope of the Study

The delimitation of the study area is limited to only Gimbi Town within 49.49 km^2 total areal coverage. As well as landslide analysis of this Town is bounded to map standardized landslide hazard and risk by using Multi-Criteria Evaluation (MCE) in GIS environment.

1.7 Limitations of the Study

During this study, Gimbi Town has no adequate data on soil, geology (lithology), laboratory and field geotechnical data.

CHAPTER II
LITERATURE REVIEW

2.1 Theoretical Background

2.1.1 Geospatial Technology

Geospatial technology is a field of information technology that focuses on the geographical, temporal and spatial context of data. Features shown on maps or those organized in a digital database that are tied to the surface of the earth by coordinates, addresses, or other means are collectively called geospatial data. These data are also called spatial or geographic data. This is accomplished by using tools such as Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS). Remotely sensed data was a major driver in the development of GIS. The enormous quantity of data produced by remote sensors needed to be efficiently analyzed and managed and dealing with these data expedited the development of GIS. Therefore the relationship between GIS and remote sensing should be obvious. Noting that GPS is the most accurate and efficient way to relate images to the ground, either from GPS positions of the satellites themselves or positions of points on the ground that are in the image (Bossler,et al., 2005). GIS have the ability to perform numerous tasks utilizing spatial and attribute data. Such functions distinguish GIS from other management information systems. Furthermore, GIS as an integrated technology allows for integration of a variety of geographical technologies (such as remote sensing, global positioning systems, computer-aided design, and automated mapping and facilities management) that can be in turn integrated with analytical and decision-making techniques. The way in which data are entered, stored and analyzed must mirror the way in which information will be used for analysis or decision-making tasks. GIS should therefore be viewed as a process rather than as merely software or hardware.

2.1.1.1 Geographic Information System (GIS)

A Geographic Information System (GIS) is a computer system that helps users to collect, process, edit, store, manage, share, analyze, model, and visualize large volumes of datasets to understand spatial relationships, patterns, and trends, and make sound decisions. The two key words in its name, “geographic” and “information,” make GIS a unique technology, different in many ways from other traditional cartographic mapping and data management systems and applications. “Geographic” (also known as geospatial or spatial) means that GIS mainly deals with spatial data features, which are in one way or another references to locations on the earth, such as sampling location points, utility lines, and land parcel polygons. By manipulating spatial data layers (also known as themes), GIS is capable of producing maps similar to other mapping systems, such as a computer-aided design and drafting (CADD) system. In addition to mapping capabilities, GIS incorporates tabular data (i.e., "information") and links information to spatial data features (e.g., attaching analytical results to sampling locations) to enable data analysis, modeling, and visualization for better understanding of data and making decisions.

GIS is widely used in natural/cultural resource management and conservation, environmental investigation and remediation, geosciences, engineering, logistics, planning, transport, utilities, telecommunication, aviation/ navigation, surveying, demographic studies, epidemiology, emergency management, disaster relief, humanitarian aid, forestry, agriculture, oil/gas/mineral exploration, mining, real estate, retail/warehousing/distribution, insurance, health/medical resource management, education, training, tourism, security, law enforcement, reconnaissance, military operations, and many other fields (Tian, 2017).

Geographical Information System (GIS) Data

The most important and essential component of any GIS is data, which includes both spatial datasets and their associated metadata**.** Spatial data (also commonly referred to as geospatial data, geographic data, or GIS data) is data or information about the locations and shapes of physical features and the relationships between them. The locations and shapes of features are usually stored as coordinates, commonly known as X, Y, and Z values in a projected coordinate system, or latitude, longitude, and altitude in a geographic coordinate system. The relationships between features are stored as topology, which represents geometric properties, spatial relations, and the arrangement of the features. With stored information about the locations, shapes, and their relationships of features, spatial datasets (also known as data layers or themes) can easily be manipulated and analyzed in GIS to find useful information, patterns, and trends to make educated and sound decisions. Due to its spatial nature, a special database format, a *geodatabase*, is needed to store GIS data. Major relational database management systems (RDBMS) have tools and/or utilities to design, develop, deploy, populate, and manage geodatabases, such as IBM DB2, IBM Informix Dynamic Server, Microsoft Access, Microsoft SQL Server, Microsoft SQL Server Express, Microsoft SQL Azure, PostgreSQL, Oracle, and so on. Metadata is the data or information that describes the spatial dataset. The prefix *Meta* in Greek means "after," "along with," "beyond," "among," and "behind." It adds to the name of something references, comments, and/or other information. In order for GIS data users to precisely understand, interpret, exchange, and reuse spatial data, data production processes are documented and saved (along with other relevant information about the data) as metadata. A metadata file contains detailed information about the spatial data, such as its name, purpose, spatial domain/bounding coordinates, scale, projection/ coordinate system, data originators, dates/times, keywords, use constraints, data quality/accuracy, sources, production processes, data formats, attributes/fields, legal disclaimers, distribution/access, and so on.

2.1.1.2 Remote Sensing Technology

Remote sensing is defined as the art, science and technology through which the characteristics of object features/targets either on, above or even below the earth's surface are identified, measured and analyzed without direct contact existing between the sensors and the targets or events being observed. This allows for information about such object features to be obtained by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. Remote sensing imagery may be acquired, not only through the use of conventional cameras, but also by recording the energy from the scene through one or more special sensors. These special sensors usually operate by electronic scanning and can record the existence of reflected or emitted radiation outside the normal visual range of film and standard cameras.

Electromagnetic radiation is normally used as the information carrier in remote sensing. Such electromagnetic radiation that is either reflected or emitted from targets normally constitutes remote sensing data. This can be detected by a sensor usually on-board airborne (e.g., aircraft or balloon) or space-borne (e.g., satellites and space shuttles) platforms. As an analogy, of the five basic human senses, three of them namely; sight, hearing and smell may be considered forms of "remote sensing", where the source of information is at some distance away from the sensors, in this case the eyes, ears and nose respectively. In contrast, however, the other two human senses (i.e., taste and touch) rely on direct physical contact with the source of information.

As shown in Fig. 2.1, the process of remote sensing is characterized by various stages and interactions summarized as follows: (a) an energy source or illumination is used to provide electromagnetic energy to the target of interest, (b) interactions between the electromagnetic radiation and the atmosphere, (c) interaction between the target and the electromagnetic radiation, (d) recording of reflected and emitted energy from the target by the sensor, (e) transmission, reception and processing of recorded energy into an image, (f) interpretation and analysis of image to extract desired information and (g) application of the information about the object or target in order to better understand it, reveal some new information, or assist in solving a particular problem.

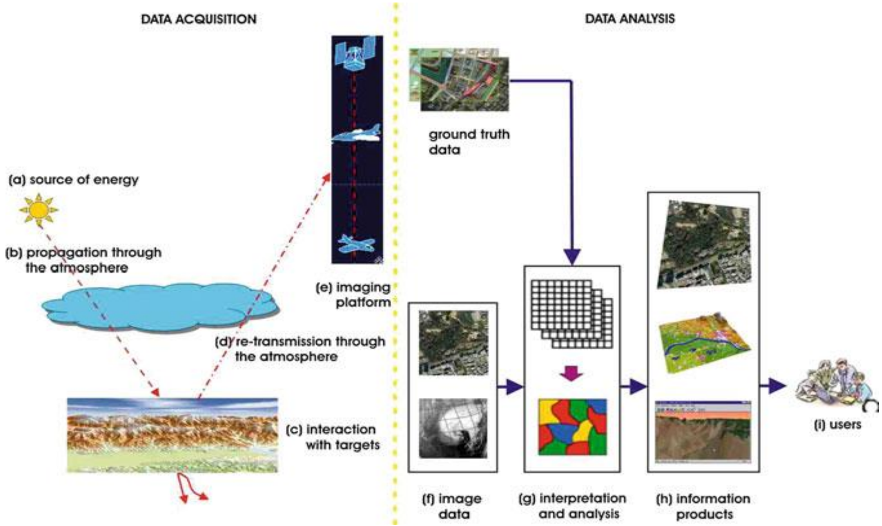


Figure 2.1 Remote sensing process

Remote sensing and photogrammetric techniques have long been applied in the mapping and monitoring of hazardous slope processes and landforms (Awange & Kiema, 2013).

2.1.1.3 Global Positioning System (GPS)

The GPS is a satellite navigation and positioning system with which the three-dimensional position and the velocity of a user at a point on or near the earth can be determined in real time. The NAVSTAR Global Positioning System (GPS) is a satellite-based radio-positioning and time-transfer system designed, financed, deployed, and operated by the US Department of Defense. GPS has also demonstrated a significant benefit to the civilian community, who are applying GPS to a rapidly expanding number of applications. The attractions of GPS are:

a. Relatively high positioning accuracy, from meters down to the millimeter level.
b. Capability of determining velocity & time, to an accuracy commensurate with position.
c. No inter-station visibility is required for high precision positioning.
d. Results are obtained with reference to a single, global datum.
e. Signals are available to users anywhere on the earth: in the air, on the ground, or at sea.
f. No user charges, requiring only relatively low-cost hardware.
g. An all-weather system, available 24 hours a day.
h. Position information is provided in three-dimensions.

Since its introduction to the civilian community in the early 1980s GPS has revolutionized geodesy, surveying and mapping. Indeed, the first users were geodetic surveyors, who applied GPS to the task of surveying the primary control networks that form the basis of all map data and digital databases. Today, around the world, GPS is the preferred technology for this geodetic application. However, as a result of progressive product innovations, the GPS technology is increasingly addressing the precise positioning needs of cadastral, engineering, environmental, planning and Geographical Information System (GIS) surveys, as well as a range of new machine, aircraft and ship location applications (Bossler et al., 2005). GNSS satellites are useful in measuring physical variables such as atmospheric temperature, pressure, and tropopause heights needed for weather and climate change monitoring (Awange & Kiema, 2013). A discussion of the GPS technology and applications starts with the identification of the three components (Fig.2.2).

A. **Space segment**: the satellites and the transmitted signals.
B. **Control segment**: the ground facilities carrying out the task of satellite tracking, orbit computations, telemetry and supervision necessary for routine operations.
C. **User segment**: the applications, equipment & computational techniques that are available to the users.

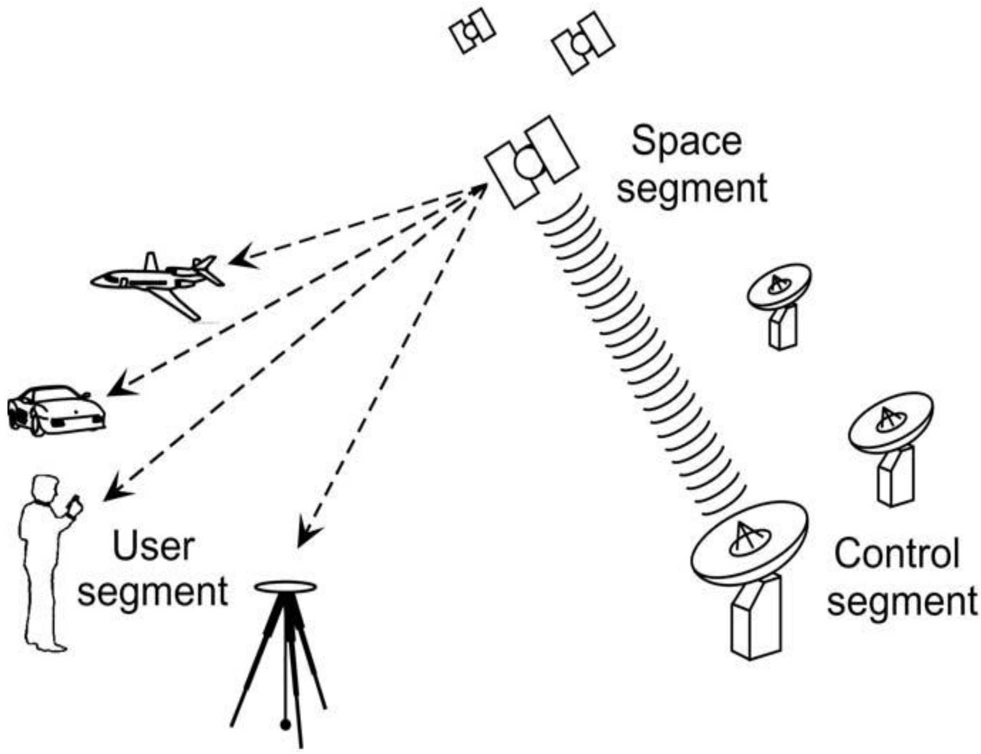


Figure 2.2 Elements of GPS

2.1.2 Methods of Landslide Zoning

According to Rai et al. (2014), remotely sensed data are used in solving various environmental tasks. This technology can be used as an effective aid in natural hazard investigation, as well as for the purpose of environmental planning. Terrain information, such as land cover, geology, geomorphology and drainage could also be derived from it and existing thematic information can be updated to enable the quantification of human interference on the earth's surface. Geographic Information System (GIS), as a computer-based system for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output, with its excellent spatial data processing capacity, has attracted sincere attention in natural disaster assessment. Furthermore, Huabin, et al., (2005) investigated that the crucial issues in GIS-based hazard assessment is the availability of suitable input data, which remain fundamentally inadequate in quantity and quality for the intended task. In addition to that, Geographic information systems (GIS) offer a technological framework for supporting efficient and effective data capture, storage, management, retrieval, analysis, integration and display, and has already shown great benefits to the study and mapping of landslide distributions and hazard potential.

Application of GIS was found immensely useful for thematic data layer generation and for their spatial data analysis, which involved complex operations (Sarkar and Kanungo, 2004). A handheld global positioning system (GPS) device was used to identify the locations of the landslide (Ahmed and Forte, 2014). GPS is also used for taking ground truths as well and field compass was used for measuring the dip of strata/ beds and orientations of geological structures (Ayele et al., 2014). Remote sensing methods, using aerial photographs and satellite images are employed to obtain significant and cost-effective information on landslides (Lee & Pradhan, 2006). Remote sensing (RS) techniques are widely used in landslide susceptibility assessment in both the generation of landslide parameters thematic layers and the production of landslide inventory maps (Kouli et al., 2009). Geographical Information System (GIS) is a system and tool that is used to manipulate and analyze the input data for mapping landslide hazard and risk. There are three steps in landslide analysis: susceptibility, hazard, and risk (Lee and Pradhan, 2006).

Generally, Geospatial technology (GIS, RS, and GPS) are crucial technology to producing qualitative map of landslide hazard and risk assessment. Global Positioning System (GPS) is a technology which is used to site and prepare landslide inventories and verify thematic data that is obtained from Remote Sensing (RS) technology. For example, Land use land cover is one of the input data for landslide hazard and risk map that was prepared from remotely sensed data like satellite image (like, Landsat) through using supervised and unsupervised classification. In order to apply supervised classification field inspection and training data for ground verification were required. For this classification, global positioning system (GPS) was used in order site exact locations of land cover classes. Topographical (DEM) data, geological data and satellite images were collected and processed using GIS and image processing tools (Lee and Pradhan, 2006). According to Mukhlisin et al., (2010) GIS technologies could provide a powerful tool to model the landslide hazards for their spatial analysis and prediction. This is because the collection, manipulation and analysis of the environmental data on landslide hazard can be done much more efficiently. Geographical Information System (GIS) has been applied to help the slope hazard assessment and analysis.

A GIS-Based techniques that can be used to combine a set of input maps or factors using a function to produce outputs of landslide susceptibility, hazard and risk maps. According to Fell et al.(2008), the function can take many forms including linear regression, multiple regression, and conditional analysis and discriminate analysis etc. Crucial factors for the construction of reliable hazard maps are the quality and the amount of available data and the selection of the best method for the analysis (Kouli et al., 2009). There are three main landslide risk assessment approaches and these are qualitative, semi-quantitative, and quantitative (Kouli et al., 2009). Quantitative methods are based on mathematical expressions of the correlation between causal factors and landslides. The two types of quantitative methods that are commonly used are deterministic and statistical which involve analytic bivariate, multivariate, logistics regression, fuzzy logic, artificial neural network analysis, etc.

On the other hand, qualitative methods are based on expert opinions in (Kouli, et al., 2009; Fell, et al., 2008).The basic types of qualitative methods use landslide index to identify areas with similar geological and geomorphologic characteristics that are susceptible to landslides. Moreover, there are qualitative methodologies which use weighting and rating procedures and these are known as semi-quantitative methods (Kouli, et al., 2009). Such kinds of methodologies are the analytic hierarchy process (AHP) (Vahidnia et al., 2009; Musinguzi and Asiimwe, 2014) and the weighted linear combination (WLC) (Ayele et al., 2014; Musinguzi and Asiimwe, 2014; Vahidnia et al., 2009). The AHP methodology involves the creation of hierarchy of decision elements (factors) and the comparison between different pairs of elements in order to assign a weight and a consistency ratio for each element. The

WLC approach involves the combination of several landslide parameters' maps. In each class of the map thematic layer, the rating value is assigned in GIS and then the parameter layers are weighted according to the importance or preference of each parameter relative to the others. Finally, all the derived maps are overlaid in order to construct the final landslide hazard map. Generally, these direct and indirect methods involve qualitative or quantitative modelling and analysis techniques of various types are mentioned for producing landslide hazard and risk (Vahidnia et al., 2009; Fell et al., 2008; Rai et al., 2014 and Corominas and Mavrouli, 2011).

A) Heuristic Analysis or Knowledge Driven Analysis

In knowledge driven or heuristic methods expert opinion plays a decisive role. A landslide susceptibility, hazard and risk map can be directly mapped in the field by expert geomorphologists, or made in the office as a derivative map of a geomorphological map (Corominas and Mavrouli, 2011). This Knowledge driven method produced landslide hazard and risk mapping through direct and indirectly method.

In the direct method GIS is used basically as a tool for entering the final map, without extensive modeling. Direct mapping can also be supported with other methods (e.g. inventory, statistical or physically-based modelling) and indirectly using a GIS, by combining a number of factor maps that are considered to be important for landslide occurrence. These methods combine the mapping of the landslides and their geomorphologic setting as the main input factors for assessing the hazard. Two main types of heuristic analysis can be distinguished: geomorphic analysis and qualitative map combination (Fell et al., 2008). In ***geomorphic analysis*** the susceptibility or hazard is determined directly by the person carrying out the study based on individual experience and the use of reasoning by analogy. The decision rules are therefore difficult to formulate because they vary from place to place. In ***qualitative map*** combination the person carrying out the study uses expert knowledge to assign weighting values to a series of input parameters. These are summed according to these weights, leading to susceptibility and hazard classes. These methods are common, but it is difficult to determine the weighting of the input parameters. There are various heuristic analysis or knowledge driven methods. These are geomorphological mapping, Direct Mapping method, spatial multi-criteria analysis or weighted linear combination method, Fuzzy logic approach and Analytical hierarchy process (Fell, et al., 2008; Corominas and Mavrouli, 2011).

B) Data Driven Methods

According to Corominas and Mavrouli (2011), landslide zoning using data-driven landslide susceptibility analysis, the combinations of factors that have led to landslides in the past are evaluated statistically and quantitative predictions are made for current landslide free areas with similar conditions. The methods are called data-driven as the data of the past occurrences of landslides is used to obtain information on the relative importance of each of the factor maps and classes. Three main data-driven approaches are used: ***bivariate statistical analysis***, ***multivariate methods***, and ***Artificial Neural Network analysis.***

In a **bivariate statistical analysis**, each factor map (slope, geology, land use etc.) are combined with the landslide distribution map, and weight values, based on landslide densities, are calculated for each parameter class (slope class, lithological unit, land use type, etc.). Several statistical methods can be applied to calculate weight values, such as the information value method, weights of evidence modeling, Bayesian combination rules, certainty factors, the Dempster-Shafer method and fuzzy logic. **Multivariate statistical models** evaluate the combined relationship between a dependent variable (landslide occurrence) and a series of independent variables (landslide controlling factors). In this type of analysis all relevant factors are sampled either on a grid basis, or in morphometric units. For each of the sampling units the presence or absence of landslides is determined. The resulting matrix is then analyzed using multiple regression, logistic regression or discriminant analysis. With these techniques, good results can be expected. Since statistical methods required a substantially complete landslide inventory and a series of factor maps, they cannot be applied easily over very large areas. These techniques have become standard in regional scale landslide susceptibility assessment. **Artificial Neural Network (ANN)** is defined as a non-linear function approximator which is extensively used for pattern recognition and classification. Neurons are the basic units of a neural network, which are organized to compute a non-linear function of their input(s). A neuron receives input(s) with an assigned weight (s), which influence the overall output of the neuron.

C) Deterministic Analysis

Deterministic methods apply classical slope stability theory and principles such as infinite slope, limit equilibrium and finite element techniques (Fell et al., 2008). These models require standard soil parameter inputs such as soil thickness, soil strength, groundwater pressures, slope geometry etc. Limitations with such methods result from data quality such as errors in mapping, incomplete inventory and poor resolution of some data sets as the models are essentially data trained. In addition, the results of such models are not readily transferable from region to region. Generally, enormous progress has been made in the development of landslide inventories, landscape susceptibility mapping and hazard zoning, whereby much of this progress is based on the extensive use of GIS, GPS and remote sensing techniques (Feizizadeh and Blaschke, 2011).

2.1.2.1 Multi-Criteria Evaluation (MCE)

The GIS-based multi-criteria evaluation procedures involve a set of geographically defined alternatives (e.g. Parcels of land) and a set of evaluation criteria represented as map layers. The problem is to combine the criterion maps according to the criterion (attribute) values and decision maker's preferences using a decision rule (combination rule). Multi-criteria Evaluation (MCE) is sometimes also referred to as multi-attribute evaluation or Multi-Attribute Decision Analysis (MADA) (Estoque, 2011). In order to applying Multi-Criteria Evaluation; firstly established criteria, Secondly standardized the factors, thirdly established factor weights and lastly Weighted linear combination(WLC) or Analytical Hierarchy Process(AHP) methods are used to map landslide hazard and risk.

GIS technology provides effective tools for the handling, integrating and visualizing diverse spatial data sets. Especially GIS Multi Criteria Decision Making (MCDM) is one of important methods of spatial analysis in GIS that allows knowledge derived from different sources to be combined in order to support landslide analysis. The multi-attribute technique that has been incorporated into the GIS-based landslide analysis procedures is the Analytical Hierarchy Process (Feizizadeh and Blaschke, 2011) and weighted linear combination method (Kouli et al., 2009). However (Drobne and Lisec, 2009) defined, two methods of multi-criteria evaluation (MCE) in GIS, the Weighted Linear Combination (WLC) and the Ordered Weighted Average (OWA). There are many ways in which decision criteria can be combined in Multi-Criteria Decision Analysis (MCDA). A *Weighted linear combination* (*WLC*) and its variants requires summation of the weighted criteria. The *Analytical hierarchical process* (*AHP*), an adoption of weight linear combination (WLC), can be used in two distinctive ways within the GIS environment: first, it can be employed to derive the weights associated with criteria map layers, and second, the AHP principle can be used to aggregate the priority for all hierarchical levels including the level representing alternatives. AHP is employed to derive the weights to weighted overlay layers. The weights are then combined with the attribute map layers in a manner similar to that used in the linear additive combination or Weighted linear combination (WLC) method (Feizizadeh and Blaschke, 2011). Over the last decade, a number of multi-attribute (or multi-criteria) evaluation methods have been introduced in the GIS environment. Among these procedures, the weighted linear combination and Boolean overlay operations, such as intersection (AND) and union (OR), are considered the most straightforward and the most employed in the GIS environment.

A) Weighted Linear combination (WLC)

According to Drobne and Lisec, (2009) Weighted linear combination, or simple additive weighting, is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average. The decision maker assigns the weights of relative importance directly to each attribute map layer. The total score for each alternative is obtained by multiplying the importance weight assigned to each attribute by the scaled value given for that attribute to the alternative and then summing the products over all attributes. The scores are calculated for all of the alternatives and that with the highest overall score is chosen. The method can be executed using any GIS system with overlay capabilities, and allows the evaluation criterion map layers to be combined in order to determine the composite map layer which is output. The methods can be implemented in both raster and vector GIS environments.

A weight can be defined as a value assigned to an evaluation criterion indicative of its importance relative to other criteria under consideration. The larger the weight, the more important is the criterion in the overall utility (Drobne and Lisec, 2009). There are four main groups of techniques for the development of weights: *ranking methods*, which are the simplest methods for assessing the importance of weights: every criterion under consideration is ranked in the order of the decision maker's preferences; *rating methods,* which require the estimation of weights on the basis of predetermined scale; *pairwise comparison methods,* which involve pairwise comparison to create a ratio matrix; *trade-off analysis methods,* which make use of direct trade-off assessments between pairs of alternatives.

B) Analytical Hierarchy Process (AHP) or Pairwise Techniques

Analytical hierarchy process or pairwise comparison method which has the added advantages of providing an organized structure for group discussions and helping the decision making group focus on areas of agreement and disagreement when setting criterion weights (Drobne and Lisec, 2009). Pair wise comparison as a decision making tool has been employed in landslide multi-criteria decision analysis involving multiple variables and found to be effective and used to derive weights for each landslide dependent parameter ranked verbally by importance (Musinguzi and Asiimwe, 2014). This was accomplished by first weighing each factor on a scale going from 1 to 9 (Table 2.1).

Table 2.1 Scale for the pair-wise comparison

Value or intensity of importance	Verbal judgement or Definition
9	Extreme importance
8	Very to extremely strong importance
7	Very strong importance
6	Strong to very strong importance
5	Strong importance
4	Moderate to strong importance
3	Moderate importance
2	Equal to moderate importance
1	Equal importance
½	
1/3	Moderately less important
¼	
1/5	Strongly less important
1/6	
1/7	Very strongly less important
1/8	
1/9	Extremely less important

Source: (Drobne and Lisec, 2009) and (Musinguzi and Asiimwe, 2014)

In developing weights, an individual or group compares every possible pairing and enters the ratings into a pairwise comparison matrix or *ratio matrix*. Since the matrix is symmetrical, only the lower triangle actually needs to be filled in. Generally in this seminar research multi-criteria evaluation is adopted for producing qualitative map of landslide hazard and risk. Different researcher have used different formula for mapping landslide risks. Risk value were obtained the product of hazard and consequence (Jamaludin and Hussein, 2006). According to Corominas and Mavrouli (2011), the classical expression for calculating landslide risk (R); R= Hx (ExV) where, H is landslide hazard, E is Element at risk and V is vulnerability. Kouli et al., (2009), landslide Risk were calculated by product of hazard and exposure. The exposure factor was estimated by the combination of population density, land use, and road network data layers. However, qualitative risk assessment, which are mostly based on integrating a hazard index, and a vulnerability index, using Spatial Multi Criteria Evaluation (Corominas and Mavrouli, 2011). As well as landslide risk is commonly expressed by the product of landslide hazard and landslide vulnerability (Akgun et al., 2012).

The qualitative approach is based on expert opinion and the risk areas are categorized with terms as “very high”, “high”, “moderate”, “low” and “very low” risk (Abella and Westen, 2006). In this research, The product of landslide vulnerability and landslide hazard was applied for producing landslide risk.

2.1.3 Landslide Zoning at Different Scales

Landslide zoning is the division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk (Corominas and Mavrouli, 2011). Hazard zoning is the subdivision of the terrain in zones that are characterized by the temporal probability of occurrence of landslides of a particular size and volume, within a given period of time. Landslide hazard maps should indicate both the zones where landslides may occur as well as the run out zones. The first formal applications of landslide zoning, based on qualitative approaches, date back to the 1970’s; Qualitative risk analysis is an analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur ,while quantitative methods have been developed in the 1980’s and particularly in the 1990’s for the risk management of an individual slope or a large number of slopes in Corominas and Mavrouli (2011). However Quantitative risk analysis is an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

According to Corominas and Mavrouli (2011) the scale of the landslide zoning maps required by State or local Authorities varies significantly from Country to Country depending on the coverage, the information provided, and the methodology that is used. In general, some common input data are used for all cases, i.e. geologic, geomorphologic and soil cover maps. The techniques to obtain input data for the landslide inventory and susceptibility maps vary in a wide range, resulting in various levels of quality and quantity of data. On the other hand, hazard and risk assessment is quantitative or qualitative, according to the use of: *i)* analytical procedures supported by computer simulation; *ii)* weighted indicators, expert judgment and field survey; *iii)* combination of the above two procedures. Accordingly, the most common mapping scales and types of landslide zoning that can be developed at different levels based on their application are shown Table 2.2. Based upon mapping scales and area coverage of landslide, this research is explored the possibility of adopting geospatial techniques to produce qualitative map of landslide hazard and risk assessment at *local* zoning map scale (1:25,000 to 1:5,000).

Table 2.2 Landslide mapping scales, types of landslide zoning and examples of zoning

Scale description	Indicative range of scale	Typical area of zoning	Types of landslide Zoning	Examples of zoning Application
National	< 1:100,000	> 10,000 km^2	Inventory mapping, susceptibility zoning of geological contexts	Landslide inventory & Susceptibility to inform policy makers and the general public.
Regional	1:100,000 to 1:25,000	1000 - 10,000 km^2	Inventory mapping, susceptibility and hazard zoning referring to local areas	Landslide inventory & susceptibility zoning for regional development; or very large scale engineering projects. Preliminary level hazard mapping for local areas
Local	1:25,000 to 1:5,000	10 - 1000 km^2	Hazard and risk zoning referring to single landslides (from qualitative to quantitative)	Landslide inventory, Susceptibility and hazard zoning for local areas. Intermediate to advanced level hazard zoning for regional development. Preliminary to advanced level risk zoning for local areas and the advanced stages of planning for large Engineering structures, roads and railways.
Site-specific	> 1:5,000	Several hectares to tens of km^2	Quantitative Risks Assessment (QRA) for individual slopes or singular locations	Intermediate & advanced level hazard & risk zoning for local and site specific areas & for the design phase of large engineering structures, roads & railways

Source: (Corominas and Mavrouli, 2011)

2.1.4 Purpose of Landslide Zoning Map

According to Awange and Kiema (2013), landslide monitoring can be undertaken in two ways: analyzing and comparing various spatial maps and images, e.g., topographic maps, aerial photographs, remotely sensed imagery, cadastral maps, and digital elevation maps, which represent instantaneous views of an unstable site on different time epochs; and carrying out in-situ measurements of the surface displacements by combining a space and time resolution adapted to the evolution speeds of the phenomena. landslide zoning may be developed by preparing different maps like, landslide inventory map; landslide susceptibility zoning map; landslide hazard zoning map; elements at risk map; consequence scenario map; Landslide risk zoning map (Fell et al., 2008; Corominas and Mavrouli, 2011). According to the type of landslide zoning map, they may pursue different purposes among those conventionally defined as information, advisory, statutory and design quoted in Corominas and Mavrouli (2011). On the basis of these descriptions, the purpose of landslide zoning maps possibly specified as follows;

Landslide inventory map may be used for susceptibility zoning and/or as information for policy makers and for the general public.

Landslide susceptibility zoning map may be used to prepare the hazard map and/or, in combination with elements at landslide risk within the susceptible area, as information for policy makers and the general public. It may be also used as advisory where the available records of incident data allows the assessment of the societal risk within the susceptible areas threatened by rapid to extremely rapid landslides.

Landslide hazard zoning map can be used as information, advisory or statutory to control the development of threatened areas, representing the most efficient and economical way to reduce future damage and loss of life. Such maps also provide the appropriate element of decision for considering the feasibility of the development with or without any stabilization or protective countermeasures.

Elements at risk map is used to prepare the consequence scenarios map and, in combination with the landslide susceptibility zoning map, may be used as information and advisory for policy makers and general public.

Consequence scenario map may be used as information and advisory showing the areas that require Quantitative Risks Assessment (QRA). Using quantitative procedures, this map provides for each element the consequence scenario related to its vulnerability and a given landslide hazard; in such a case, it may be used as information, advisory and statutory.

Landslide risk zoning map may be used as statutory and allow the implementation of alert system aimed at protecting the human life. In addition, QRA provides a global view of the expected annual damage for the elements at risk due to the landslide hazard. It can be used as statutory and design and, on the basis of cost-benefit analysis, either control or stabilization works can be identified and designed for landslide risk mitigation.

2.2 Empirical Review

It is essential that a researcher first identify an appropriate technique, which is most suitable for the proposed methodology. The selection of an appropriate technique for data analysis may depend on certain criteria, which may vary from study to study. These criteria for selection of technique are; requirement of input data for the proposed technique, limitations and required general conditions for the technique, merit and demerits over other techniques, Simplicity in application of technique, Quality and accuracy of output data. This research is demonstrable, relying on developing empirical framework in three ways: first way as Global, second way as Continental and the third way as local empirical data based on related research with this study.

2.2.1 Global Experience

This empirical data is comprised world realistic research that worked on landslide susceptibility, landslide hazard and landslide risk using geospatial technology like GIS, RS and GPS with different method as well as using quality of data requirement. The methods and data quality used for assessing hazard and risk, may give different result.

According to Akgun et al. (2012), assessing landslide hazard and risk in Turkey were produced using two groups of data namely, conditioning and triggering data. With the help of conditioning data such as lithology, slope gradient, slope aspect, distance from roads, distance from faults and distance from drainage lines, a landslide susceptibility model was constructed by using logistic regression modelling approach. Seismic region, earthquake and precipitation data were used as triggering factors. Considering the susceptibility data and triggering factors, a landslide hazard index was obtained. Land cover map were produced from Aster data. From this map, settlement areas were extracted, and these extracted data were assessed as elements at risk in the study area. Next, a vulnerability index was created by using these data. Finally, the hazard index and the vulnerability index were combined, and a landslide risk map for Izmir city (west turkey) was obtained.

To determine landslide risk, risk assessment procedures can be separated into two categories; quantitative (probabilistic) and qualitative (heuristic) approaches (Akgun et al., 2012). A key step in quantitative landslide risk assessment is the identification of the “elements at risk” and the estimation of the outcome or “consequence” of the landslide event on these elements (Corominas and Mavrouli, 2011). Qualitative risk analysis is an analysis which uses word form, descriptive or numeric rating scales to describe the magnitude (area) based of potential consequences and the likelihood that those consequences will occur. Risk analysis aims to determine the probability that a specific hazard will cause harm, and it investigates the relationship between the frequency of damaging events and the intensity of the consequences.

According to Kouli et al., (2009) landslide hazard zonation of high risk area in Greece. Landslide preparatory and triggering causal factors are considered to be the ground conditions (lithology), geomorphological processes (fluvial erosion, etc.), and the man-made actions (excavations, loading etc.) were used to model semi-quantitative hazard zonation through the use of Weighted Linear Combination Method in GIS environment.

In this study four groups of data were used to assess landslide hazard and risk, namely Environmental factors which prepared to produce landslide susceptibility, Element at risk were identified to map vulnerability of element at risk due to landslide hazard, triggering factors that of initiated to form hazard and landslide inventories data were prepared for validating the result. From these empirical review WLC method were adopted to model landslide susceptibility whereas risk analysis were prepared from product of landslide hazard and vulnerability of element at risk.

2.2.2 Continental Experience

As Musinguzi and Asiimwe (2014) researched on application of geospatial tools for landslide hazard assessment of Uganda and recommended that pair-wise comparison and linear combination GIS techniques and the available spatial datasets could still be used to predict landslide susceptibility. Therefore, this study were used analytical hierarchy process and weighted linear combination techniques to assess Semi-quantitative analysis of Landslide hazard and Risk.

2.2.3 Local Experience

In Ethiopian context different researcher used Geospatial techniques like GIS, RS and GPS for analysis and assessing landslide susceptibility and hazard. Ayele et al., (2014) although used Weighted Linear Combination method for mapping landslide susceptibility of Abay Gorge. The data were used to model landslide hazard zonation are: land cover, slope angle, lithology, geological structures, drainage pattern & hydrogeology/groundwater conditions, degree of weathering and soil types. Whereas Girma et al., (2015) used Geographical Information System (GIS) based Stastical approach for evaluating landslide hazard zonation in Ada Berga district. For this analysis different factors like lithology, soil type, slope, aspect, curvature, elevation, land use/land cover, and ground water conditions were used. Chimdi et al., (2017) also studied landslide hazard evaluation and zonation in Gimbi area using GIS based statistical approach. Slope material, elevation, slope, aspect, curvature, Land use/land cover, groundwater, distance to road, and distance to stream factors were used for the LHZ map preparation. This empirical framework is ultimately supported for mapping landslide hazard and risk of Gimbi Town. However, the factors identified and method used for assessing landslide hazard and risk of the Town vary from the researcher that studied landslide hazard evaluation and zonation of Gimbi and its area. Even the results of this study were different.

2.3 Conceptual Framework

In order to generate a landslide hazard and risk map, criteria need to be identified that are relevant to the particular situation under consideration. According to Akgun et al., (2012) risk is a function of hazard and vulnerability parameters, which are obtained from elements at risk. In this study the product of hazard and vulnerability at risk were developed to produce risk of the study area.

This study summarizes Landslide hazard and risk mapping by using of assigning weighting and ranking for each class of each theme which is called weighting factor map. Weighting and Ranking has been assigned to each class based on their influence on landslide and land erosion. The influence of each class of each theme has been identified using landslide inventory map. The weights were developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These pairwise comparisons are then analyzed to produce a set of weights that sum to one. The larger the weight means the more influencing is the factor. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination or for other MCE modules.

2.2. 1 Input Data for Landslide Hazard and Risk Mapping

The factors that determine the landslide hazard of an area may be grouped into two categories: intrinsic variables, such as geological conditions and slope structures, and extrinsic variables, such as rainfall and human activities (Huabin et al., 2005). Moreover Corominas and Mavrouli (2011), the main data layers required for landslide susceptibility, hazard and risk assessment can be subdivided into four groups: landslide inventory data, environmental factors, triggering factors, and elements at risk. Landslides are the result of complex interaction among several factors, primarily involving geological, geomorphological, and meteorological factors (Sarkar and Kanungo, 2004). According to Dibs et al. (2018), landslides usually happen due to two types of factors: Triggering factors, such as heavy precipitation events and/or earthquakes, and preparatory conditions such as soil property, slope, topography, land use / land cover, hill slope saturation and vegetation which play important roles in the occurrence of landslides. In this research the input data requirements for mapping landslide hazard and risk are categories into for groups, these are; landslide inventory data, environmental factors, triggering factors, and elements at risk.

2.2.1.1 Landslide Inventory Data

Landslide inventories are essentially factual in nature (Fell et al., 2008). As Corominas and Mavrouli (2011), landslide inventory data is highly important for producing reliable map that predicts the landslide hazard and risk in a certain area, it is crucial to have insight in the spatial and temporal frequency of landslides, and therefore each landslide hazard or risk study should start by making a landslide inventory that is as complete as possible in both space and time. Landslide inventory map is digitized from high resolution satellite data, tracking using Handheld GPS through field surveying, and digitized from Google earth.

The landslide inventory map is the most important data layer, since this contains information on the locations where landslides have actually taken place. Each landslide information should be stored related to the type of landslide, the state of activity, and (if possible) the date of occurrence and damage caused (Corominas and Mavrouli, 2011). Landslide inventories are rudimentary analysis and recording of landslides that form the basis of ‘‘past is the key to the future’’ (Michael and Samanta, 2016). A landslide inventory is the most important information source for quantitative and qualitative zoning of landslide susceptibility, hazard and risk. It should give insight into the location, date, type, size, activity and causal factors of landslides as well as resultant damage. In Gimbi Town, there are so many event and past landslide inventories area. Some of events landslide inventories prone area were collected via field observation are shown Annex 13.

2.2.1.2 Environmental factors

The environmental factors are a collection of data layers that are expected to have an effect on the occurrence of landslides, and can be utilized as causal factors in the prediction of future landslides (Corominas and Mavrouli, 2011). As topography is one of the major factors in landslide hazard analysis, the generation of a Digital Elevation Model (DEM) plays a major role. Accordingly, the casual factors of mapping landslide hazard and risk assessments are; elevation, slope, aspect, lithology, soil, NDVI, road network, land use and lineament.

i. Elevation

The topography of study area is varies from 1733 to 2129 m above sea level as per 12.5m resolution DEM (Fig.3.3). According to (Ali et al., 2017), the elevation of Gimbi Town was classified into four (Table 2.3).

Table 2.3: Topographic or Elevation of Gimbi Town

No	Parts of the study area in direction	Elevation above mean sea level
1	Southern part of the Town	Above 2000m
2	Central and south west part of the Town	1900m-2000m
3	Large part (area) of the Town	1800m-1900m
4	North part of the Town	Below 1800m

Source: (Ali et al., 2017)

Ali et al (2017), analyzed & illustrated the data in the Table 2.3 above as follows:

The topography elevation above 2000 m is found in southern part of the Town. In general, landslide site is not observed in this elevation range, since the area is covered by forest and moderately vegetated area, low drainage problem and low man made activities for slope instability. The topographic elevation from 1900-2000 m is found central and south west part of the Town. About twelve sites were identified related to landslide in this elevation range area. This is mainly due to the land use of the area covered by developed part of the town (there is large man made activities carried due to road and house construction), scarcely vegetated and poor drainage system. The topographic elevation between 1800 m-1900 m is large part of the Town area. About seven sites were identified related to landslide in this elevation range area. Similarly, these sites are found within the developed part of the Town and poor drainage area. Below 1800m elevation found at the periphery of the town at the riverbeds.

The influence of elevation may be attributed in terms of degree of weathering, variation in humidity, rate of hydrate reaction, erosion process and depth of weathering (Girma et al., 2015). Higher elevation will be the intensity of erosion and weathering during rainfall season. Thus elevation can influence indirectly landslide susceptible.

ii. Slope

Slope identifies the steepest downhill slope for a location on a surface. The slope command takes an input surface raster and calculates an output raster containing the slope at each cell. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. The output slope raster can be calculated as percent slope or degree of slope. According to Rai et al., (2014), steep slopes is a terrain characteristics which are very important for assessment of potential areas of landslide. Construction on or at the base of steep slopes has to be done carefully. For any type of construction of steep slope with slope angles larger than 25 degrees, it is mandatory to make sure that the ground is stable.

The inherent stability of a slope depends on three factors: the soil texture, the slope angle, and the slope height. Slopes higher than 40 percent and with angles over 30 degrees should be avoided for any type of developmental activities if possible. Slope is an important parameter for stability evaluating. It is the first derivative of elevation with each pixel denoting the angle of slope at a particular location. As the slope angle increases, shear stress in soil or other unconsolidated materials generally increases as well. With increase in vegetation, the stability of slope tends to increase, hence ratings were given accordingly. According to Sharma, et al.(2012), the degree and length of slope determine the amount of runoff and extent of soil erosion. As water flows down the slope, it accelerates under the force of gravity. If the percent of slope is increased four times, the velocity of water flowing down is doubled. Doubling the velocity quadruples the erosive power. Sediment transport capacity of runoff increases by 10 to 100 times at 1% slope compared to 0.2% slope (Sharma et al., 2012). The slope stability in the area is influenced by the unstable unconsolidated slope material, rugged topography, and complex hydrological conditions (Chimdi et al., 2017). It is well established that as the degree of inclination of the earth’s surface or slope increases, the likelihood of a landslide increases and the most important terrain-related risk factor influencing slope stability is the steepness of the slope (Musinguzi and Asiimwe, 2014). So slope gradient of the study is highly susceptible to cause landslide through increased runoff due to high amount of rainfall and precipitation.

iii. Aspect

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. The values of the output raster will be the compass direction of the aspect. The Aspect function is often applied to a digital elevation model (DEM). The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1. The value of each cell in an aspect dataset indicates the direction the cell's slope faces.

iv. Lithology

Rock types play an important role in slope stability. The lithological constituents, their texture and degree of weathering are the basic elements which differentiate various rock types in influencing slope instability (Sarkar and Kanungo, 2017). In this study, there are two grouped of lithological data these are; Precambrian/Aba Sina Domain group, which contains granitoid orthognesis (pgtgn) unit and Mafic-ultramafic and associated rocks groups, which is metagabbro-amphibolite (pgb1) unit. These rocks are the metamorphic rocks that form by the effects of heat, pressure, and shear upon igneous and sedimentary rocks. Some form during mountain-building by forces of others from the heat of igneous intrusions in regional metamorphism others from the heat of igneous intrusions in contact metamorphism.

Gneisses lithotectonic units are exposed in the western part of the Gimbi Town which accounts for the largest part of the gneissic units. The rock is weakly to strongly gneissose, and the gneissosity being defined by the segregation of elongated felsic minerals on the one hand, and mafic minerals like biotite and hornblende on the other. Gabbro lithotectonic unit is one of the mafic intrusive rocks exposed in the eastern part of the Town. This intrusion is fresh and un-metamorphosed rock unit. The marginal zone consists of melanocractic gabbro, which is generally fine-grained, but coarsens towards the interior of the intrusion and exhibits hypidiomorphic texture. In this group landslides are frequently encountered.

v. Soil texture

Refers to the composition of the soil in the terms of the amounts of small (clays), medium (silts), and large (sands) size particles. Soils with high percentage of clay form very stable aggregates resistant to detachment. On the other hand, light soils like sandy or coarse loams are easy to detach as they have low organic matter content, resulting in their inability to form very stable aggregates. Hence, soil with more sand, high slope, and intensive rainfall, which constitute most dominant factors of landslide, cause severe damage to the land (Sharma et al., 2012). Soils which contain a lot of water (i.e. are poorly drained), and soils and rocks which have high clay content, or are otherwise known to be susceptible to instability (Mason, 1998). Soil texture is important because the size of soil particles determine the tendency of soil particles to resist sliding across each other. Soils with large particles such as clay soils are the most cohesive while sand soils with fine particles are almost cohesion less. Friction forces are dependent upon the load placed on the soil surface so the greater the load, the greater the likelihood that the forces of friction will be overcome (Musinguzi and Asiimwe, 2014). The complete surface portion of soil may slip down from its actual position, causing landslides (Sharma et al., 2012).Generally in Town four soil texture type: sandy loamy; clay loamy; loam; clay were founded with Nitisols, Greysoils, Acrisols, Nitisols and cambisoils major soil group respectively.

vi. Proximity to Lineament

Geological structures such as faults, folds, joints, bedding and shear zones have a greater influence on the stability of the slopes. The presence of a dense vegetation canopy, extensive weathering and recent non-consolidated deposits (fluvial terraces, pediments or alluvial sediments) may prevent the identification of lineaments (Ramli et al., 2010). The lineaments considered very important indicator to determine the general and local tectonic trends and area of fractures in rocks. Fractures and discontinuities are interpreted from Digital Elevation Model (DEM). The lineaments were superimposed on the lineament density map. The map shows no lineaments in the low density class, a single lineament in the moderate class, and mostly more than one and/or intersecting lineaments in the high density class (Sarkar and Kanungo, 2004). As Ramli, et al. (2010), there are two main types of lineament positive and negative, referring to ridge trends and river valleys respectively. Whereas the topographically negative straight lineaments may represent joints, faults and shear zones, the topographically positive straight lineaments may be interpreted as dykes and dyke swarms. Lineament affect surface material structures and have a significant influence on topography permeability and thus slope stability. The proximity of a slope to these features greatly influences its stability, increasing the susceptibility of landslides occurrence (Michael and

Samanta, 2016). So the lineaments can cause landslide formation. The risk is decreased with increasing distance from lineament structures.

vii. Land Use/Land Cover

LU is one of the very important factors in landslide hazard and risk assessment. Land use map in hilly areas generally shows the distribution of forest cover, water bodies and habitats (Sarkar and Kanungo, 2017). Change in LULC with time greatly influences the slope stability and erosional activities. LU change is depends on the population and their needs for survival that include deforestation, conversion of forest for agricultural purposes and unplanned or unprofessional slope cutting for infrastructure developments (Michael and Samanta, 2016).

viii. NDVI

The vegetation index is also considered an influencing factor in landslide susceptibility assessment studies (Tseng et al., 2015). NDVI was used in this study to reflect the vegetation density. In general, the value of NDVI ranged from -1 to 1; the higher the value of NDVI the denser the vegetation cover. The NDVI value was calculated by using the multi-spectrum information from the Landsat OLI/TIRS image based on the following formula.

$$\text{NDVI} = \frac{(Near\ InfraRed(NIR) - Red(R))}{(Near\ InfraRed(NIR) + Red(R))}$$

The NDVI value in this study area was less than 0.5. The relation between landslide occurrence and NDVI (Fig. 4.3) shows that most of the landslides were in areas with low NDVI values. If there is no healthy vegetation the probability of rainfall infiltrations is less and high soil runoff may occur which means, no vegetation canopy, the terrain may call as bare land and highly eroded during rainfall seasons. So NDVI is indirectly causes of landslide prone area.

2.2.1.3 Triggering factors

Information related to triggering factors generally has more temporal than spatial importance, except when dealing with large areas on a small mapping scale. This type of data is related to rainfall, temperature and earthquake records over sufficiently large time periods, and the assessment of magnitude-frequency relations. Rainfall and temperature data are measured in individual meteorological stations (Corominas and Mavrouli, 2011).Human activities such as the construction of roads cutting slopes and clearing of land can be triggering factors of landslide (Sideng, et al., 2018). But in this research rainfall data is the most triggering factor of landslide over the study area.

ix. Rainfall

Precipitation affects slope stability in many ways. First, precipitation affects rock formations hence the likelihood of slope failure. Secondly, precipitation increases the amount of water in surface soils which can increase the likelihood of landslide events. Precipitation increases the saturation level of surface soils, which increases pore water pressure in the voids between soil particles. This increase in pore water pressure decreases the friction and cohesion between soil particles and may lead to shallow seated landslides and debris flows (Musinguzi and Asiimwe, 2014). In Gimbi, for example, most of the previous fatal landslides occurred after a heavy rainfall.

2.2.1.4 Element at Risk

Elements at risk inventories can be carried out at various levels, depending on the requirement of the study (Corominas and Mavrouli, 2011). Accordingly, element at risk data in this study are road network (transportation lines) and Land cover (building and settlement area) which are more vulnerable to landslide. Landslide risk can also be calculated if one takes into account the potential vulnerability of houses and buildings (Lee and Pradhan, 2006).

x. Proximity to Road

Proximity to road element is considered because of the terrain and the infrastructure properties which is undertaken to landslide risk in the study area. Road cuts at the outset decrease the general stability of the slopes and increase depending on the dip directions lithological units. Effects of induced vibration from moving trucks or vehicles are also considered based on hypotheses that rebound settling time is not sufficient before another truck passes over. This artificial vibrations and surcharge along slope cuts can induce or increase instabilities (Michael and Samanta, 2016). Landslide Risk is decreases as distance increases away from the road corridor.

CHAPTER III

MATERIALS AND METHODS

3.1. General Description of the Study area

3.1.1 Location

Gimbi Town is located in the western part of the Ethiopia at a distance of 441 Km from Addis Ababa capital city of Ethiopia. Gimbi Town is located in western welega zone of Oromia Region. It has total area of 49.49Km^2 and geographically positioned between latitude 9°07’30’’N to 9°12’30’’N and longitude 35°47’30’’E to 35°52’30’’E (Fig.3.1).

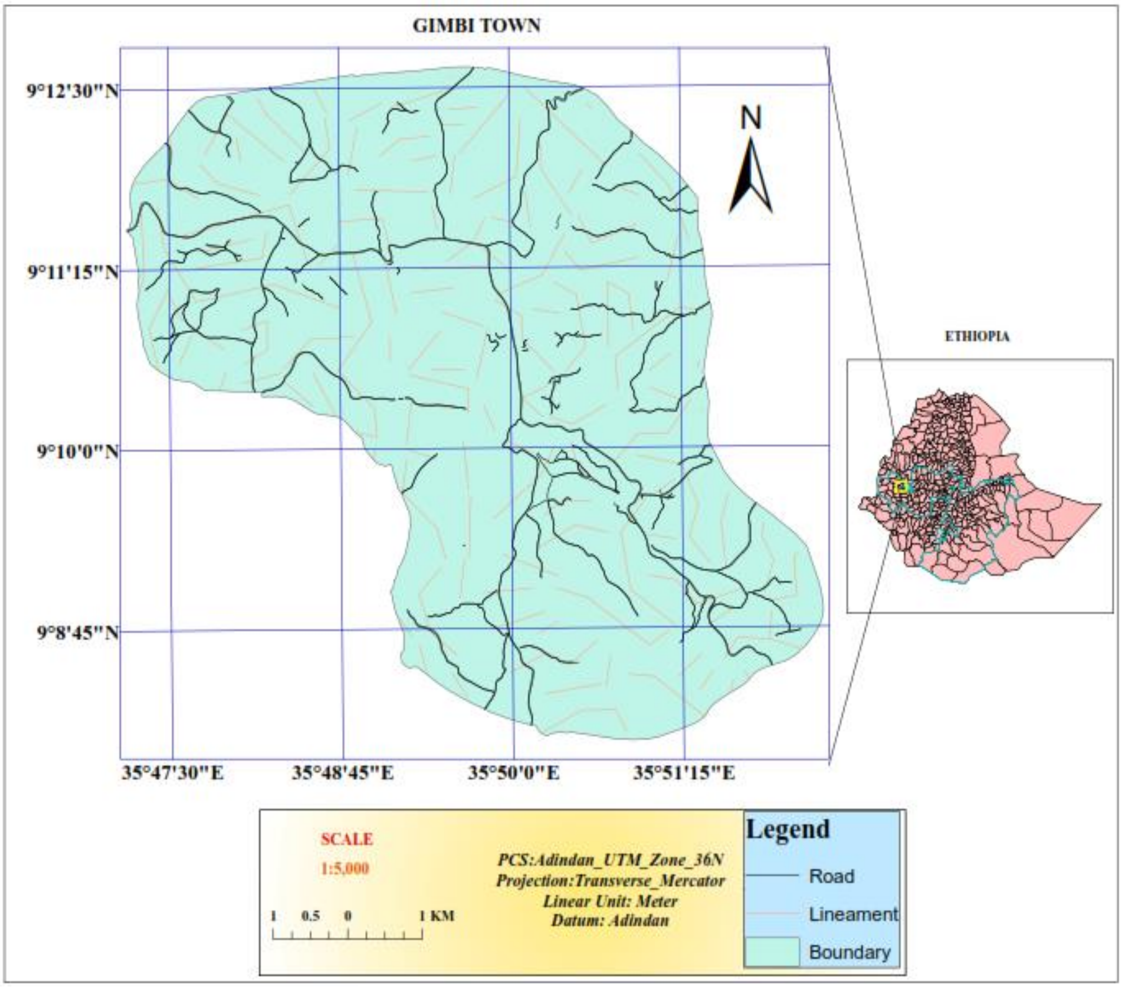


Figure 3.1 Location Map of the study area

3.1.2 Rainfall and Temperature

According to Ali et al. (2017), , temperature of Gimbi town lies in semi-temperate zone of altitude between 1500 - 2300 m above mean sea level has the annual mean temperature of 15 to 20° C while the annual rainfall varies between 1922.49 to 1969.18 mm as shown in Fig.3.2a. However, annual rainfall of Gimbi Town is varies from 1922.49 to 1969.18 millimeters shown figure 3.2a. The climate in the Town is warm and temperate with an intense rainfall even in the driest season. The average annual temperature is 14.7 °C in Gimbi. The driest month is December, with 13 mm of rain. Most of the precipitation here falls in August with a monthly rainfall of 269 mm. March is the warmest month of the year. The temperature in March averages 16.1 °C. August is the coldest month, with temperatures averaging 13.6 °C as shown in Annex 14.

3.1.3 Topography

The highlands of Ethiopia are generally characterized by highly variable topography, which is a reflection of the past geological and erosion process. Much of the elevation of the highlands ranges from about 1500 to 3500 m: with some of the gorges within the highlands having elevations up to 1000 m while some mountains rising over 4600 m above sea level (Ali, et al., 2017).The topography of study area is varies from 1733 to 2129 m above sea level as per 12.5m resolution Digital Elevation Model as shown Fig.3.2b.

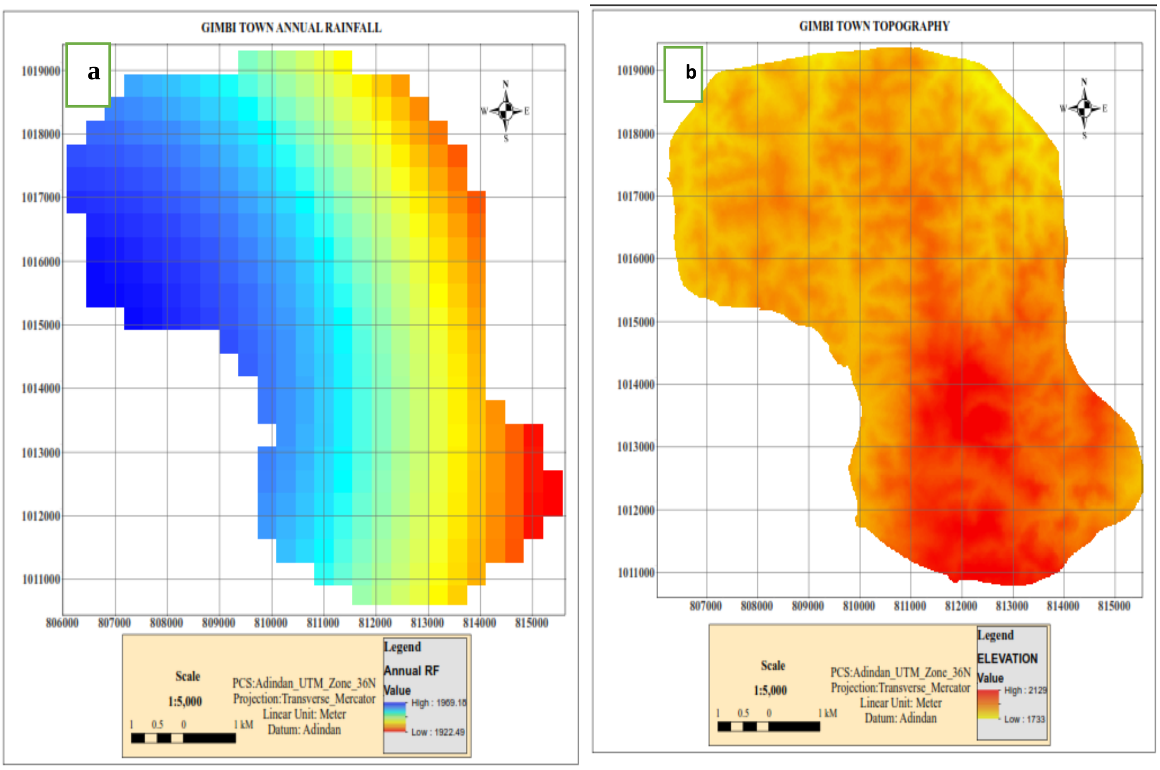


Figure 3.2 Annual rainfall (a) and Topographic (b) map of Gimbi Town

3.1.4 Population

The 2007 national census reported a total population for this woreda of 74,623 in 14,925 households, of whom 36,708 were men and 37,915 were women. None of its population were urban dwellers (CSA, 2007). The majority of the inhabitants observed Protestantism, with 65.37% reporting that as their religion, while 28.76% observed Ethiopian orthodox Christianity and 4.12% were Muslim.

3.2. Data and Materials

The data and their sources used to generate landslide hazard map and used to assess landslide risk in Gimbi Town are listed below (Table 3.1).

Table 3.1 Data and Their sources

No	Data	Source	Data Type	Scale	Purpose
1.	Geological map	EMA	Raster	1:250,000	Digitized Lithology
1.	Landsat OLI/TIRS	USGS	Raster	28.5/30m	To interpret Land use/Land cover and NDVI
1.	Climate	EMA	Tabular		Rainfall map
1.	DEM	ASFDAAC	Raster	12.5m	To produce Slope, Aspect, Lineament and Elevation
1.	Soil texture	OWWDSE	shapefile	1:10000	To produce soil map
1.	Road	OUI	shapefile		To map road network
1.	boundary	OUI	Shapefile		To zonal information

Different software and material or equipment that are used to achieve the objectives in this study (Table 3.2).

Table 3.2 Software and its purpose

No.	Software & equipment	Version	Purpose
1	ArcGIS	10.4.1	To prepare landslide hazard and risk map
2	Terrset	18.31	To derive the weights to weighted overlay layers
3	ERDAS	2014	To produce land use land cover
4	Geomatica	2016	To Generate lineament from DEM
5	Handheld GPS	GPS72	To collect data and map landslide inventories.

3.3. Methods

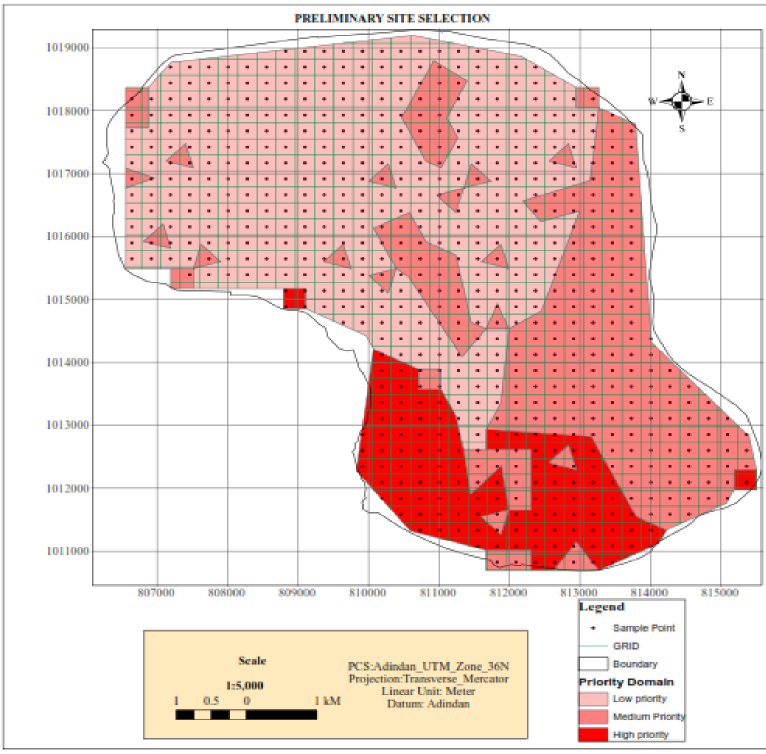
As mentioned in literature review section of 2.1.2, there are different approaches/methods that are used to delineate landslide hazard zonation. In this study Multi-Criteria Decision Analysis (MCDA) methods were used to delineate and map landslide hazard and risk of the study area. The method includes four stages; 1) pre-field work, 2) field work, 3) post field work and 4) field for validation.

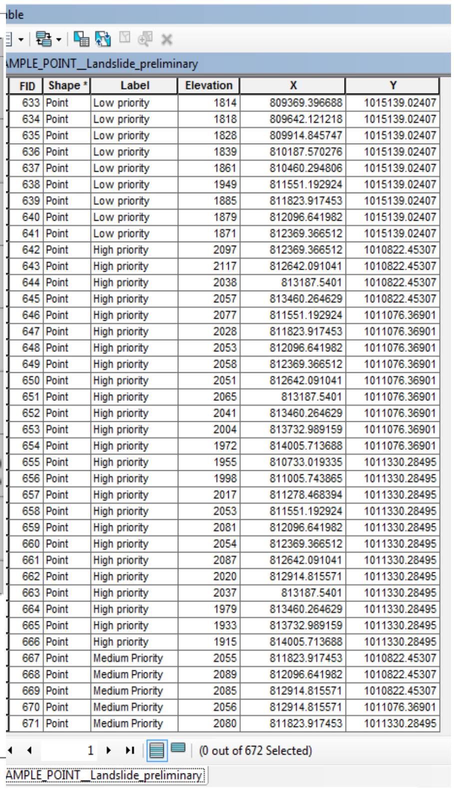
First, pre-field work (data preparation) includes data collection and map preparations. In this stage, lithology of the study were digitized from existing geological map; Rainfall data were accessed from EMA; soil map has been produced from OWWDSE; DEM, slope, aspect and lineament maps were prepared from ASFDAAC data; Road is digitized from Google earth and OUI; land use/land cover and NDVI map was derived from Landsat OLI/TIRS 2019 via image interpretation and image classification. For preliminary site selection analysis four main causes of landslide prone area like; lithology, soil, slope, and rainfall factors are reclassified and combined to identify priority area for field observation. The priority field observation domains are classified into three: high priority, medium priority, and low priority (Fig 3.3). Total Grid sampling point generated for priority field observation domains are 672, i.e., 341, 224, and 107 Points are low, medium and high priority respectively as summarized in Table 3.3below. The distance between each stations is 272 meter.

Second, field observations were carried out. This was done with the help of handheld GPS, and field observation checklist.

For field observation and data verification 50 total sample points from preliminary priority map (shown in Table 3.3) were selected based on the percentage of each priority class calculated using the following Equation 3.1. The selected sampling points for field observation was observed and proved some of the existing conditioning factors of landslide in the study area (Annex 1).

Percentage = each of priority class area/Total area of priority class *100%.......Equation 3.1





ble

AMPLE_POINT__Landslide_preliminary

FID	Shape *	Label	Elevation	X	Y
633	Point	Low priority	1814	809369.396688	1015139.02407
634	Point	Low priority	1818	809642.121218	1015139.02407
635	Point	Low priority	1828	809914.845747	1015139.02407
636	Point	Low priority	1839	810187.570276	1015139.02407
637	Point	Low priority	1861	810460.294806	1015139.02407
638	Point	Low priority	1949	811551.192924	1015139.02407
639	Point	Low priority	1885	811823.917453	1015139.02407
640	Point	Low priority	1879	812096.641982	1015139.02407
641	Point	Low priority	1871	812369.366512	1015139.02407
642	Point	High priority	2097	812369.366512	1010822.45307
643	Point	High priority	2117	812642.091041	1010822.45307
644	Point	High priority	2038	813187.5401	1010822.45307
645	Point	High priority	2057	813460.264629	1010822.45307
646	Point	High priority	2077	811551.192924	1011076.36901
647	Point	High priority	2028	811823.917453	1011076.36901
648	Point	High priority	2053	812096.641982	1011076.36901
649	Point	High priority	2058	812369.366512	1011076.36901
650	Point	High priority	2051	812642.091041	1011076.36901
651	Point	High priority	2065	813187.5401	1011076.36901
652	Point	High priority	2041	813460.264629	1011076.36901
653	Point	High priority	2004	813732.989159	1011076.36901
654	Point	High priority	1972	814005.713688	1011076.36901
655	Point	High priority	1955	810733.019335	1011330.28495
656	Point	High priority	1998	811005.743865	1011330.28495
657	Point	High priority	2017	811278.468394	1011330.28495
658	Point	High priority	2053	811551.192924	1011330.28495
659	Point	High priority	2081	812096.641982	1011330.28495
660	Point	High priority	2054	812369.366512	1011330.28495
661	Point	High priority	2087	812642.091041	1011330.28495
662	Point	High priority	2020	812914.815571	1011330.28495
663	Point	High priority	2037	813187.5401	1011330.28495
664	Point	High priority	1979	813460.264629	1011330.28495
665	Point	High priority	1933	813732.989159	1011330.28495
666	Point	High priority	1915	814005.713688	1011330.28495
667	Point	Medium Priority	2055	811823.917453	1010822.45307
668	Point	Medium Priority	2089	812096.641982	1010822.45307
669	Point	Medium Priority	2085	812914.815571	1010822.45307
670	Point	Medium Priority	2056	812914.815571	1011076.36901
671	Point	Medium Priority	2080	811823.917453	1011330.28495

1 (0 out of 672 Selected)

AMPLE_POINT__Landslide_preliminary

Figure 3.3 Generated Grid sampling points and Preliminary site selection map

Table 3.3 Areal extent of priority classes and selected sample points for field observations

No.	Priority class	Area (km^2)	% of area coverage	Generated Sample point	Selected sample Point based on area coverage & amount of generated sample point in priority classes
1	Low Priority	24.0773	51.7392	341	25 point
2	Medium Priority	15.317073	32.9145	224	16 point
3	High Priority	7.141511	15.3463	107	9 point
Total		**46.535884**	**100%**	**672**	**50**

In the third stage /post field work/ of data analysis and interpretation, maps from secondary data sources and maps from field observation were standardized using raster calculator tool. Therefore, standardized landslide susceptibility, landslide hazard and risk maps were prepared from standardized factor maps, which were again produced from existing data sources and field observations.

In the fourth stage, field observation for the validation of the final result was carried out. Eight existing landslide inventory prone area was recorded by field survey using GPS points (Annex 2). These collected landslide inventory map were used for validation of the standardized landslide hazard and risk maps.

Different researchers have used different formula for mapping landslide risks. Risk value were obtained from the product of hazard and consequence (Jamaludin and Hussein, 2006). According to Corominas and Mavrouli (2011), the classical expression for calculating landslide risk (R); R= Hx (ExV) where, H is landslide hazard, E is Element at risk and V is vulnerability. According to Kouli et al. (2009), landslide Risk were calculated by product of hazard and exposure. The exposure factor was estimated by the combination of population density, land use, and road network data layers. However, qualitative risk assessment, which are mostly based on integrating a hazard index, and a vulnerability index, using Spatial Multi Criteria Evaluation (Corominas and Mavrouli, 2011). Landslide risk is commonly expressed by the product of landslide hazard and landslide vulnerability (Akgun et al., 2012). Landslide risk of the Gimbi Town were produced from the following general risk equation.

Risk= landslide hazard* landslide vulnerability……………….Equation 3.2

Generally, in this study landslide hazard and risk analysis after field observation and data verification were computed using Multi Criteria Decision Analysis (MCDA) as shown Fig. 3.4 below.

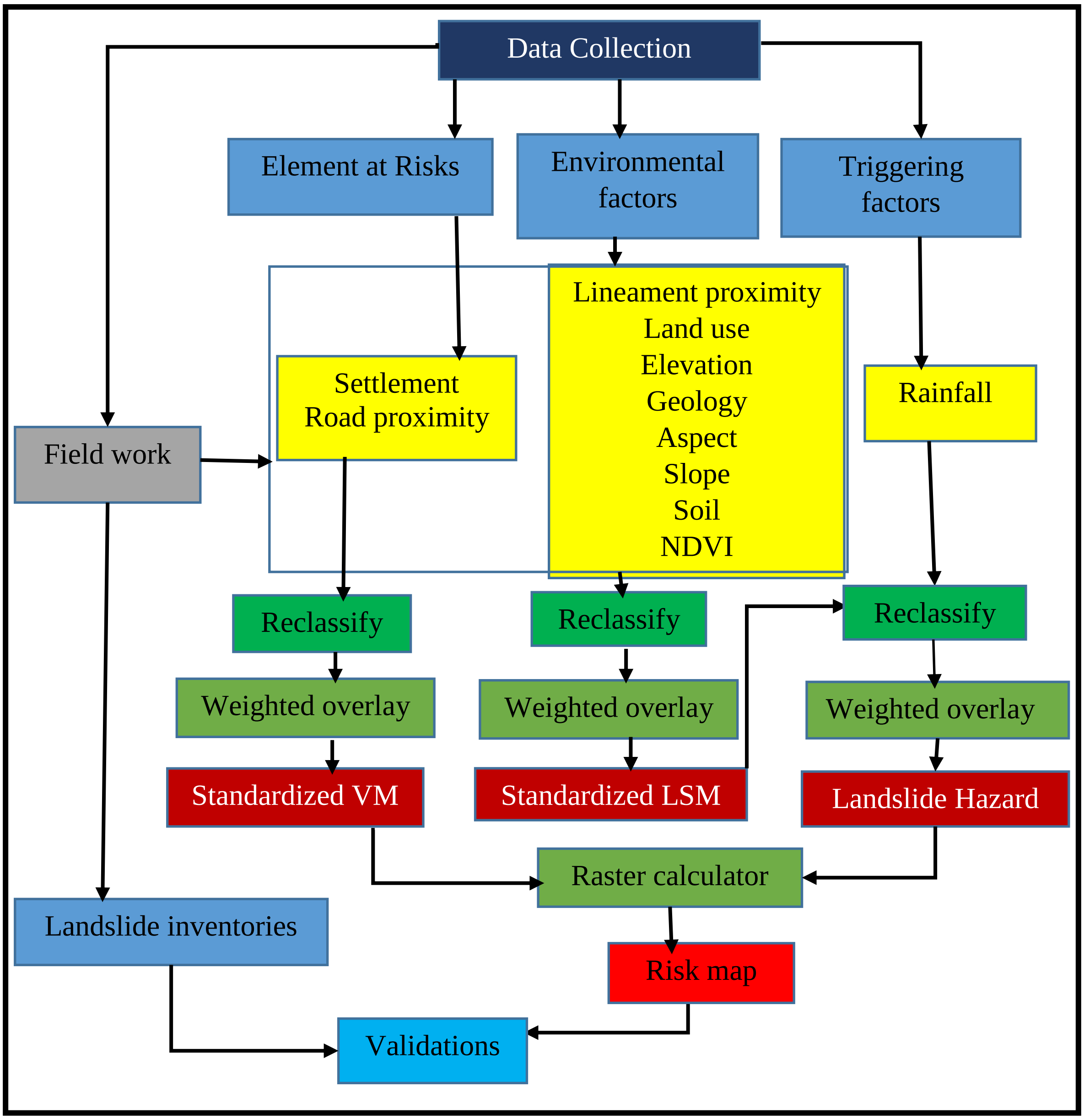


Figure 3.4 Workflow of mapping landslide hazard and risk of study area

CHAPTER IV

DATA ANALYSIS, RESULTS AND DISCUSSIONS

4. 1 Data Analysis

4.1. 1 Introduction

The factors that are necessary for the occurrence of the landslide catastrophe were reviewed and the local dwellers were interviewed about element at risk due to landslide. Accordingly Geology, lineament, soil, slope, elevation, land use type, NDVI, rainfall and road proximity are listed in order of importance. To assess landslide risk of the Town, GIS based Multi-Criteria Decision Analysis was used. MCDA is a procedure which needs several criteria to be evaluated to meet a specific objective. It is most commonly achieved by one of two procedures. The first involves Raster calculator whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as product (*) and Sum (+). The second procedure which was used in the study is known as WLC where continuous criteria (factors) were standardized to a common data model that was raster layer with a resolution of 30m cell size, and then combined by means of a weighted overlay. The result is a continuous mapping of landslide susceptibility and finally thresholded to yield a final decision.

The standardized raster layers were weighted using Eigen vector that is important to show the importance of each factor as compared to other in the contribution of landslide vulnerability. Accordingly, the Eigen vector of the weight of the factors was computed in TerrSet Geospatial Monitoring and Modeling System 18.31 Software in IDRISI GIS Analysis menu Decision Support/ Weight module. The Weight module was served with the pair wise comparison matrix file of the factors in a Pair wise comparison 9 Point continuous scale and the Eigen vector of weights to weighted overlay factors were calculated. The computed Eigen vector, which is an output of the pair wise comparison matrix to produce a best fit set of weight, of Weight Module was; Land use land cover type: 0.0706, NDVI: 0.0166, Aspect: 0.0296, Elevation: 0.0333, Lineament: 0.0610, Lithology: 0.4034 Slope: 0.1424, Soil: 0.2431. The consistency ratio of the calculated Eigen vector is 0.09 which is acceptable. (Fig 4.1). The computed Eigen vector is used as a coefficient for the respective factor maps to be combined in Weighted Overlay in ArcGIS environment and landslide susceptible map was produced. Whereas landslide susceptibility and rainfall were sum up to produced hazard. Vulnerability of element at risk was produced from Land use (built up like

Residential and agriculture like coffee plantation) and Road to be equally important in Weighted Overlay (Table 4.1, 4.2, and 4.3).

Factors	Weight	Class	Rank	N° of pixels in domain
Land use type	0.0706	Bare land	4	10196
		Built up area	3	6589
		Agriculture	2	11166
		Shrub land	1	27586
NDVI	0.0166	0.023 - 0.179	5	840
		0.179 - 0.239	4	9749
		0.239- 0.291	3	25794
		0.291 - 0.344	2	16069
		>0.344	1	840
Aspect(degree)	0.0296	Flat(-1)	0	3745
		0 - 45	1	12240
		45 - 90		
		90 - 135	2	14243
		135 - 180		
		180 - 225	3	13957
		225 - 270		
		270 - 315	4	5823
		315 -358	5	4075
Elevation(meter)	0.0333	1,764.32 - 1,832.60	1	12568
		1,832.60 - 1,900.89	2	17266
		1,900.89 - 1,969.18	3	10347
		1,969.18 - 2,037.46	4	7749
		2,037.46 - 2,105.75	5	6106
Lineament proximity (meter)	0.0610	0-100	5	19068
		100-200	4	6849
		200-300	3	5839
		300-400	2	4707
		> 400	1	7321
Lithology	0.4034	granitoid orthognesis	1	7517
		metagabbro-amphibolite	2	35253
Slope(degree)	0.1424	0 - 10	1	28285
		10- 20	2	23855
		20 - 30	3	1161
		30- 35	4	23
Soil texture	0.2431	Sandy Loam(SL)	1	34262
		L (Loam)	2	241
		CL(Clay Loam)	3	20237
		Clay(C)	4	344

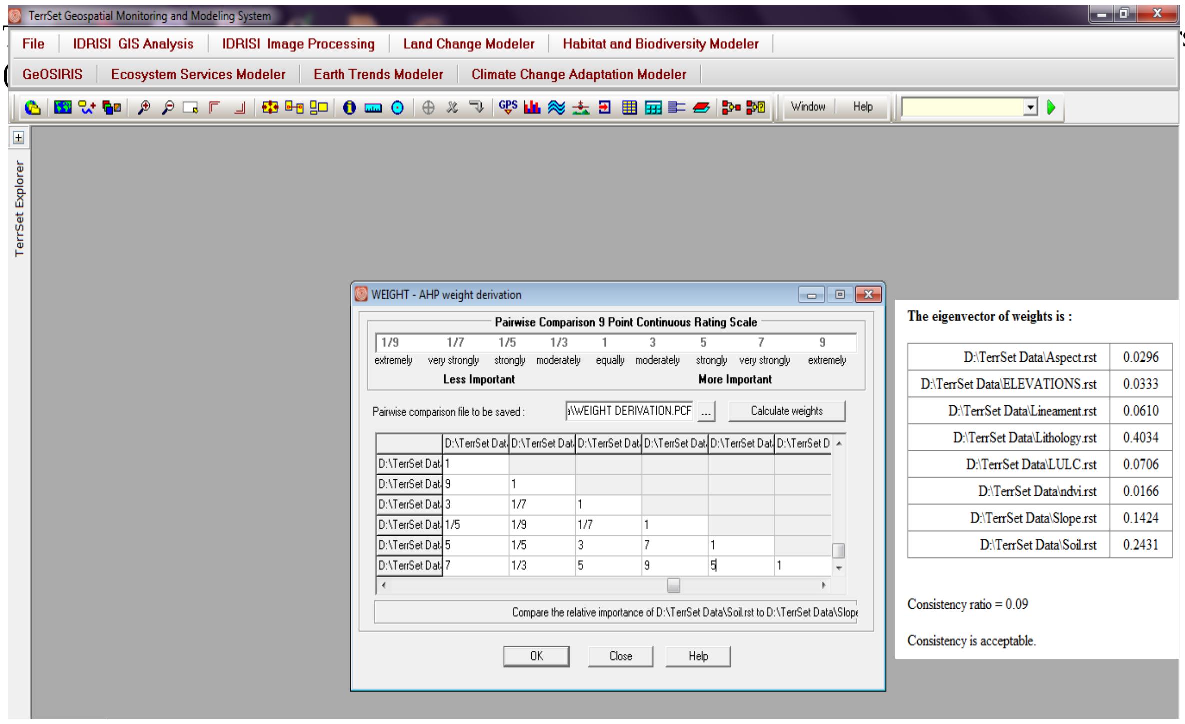


Figure 4.1 Computed weights of factors to a landslide susceptibility map

Table 4.2 Weighted landslide hazard ranking for Gimbi Town (Hazard analysis)

Factors	Weights	Class	Rank	N° of pixels in domain
Landslide susceptibility	1	Very low susceptible	1	2082
		Low susceptible	2	15216
		Moderate susceptible	3	22327
		High susceptible	4	10203
		Very high susceptible	5	456
Annual Rainfall(mm)	1	1,922.49 - 1,938.06	1	60
		1,938.06 - 1,953.62	2	144
		1,953.62 - 1,969.18	3	176

Table 4.3 Weighted Vulnerability of element at risk ranking for Gimbi Town

Element at risk	Weights	Class	Rank	N° of pixels in domain
Road proximity(meter)	1	0 - 100	5	20929
		100 - 200	4	16379
		200 - 300	3	10024
		300 - 400	2	4952
		>400	1	2092
Land use	1	Shrub land, bare land,	0	37782
		Coffee plantation	1	11166
		Built up area(residential, road)	2	6589

4.1. 2 Factor Data Development

As stated in literature review sections of 2.2, four groups of factors theoretically identified were used to produce semi quantitative map of landslide hazard zonation and risk assessment of Gimbi Town.

4.1.2. 1 Land use Factor

Land use land cover type of the Town was prepared from 30 meter resolutions of Landsat OLI/TIRS January 2019 by using maximum likelihood of supervised classification through the use of ground verification or field inspections. It was classified into four general classes for landslide susceptibility while three classes for element at risk and these classes converted to polygon shapefiles by class name type, then after converted each classes have been merged and area of classes were calculated. Finally, land use type of the Town was reclassified into four groups and re-assigned the value in order of their landslide susceptible (Table 4.1) whereas, reclassified into two groups and re-assigned the value in order of their element at risk (Fig. 4.2). Accuracy assessment of Land use classes for landslide susceptibility was calculated as shown Table 4.4 below.

Table 4.4 Confusion/ Error matrix of land use classes of Gimbi Town

	Reference data				Total row
Classified data	Built up	Shrub land	Bare land	Agriculture	
Built up area	1695	7	9	5	1716
Shrub land	38	2319	18	6	2381
Bare land	301	131	27	12	471
Agriculture	388	40	4	52	484
Total column	2422	2497	58	75	5052

Confusion matrix or Error matrix is used to determine the nature and frequency of errors. Therefore overall land use type map accuracy were calculated by using equation 4.3 shown below:

Total Diagonal = $\sum Main\ \boldsymbol{diagonal}$=1695+2319+27+52=**4093**…….equation 4.1

Grand Total=$\sum Total\ column$= $\sum Total\ row$= **5052**…………..…….equation 4.2

Overall map accuracy = $\frac{total\ on\ diagonal}{grand\ total} * 100\%$.................................equation 4.3

Overall Accuracy of land use =$\frac{4093}{5052}$*100%, Therefore overall accuracy of land use type (figure 4.2a) was **81.017%** which is accepted

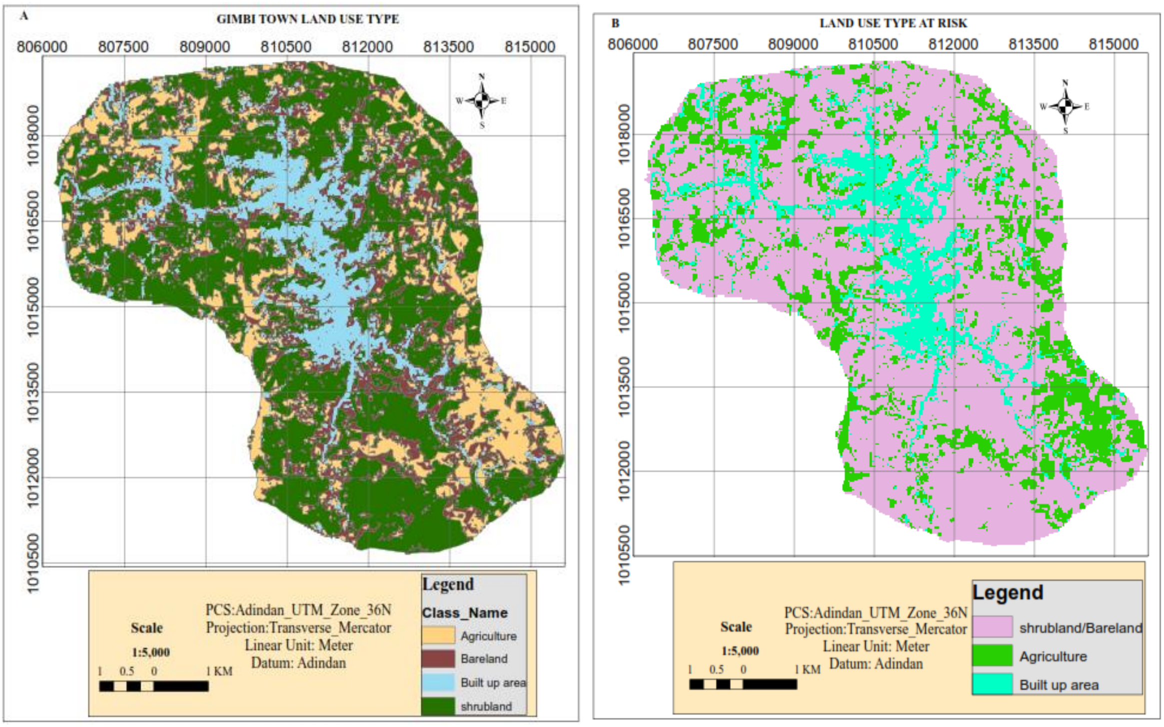


Figure 4.2 Land use type for landslide susceptibility (A) and for element at risk (B)

4.1.2. 2 NDVI Factor

Normalized Difference Vegetation Index was computed from 30 meter resolution of Landsat OLI/TIRS January 2019 which quantifies vegetation by measuring the difference between near-infrared(which vegetation strongly reflects) and red light (which vegetation absorbs).NDVI always ranges from -1 to +1. If NDVI is Negative values, is highly likely that it's water and if NDVI value close to +1, there's a high possibility that it has dense green leaves. But when NDVI is close to zero, there isn't green leaves and it could even be an urbanized area. NDVI uses the NIR and Red channels in its formula (equation 4.4).

$$\text{NDVI} = \frac{(Near\ InfraRed(NIR) - Red(R))}{(Near\ InfraRed(NIR) + Red(R))} \text{..........equation 4.4}$$

Accordingly, the NDVI values of the Town range from 0.023449193 to 0.501237984. The lowest NDVI was low healthy vegetation and highly vulnerable to landslide while the largest NDVI values was high healthy vegetation and low runoff as well as low landslide susceptible prone area. Generally, the NDVI value of this study was further reclassified in five sub groups using standard classification schemes namely equal interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing you to specify the number of intervals while Arc Map determines where the breaks should be and new values were re-assigned in their order of landslide susceptibility ratings (Fig. 4.3).

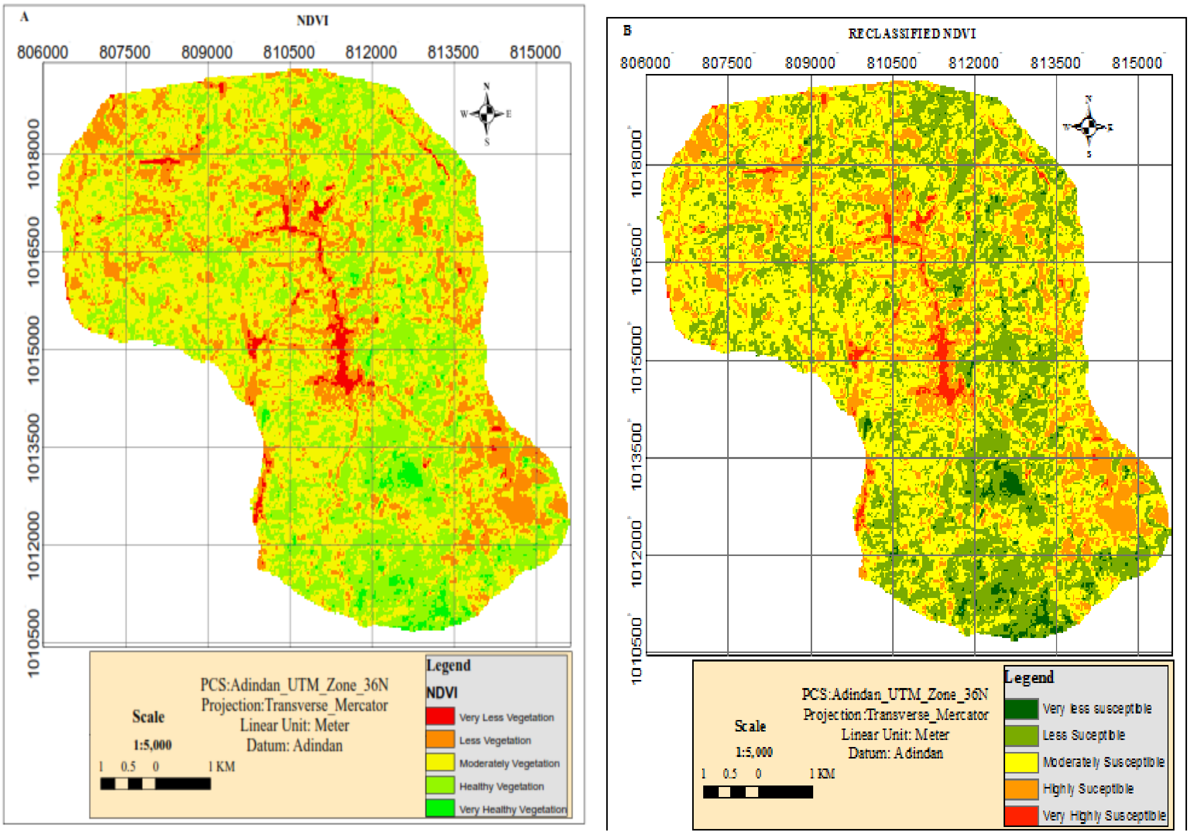


Figure 4.3 NDVI classes (A) and reassigned value for landslide susceptible (B)

4.1.2. 3 Aspect Factor

The standardized aspect of the Town was computed from 65 % of Aspect from the existing Elevation and 35% of Aspect from the field observation using raster calculator tool in ArcGIS. Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. Aspect is expressed in positive degrees from 0 to 359.9, measured clockwise from north (0 degree) to 360 degree (again due north). The aspect of a slope can influence indirectly the landslide initiation, because it controls the exposition to several climate conditions (duration of sunlight exposition, precipitation intensity, moisture retention, etc.) and as a result the vegetation cover (Kouli et al., 2009). Based on meteorological data of the study area, the NW, W, and SW oriented slopes are highly affected by rainfalls.

In this study Aspect ranged from negative 0.312 to 357.26 that produced by spatial analyst on ArcGIS environment from standardized Elevation (30m) layers. Cells in the input raster that are flat with zero slope are assigned an aspect of -1. The Aspect raster layer was further reclassified in to five sub group using standard classification schemes namely equal intervals as shown in Table 4.1. The value of each cell in an aspect dataset indicates the direct the cell's slope faces. That means, 0^0N, 45^0NE, 90^0E, 135^0SE, 180^0S, 225^0SW, 270^0W, and

315^{0}NW. Accordingly, Aspect classes and reclassified in order to assign new value for landslide susceptibility as shown in Fig. 4.4.

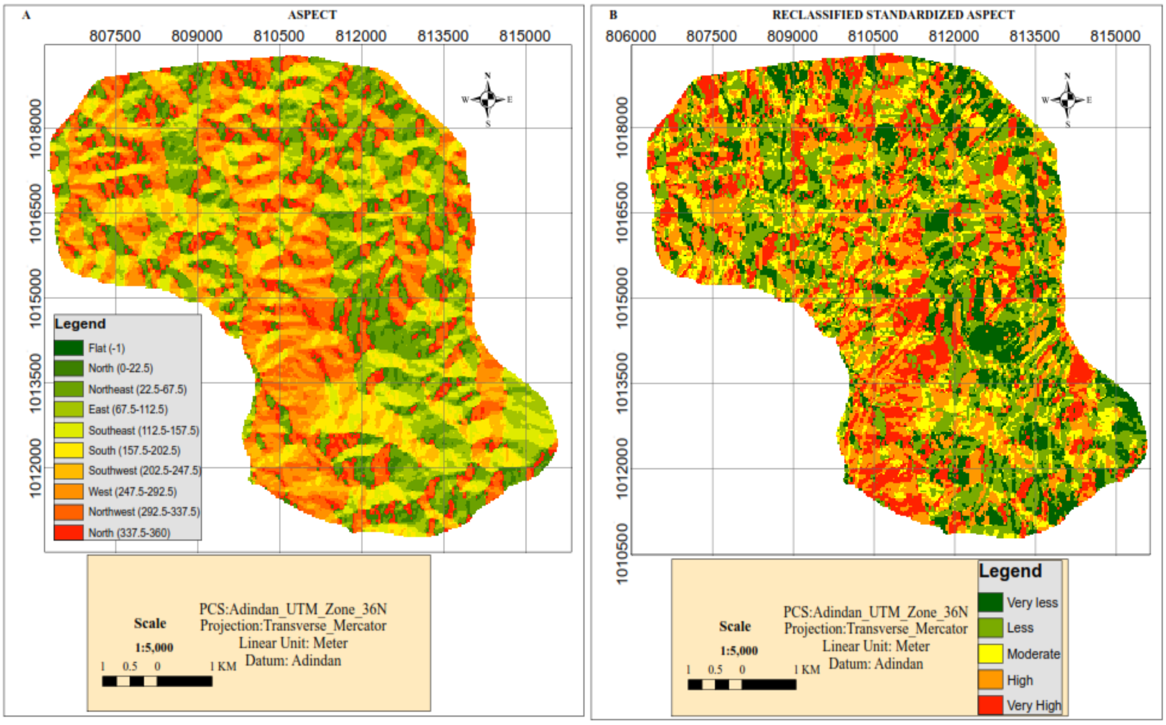


Figure 4.4 Standardized Aspect classes (A) and reclassified and reassigned value for landslide susceptibility (B)

4.1.2. 4 Elevation Factor

The standardized elevation of the Town is obtained from ASFDAAC 12.5m and field observation through using Raster calculator in ArcGIS environment. The Standardized Elevation map of the Town was generated from the summation of 65 %(0.65) elevation from ASFDAAC and 35 %(0.35) elevation from the field. The Standardized elevation (30 meter resolution) raster layer was further reclassified in five sub groups using standard classification schemes namely equal interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing us to specify the number of intervals while Arc Map determines where the breaks should be and new values were re-assigned in their order of landslide susceptibility ratings (Fig. 4.6).

4.1.2. 5 Lineament Proximity Factor

The standardized lineaments of the study was computed from the existing lineament which was automatically generated from ASFDAAC Elevation of the Town using PCI Geomatica software and lineament computed from the field data. Generally, Standardized Lineament proximity factor of the Town was computed using raster calculator in ArcGIS environment by assigning 65 %(0.65) value for lineament from the field and 35 %(0.35) lineament extracted from the Digital Elevation Model of the study. The standardized lineament proximity was computed using Euclidean Distance tool in ArcGIS with 1kilometer of maximum distance from the original. The lineament proximity layer was further reclassified in six sub groups using standard classification method known as manual and new values were re-assigned in their order of landslide susceptibility ratings (Fig. 4.5).

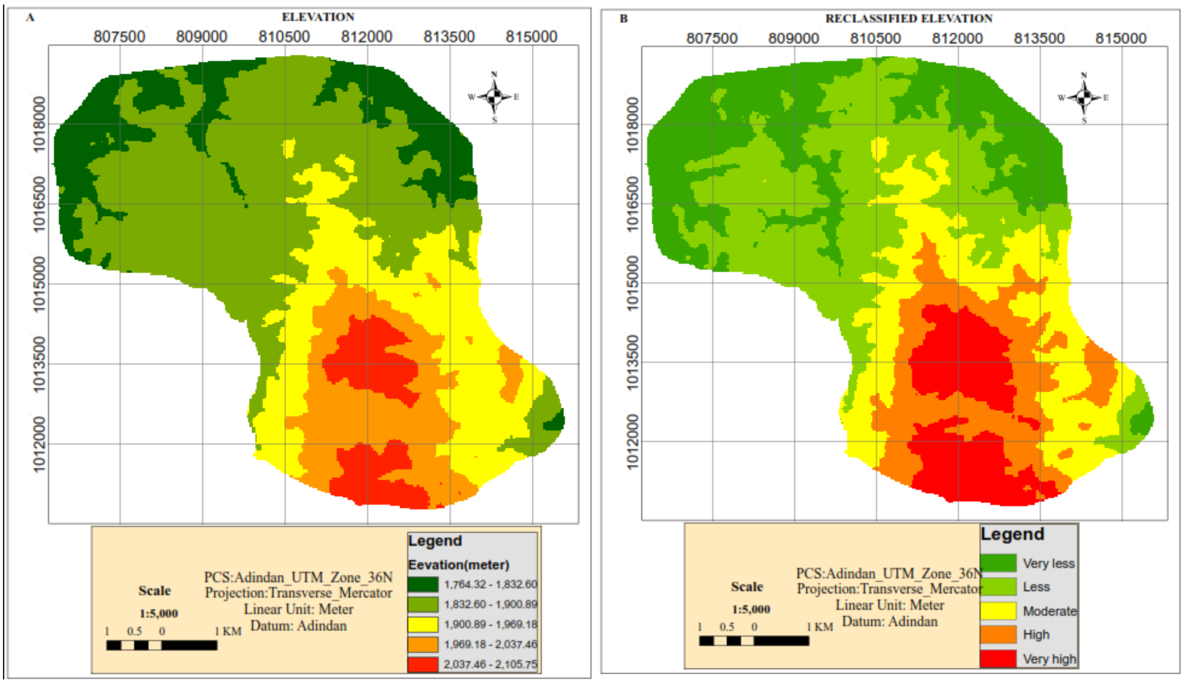


Figure 4.5 Standardized Elevation (A) and re-assigned in order of landslide susceptibility (B)

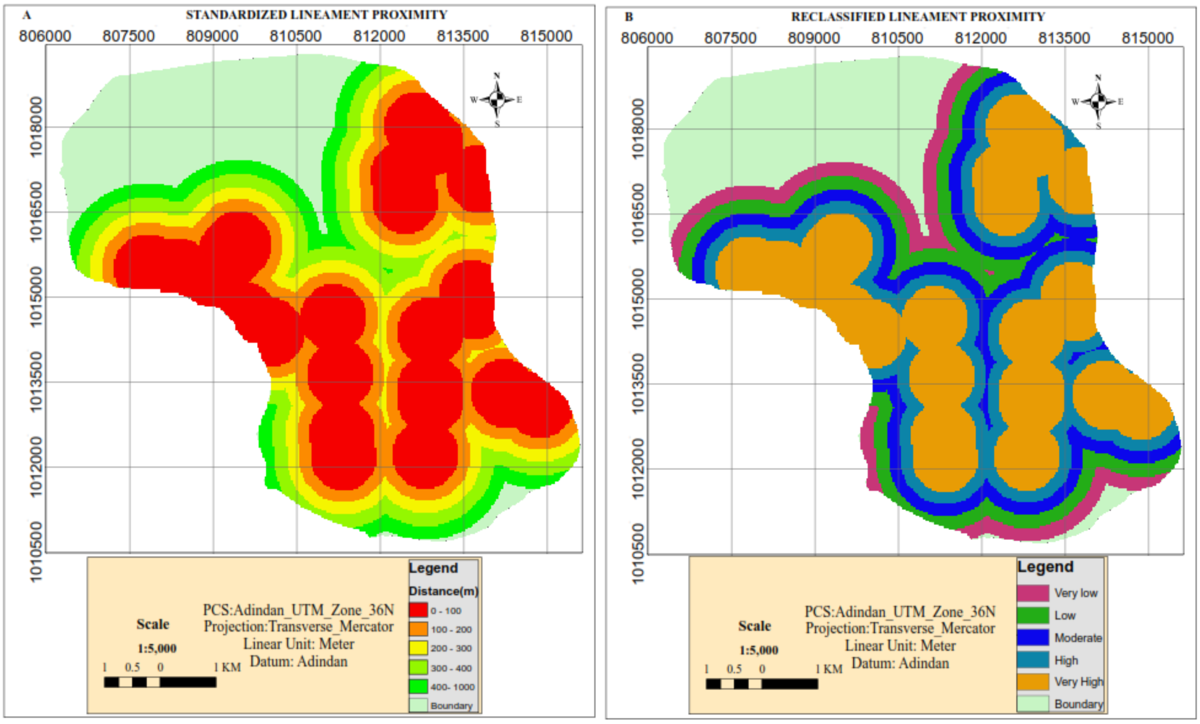


Figure 4.6 Lineament proximity (A) and re-assigned in order of landslide susceptibility (B)

4.1.2. 6 Lithology Factor

Geology of the Town was digitized from georeferenced Geological Survey of Ethiopia (GSE). Geology of the study consists of two lithotectonic units: Granitoid orthognesis unit and metagabbro-amphibolite unit (Fig. 4.7A). Rocks belonging to granitoid orthognesis unit mainly consist of granitic gneiss with subordinate granodiorite tonalite and diorite gneiss. This lithologic unit is Precambrian group/ Aba sena Domain, which is fine to medium grained, foliated and locally migmatized, while metagabbro-amphibolite lithologic unit is mafic-Ultramafic and Associated rocks group which is fine medium grained and sheared (GSE, 2000). This lithologic unit is highly susceptible to landslide occurrence where large areas in this unit were observed to be landslide prone. Accordingly, the lithologic unit was re-assigned with new values in their order of landslide susceptibility rating (Fig. 4.7B).

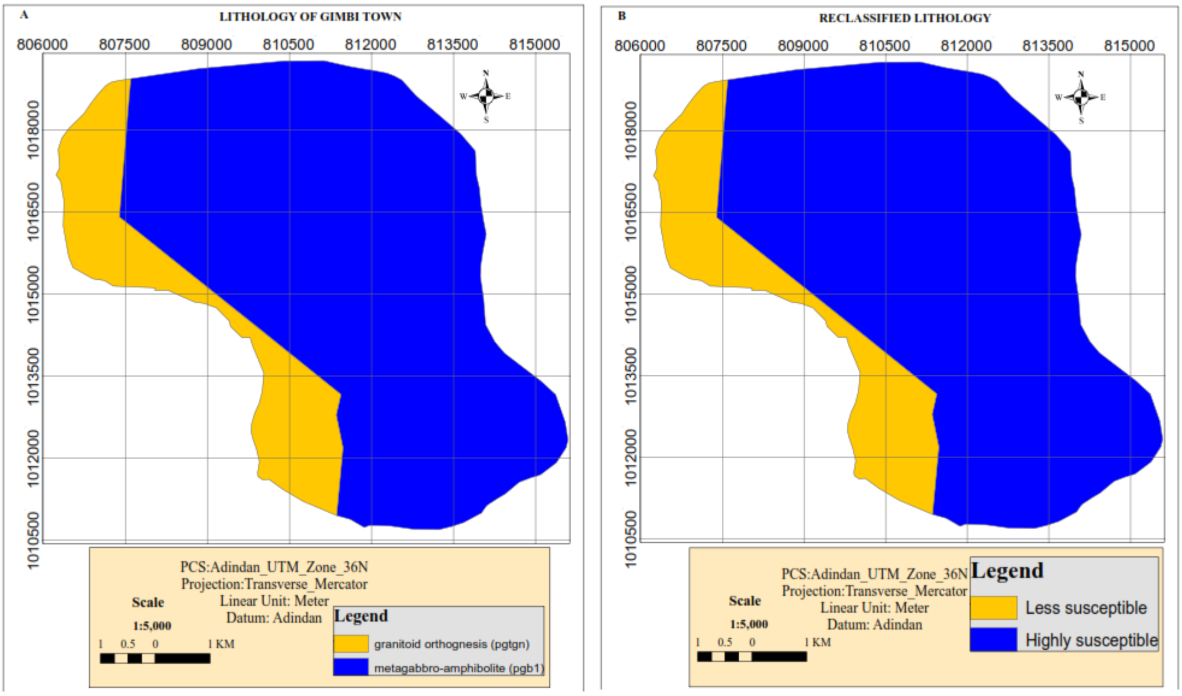


Figure 4.7 Lithology map (A) and assigned values for landslide susceptibility rating (B)

4.1.2. 7 Slope Factor

The standardized slope factor of the Town was derived from 65% of slope generated from the ASFDAAC elevations and 35% slope generated from the field using raster calculator in ArcGIS. The standardized slope raster layer was further reclassified in four sub group using standard classification schemes namely equal intervals. This classification scheme divides the range of attribute values into equalized sub ranges via manual methods thereby allowing us to specify the number of intervals while ArcMap determines where the breaks should be and new values were re-assigned in their order of landslide susceptibility ratings (Fig. 4.8).

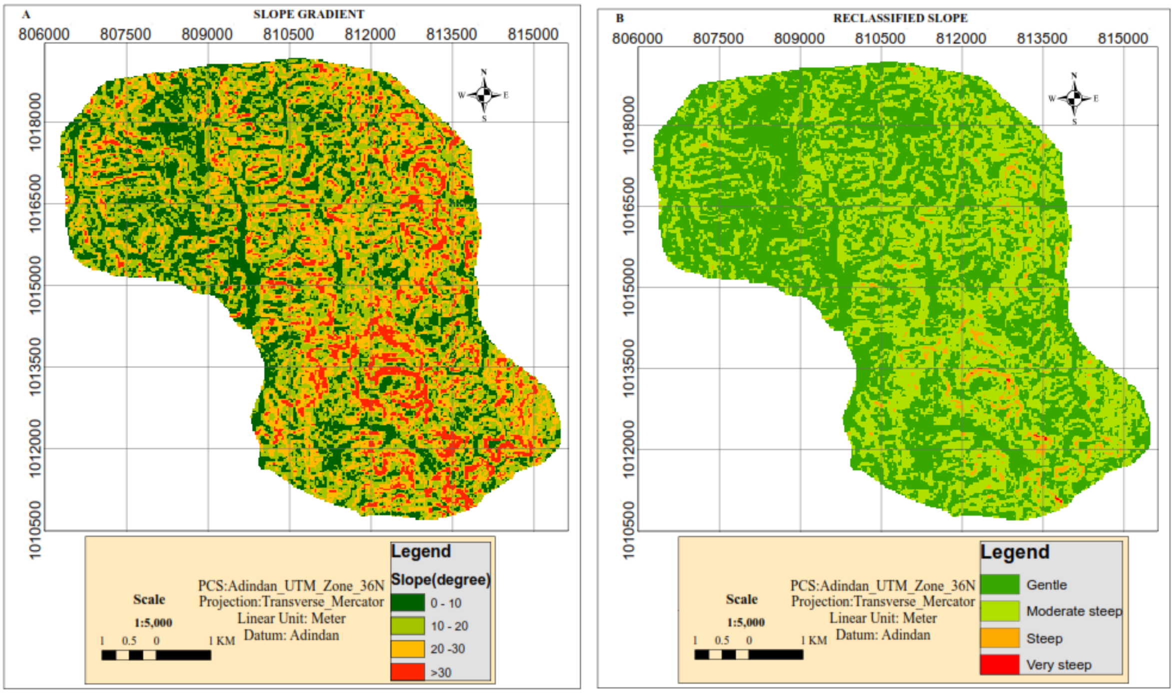


Figure 4.8 Standardized Slope (A) and re-assigned in order of landslide susceptibility (B)

4.1.2. 8 Soil Factor

Soils of the Town were clipped from Dhidhessa basin soil that were prepared by Oromia Water Works Design and Supervision Enterprise (OWWDSE). The soils of the study area were converted to raster data using polygon to raster conversion tool in GIS environment. There are four classes of soil texture in the Town (Fig. 4.10) and these classes were assigned according to their ranks based on their influence to landslide susceptibility (Table 4.1, figure 4.10B). Sandy soil has less moisture content, is less cohesive and more resistant than silt and clay soils but has high drainage potential. But in high rainfall areas, clay soils are more susceptible to landslides.

4.1.2. 9 Rainfall Factor

Annual Rainfall map of the Town was prepared from the interpolations of six rain gauge stations record in 2010. This rainfall factors was computed by IDW tools in ArcGIS environment. The Rainfall factor of the study was clipped from the six rain gauge stations interpolated by using extract by mask tool in ArcGIS. The rainfall raster layers of the study was further reclassified in three sub group using standard classification schemes namely equal intervals. This classification scheme divides the range of attribute values into equalized sub ranges by manual method allowing us to specify the number of intervals in Arc GIS that determines where the breaks should be and new values were re-assigned in their order of landslide hazard ratings (Fig. 4.9).

4.1.2. 10 Road Proximity Factor

The Road proximity of the Town was computed using Euclidean Distance tool in ArcGIS with 1km of maximum distance from the road. The Road proximity layer was further reclassified in five sub groups using standard classification scheme known as manual method and new values were re-assigned in their order of risk by landslide hazard ratings (Fig. 4.11).

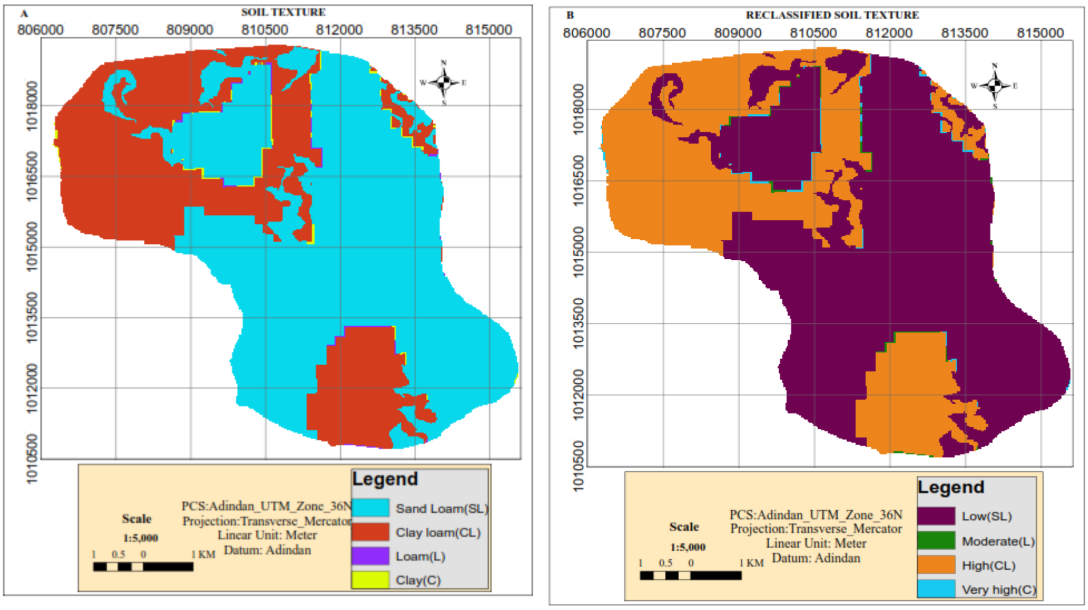


Figure 4.9 Soil texture (A) and re-assigned in order of landslide susceptibility (B)

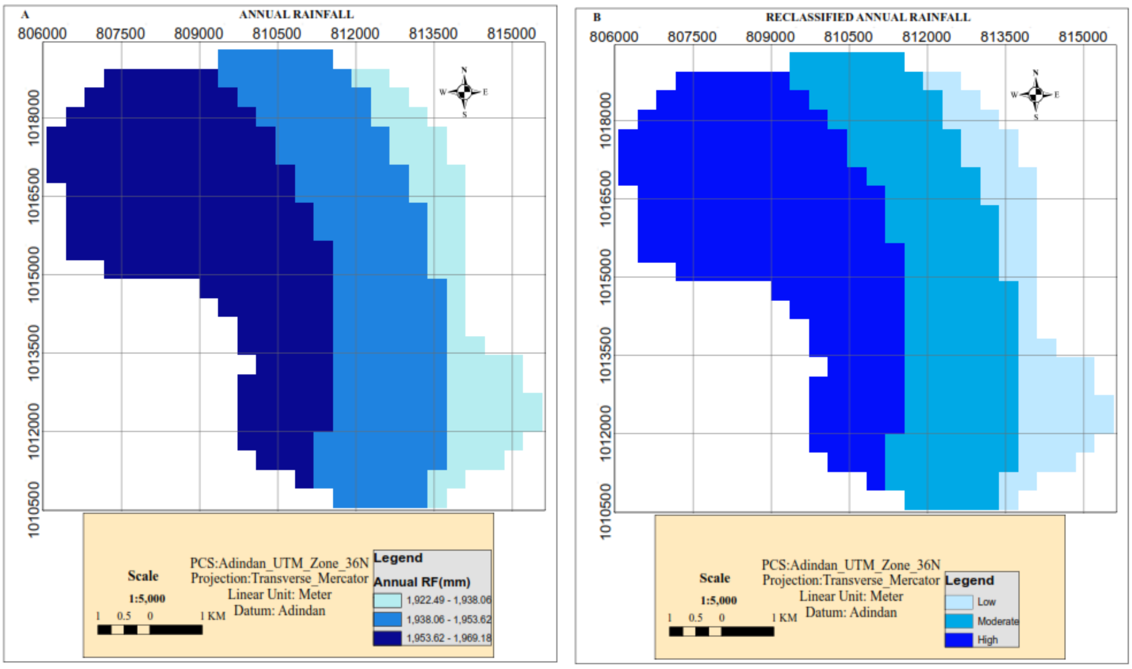


Figure 4.10 Annual rainfall map (A) and re-assigned in order of landslide hazard (B)

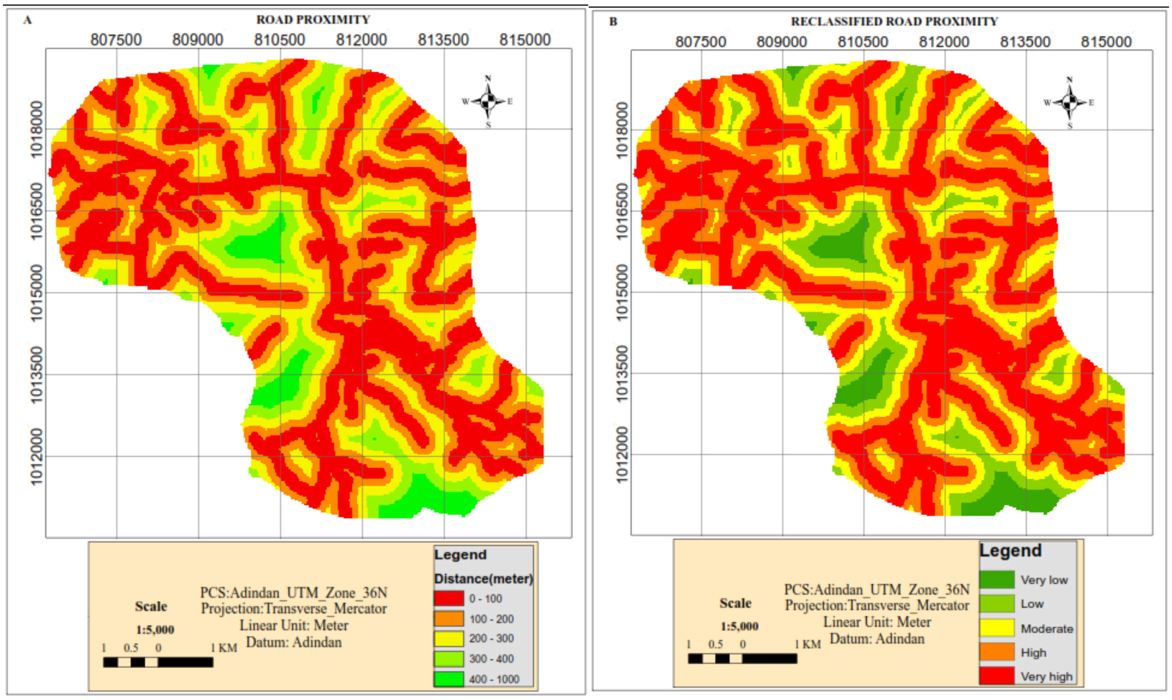


Figure 4.11 Road proximity classes (A) and re-assigned in order of distant at risk (B)

The first data analysis for generated landslide hazard zonation and risk of the Town was standardized factor analysis. So, data prepared before field and after field (annex15-18) were standardized by assigned weight using raster calculator in ArcGIS environment (Fig.4.12).

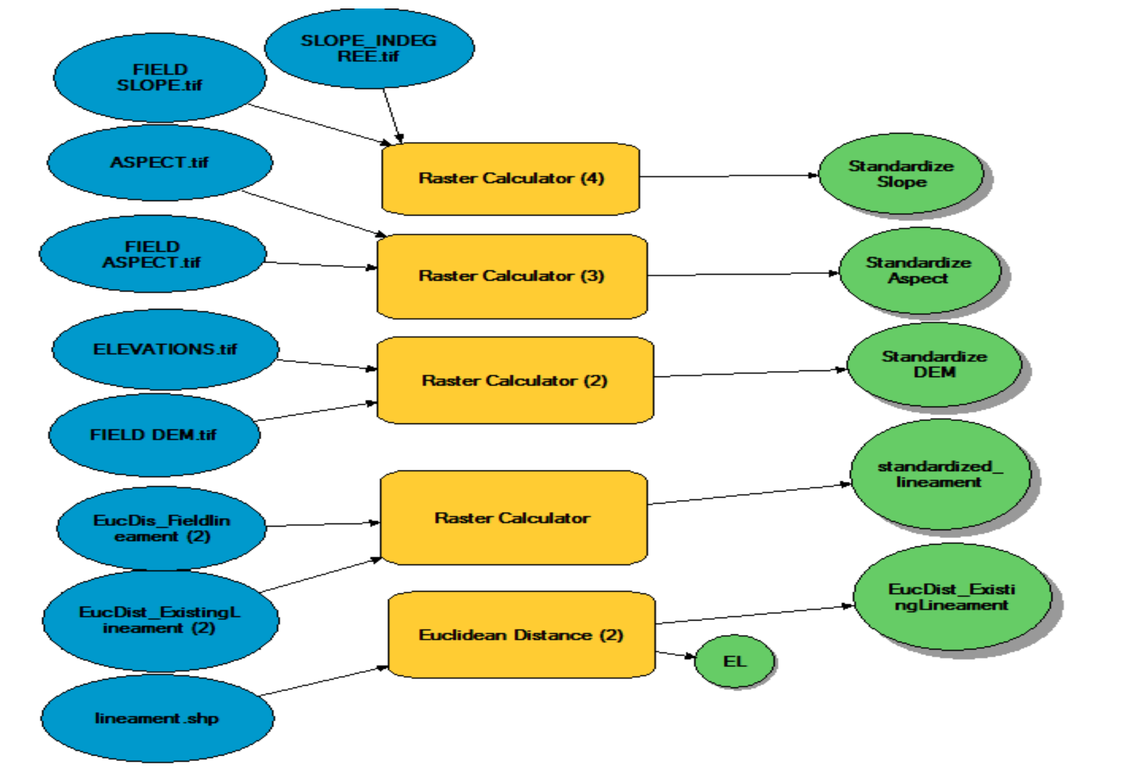


Figure 4.12 Standardized factors analysis model builder dialogue box

As shown Fig. 4.13 below landslide susceptibility zonation were produced from identified environmental factors using GIS based MCDA.

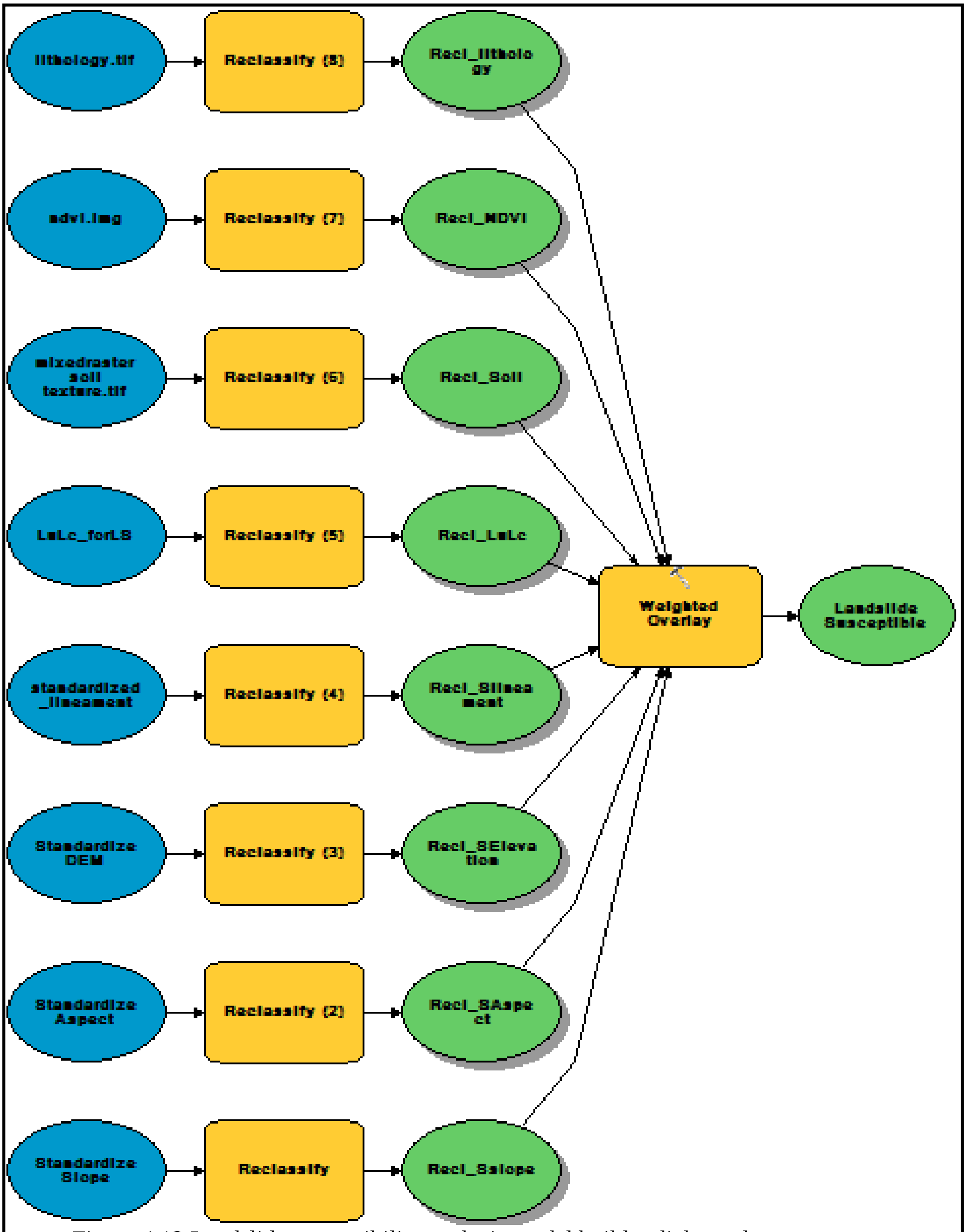


Figure 4.13 Landslide susceptibility analysis model builder dialogue box

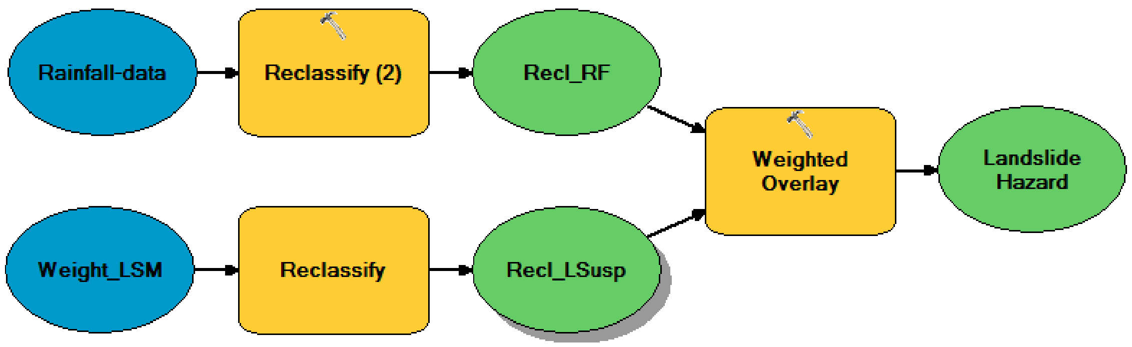


Figure 4.14 Landslide hazard analysis model builder dialogue box

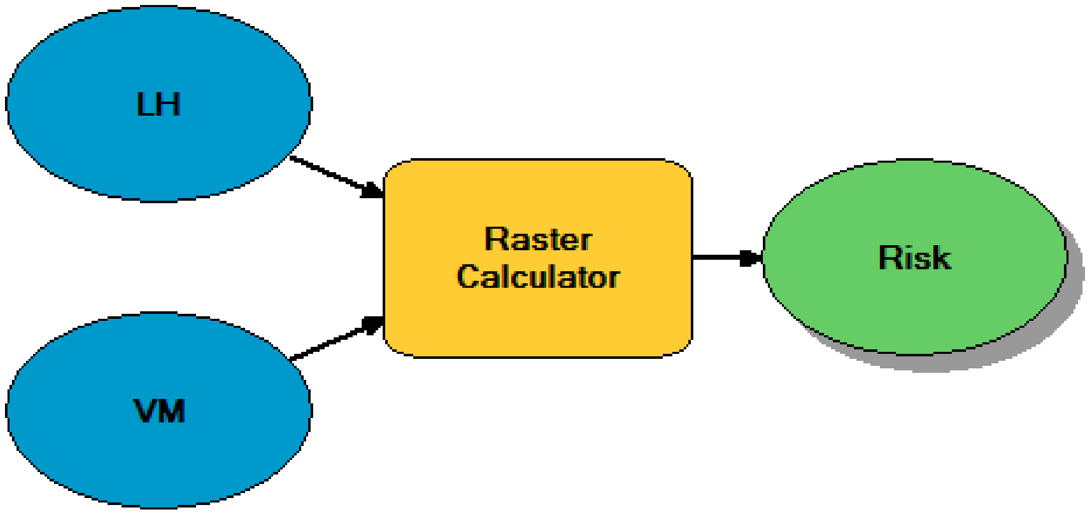


Figure 4.15 Landslide risk analysis model builder dialogue box

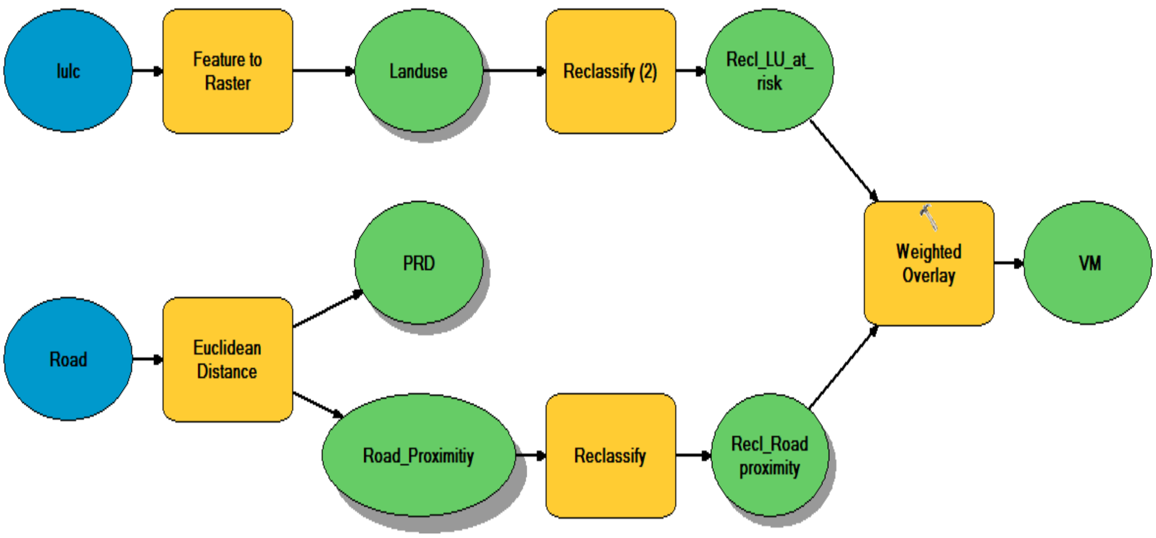


Figure 4.16 Vulnerability of element at risk analysis model builder dialogue box

4. 2 Results

4.2. 1 Landslide Susceptibility Analysis

A pairwise comparison matrix was then established using the prior knowledge of goodness-of-fit in order to assign weights before producing a landslide susceptibility map (Fig. 4.1). The standardized predictor variable values were combined with weights derived from AHP in order to evaluate the sensitivity of the landslide susceptibility map to different predictor variables. Landslide susceptibility analysis was computed by Weighted Overlay of lineament proximity, Normalized Difference Vegetation Index (NDVI), lithology, slope, slope aspect, soil texture, elevation, and land use developed factors by used 1 to 5 by 1 evaluation scale (Figure 4.13). From the landslide susceptibility map (Figure 4.17), it was estimated that 1.92, 14.09, 20.94, 9.61 and 0.36 km^2 of the area considered in Gimbi Town, were subjected respectively to very low, low, moderate, high and very high landslide susceptibility (Table 4.5). Moreover, this result was compared with ground truth data which shows that landslide inventories sites fall in low, moderate and high landslide susceptibility zones (Figure.4.17). Statistical analysis of these classes were also computed (annex 5).

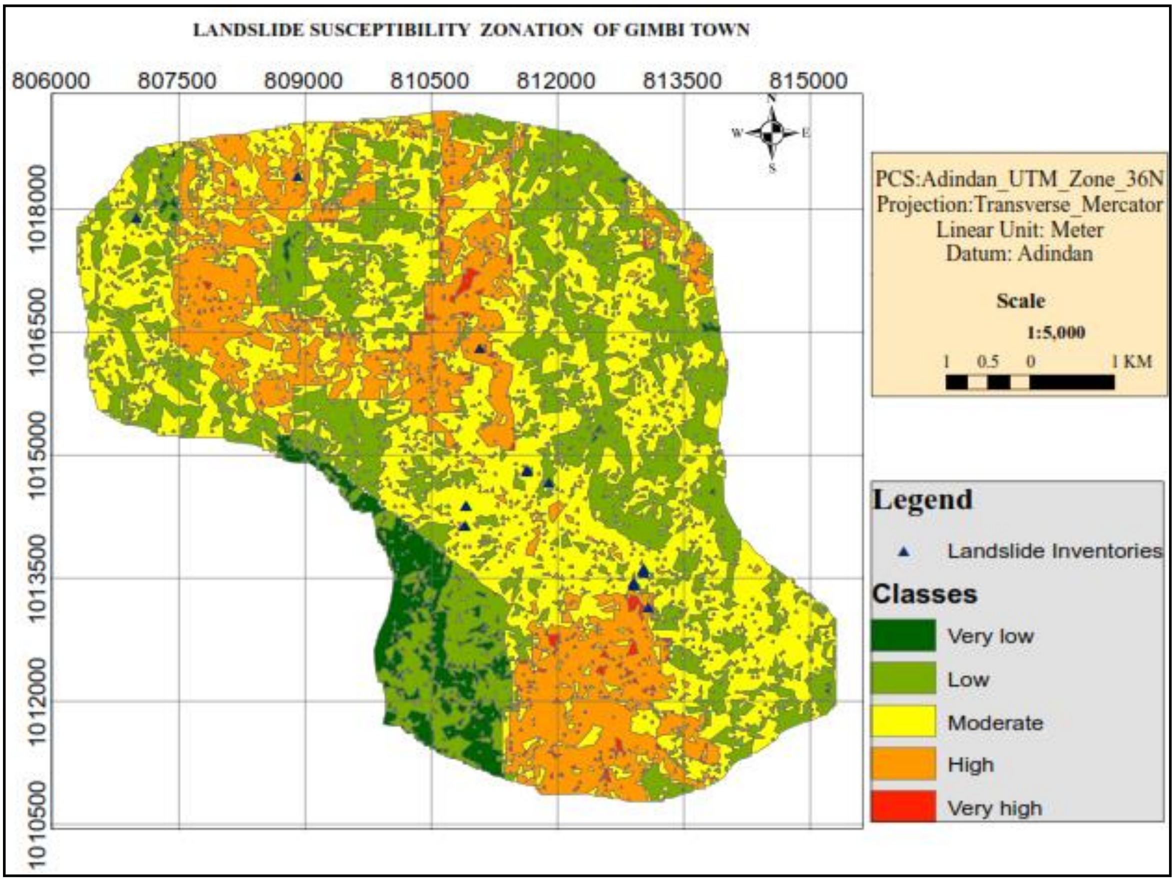


Figure 4.17 Landslide susceptibility analysis map of Gimbi Town

Generally, the landslide susceptibility map (LSM) of the study area was computed from equation 4.5 as follows:

LS = 0.4034*Recllithology + 0.21431*Reclsoil +0.1424*Reclslope + 0.0706*ReclLU+ 0.06*Recllineament + 0.0333*Reclelevation + 0.0296*Reclaspect +0.0166*NDVI...Eq.4.5

Table 4.5 Area tabulation of landslide susceptibility map of Gimbi Town

Classes	Landslide susceptibility rank	Area in km^2	Percentage (%)
1	Very low susceptible	1.92	4.09
2	Low susceptible	14.09	30.03
3	Moderate susceptible	20.94	44.63
4	Highly susceptible	9.61	20.48
5	Very high susceptible	0.36	0.77
Total		**46.92**	**100**

4.2. 2 Landslide Hazard Analysis

Landslide susceptibility and hazard are different in that hazard include the likelihood of the occurrence of a landslide where the triggering variables are considered while susceptibility map doesn't include the triggering variables (Ramli et al., 2010). Accordingly, Landslide hazard analysis was computed by Weighted Overlay setting of equal importance of landslide susceptibility map and rainfall triggering factor by using 1 to 5 by 1 evaluation scale (Fig. 4.14). From the landslide hazard map (Fig. 4.18), it was estimated that 2.87, 10.01, 15.24, 13.60 and 4.83 km^2 of the area considered in Gimbi Town, were subjected respectively to very low, low, moderate, high and very high landslide hazard (Table 4.6). Moreover, this result was compared with ground truth data which shows that landslide inventories sites fall in less to very high landslide hazard zonation (Fig.4.18). The statistical properties of each zonation were computed (annex 6).

Table 4. 6 Area tabulation of landslide hazard map of Gimbi Town

Classes	Landslide hazard rank	Area in km^2	Percentage (%)
1	Very low hazard	2.87	6.17
2	Low hazard	10.01	21.50
3	Moderate hazard	15.24	32.73
4	High hazard	13.60	29.22
5	Very high hazard	4.83	10.38
Total		**46.55**	**100**

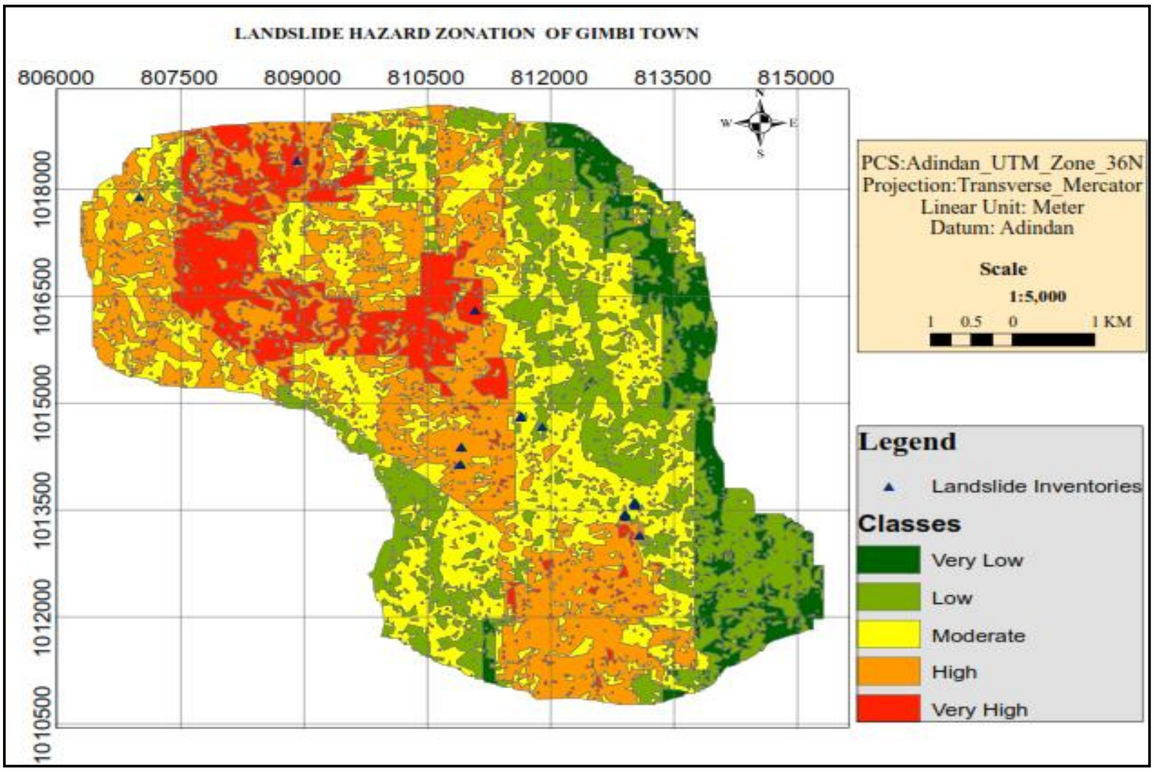


Figure 4.18: Landslide hazard analysis of Gimbi Town

4.2. 3 Vulnerability of Elements at Risk Analysis

Vulnerability of elements at risk analysis was computed by weighted overlay through setting equal importance of factors like land use at risk and road proximity (Table 4.3) by using 1 to 5 evaluation scale (Fig. 4.16). According to vulnerability of elements at risk map (Fig. 4.21), it was estimated that 5.19, 7.19, 12.06, 16.18 and 8.26 km^2 of the area considered in Gimbi Town, were subjected respectively to very low, low, moderate, high and very high vulnerability of elements at risk (Table 4.7). Moreover, this result was compared with ground truth data which shows that landslide inventory sites fall in very low, moderate, high and very high vulnerability of elements at risk zonation (Fig.4.19). Although statistical properties like minimum value, maximum value, range, standard deviation, summation value of each vulnerability classes were calculated (annex 7).

Table 4.7 Area tabulation of vulnerability map

Classes/rank	Vulnerability rank	Area in km^2	Percentage (%)
1	Very low vulnerable	5.19	10.62
2	Low vulnerable	7.19	14.71
3	Moderate vulnerable	12.06	24.67
4	High vulnerable	16.18	33.10
5	Very high vulnerable	8.26	16.90
Total		**48.88**	**100**

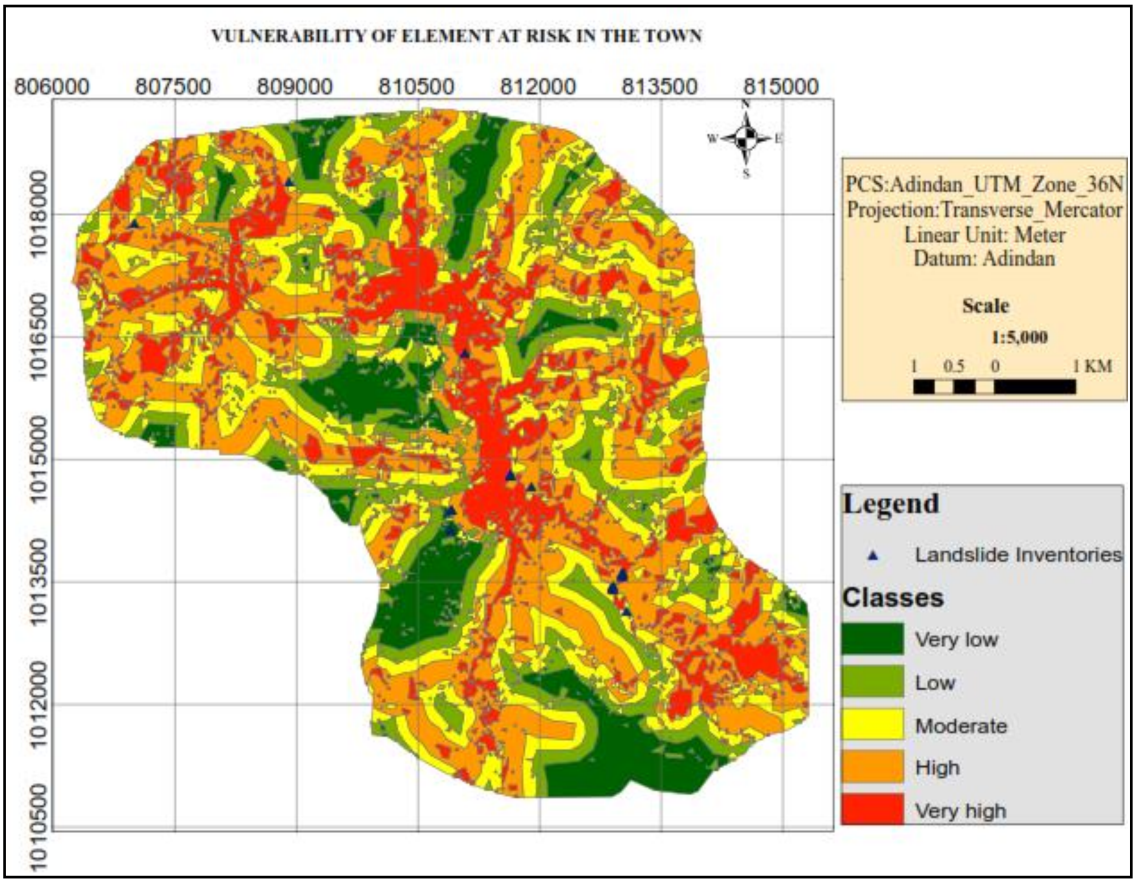


Figure 4.19 Vulnerability map of element at risk of Gimbi Town

4.2. 4 Landslide Risk Analysis

Landslide risk were produced from result of landslide hazard and Vulnerability of element at risk using product operates by raster calculator tool (Fig. 4.15). According to the landslide risk map (Fig 4.20), it was estimated that 9.11, 16.28, 11.77, 8.03 and 1.20km^2 of the area considered in Gimbi Town were subjected respectively to very low, low, moderate, high and very high landslide risk (Table 4.8). The statistical analysis of each classes were considered (Annex 8). All these risk zonations are in line with landslide inventories map that were produced by field observation.

Table 4.8 Area tabulations of landslide risk map of Gimbi Town

Classes	Landslide risk rank	Area in km^2	Percentage (%)
1	Very low risk	9.11	19.64
2	Low risk	16.28	35.09
3	Moderate risk	11.77	25.37
4	High risk	8.03	17.31
5	Very high risk	1.20	2.59
Total		**46.39**	**100**

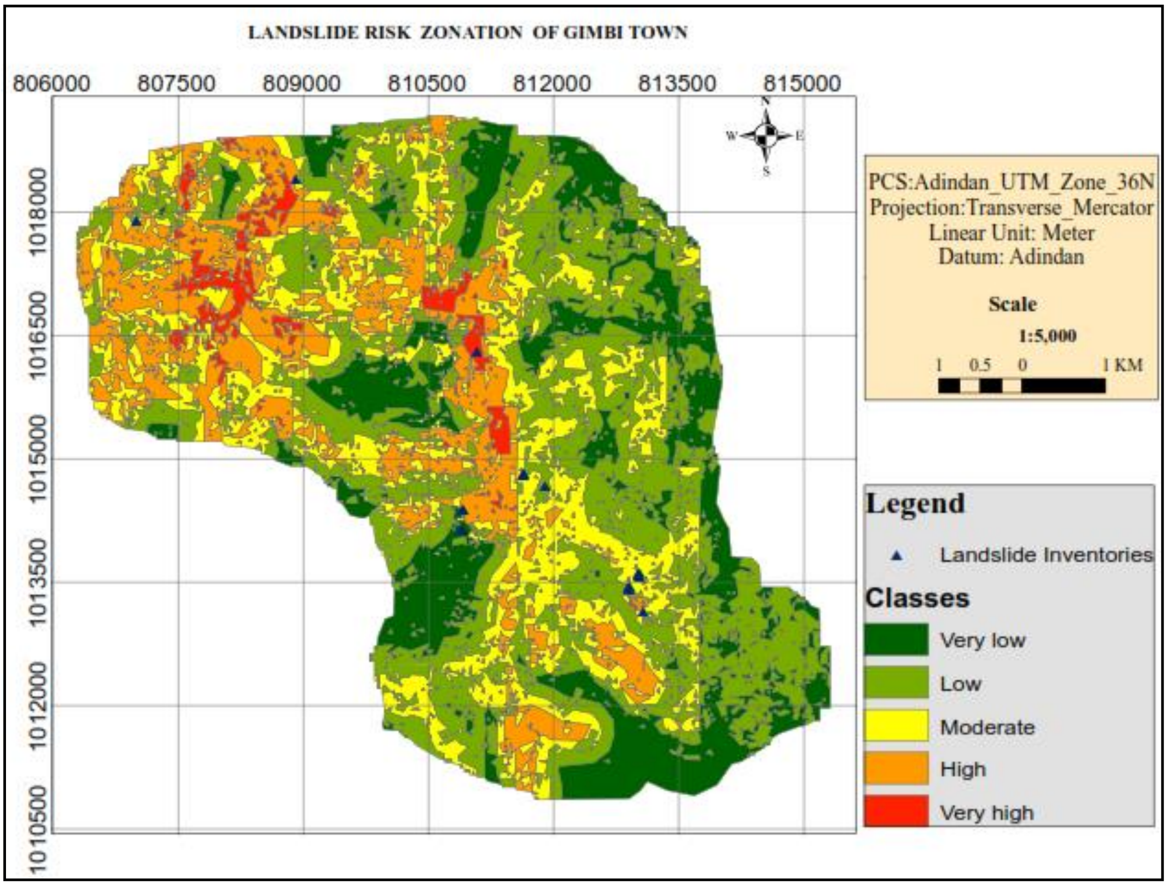


Figure 4.20 Landslide risk analysis map of Gimbi Town

4.2. 5 Validation Map

For validating landslide susceptibility , landslide hazard, vulnerability of elements at risk, and landslide risk map of Gimbi Town, nineteen Event-based landslide inventories point were collected with spatial information related to the information(as point) combined with attribute information are used. The validated landslide susceptibility zonation, landslide hazard zonation, vulnerability of elements at risk zonation and landslide risk zonation were computed by zonal statistical analysis through using raster format of event-based landslide inventories layer. The computed statistical analysis of validated landslide susceptibility map, landslide hazard map, vulnerability of elements at risk map, and landslide risk map were summarized as shown in Annex 9, annex 10, annex 11, and annex 12 respectively. The percentage of landslide inventories that overlaid with the zone of landslide susceptibility, hazard, risk, and Vulnerability of element at risk were calculated. As shown in fig. 4.21 to 4.24, the percentage sum of very low, low class were considered as disagree statistical level of argument and summation of moderate, high and very high zones were agree statistical level of argument.

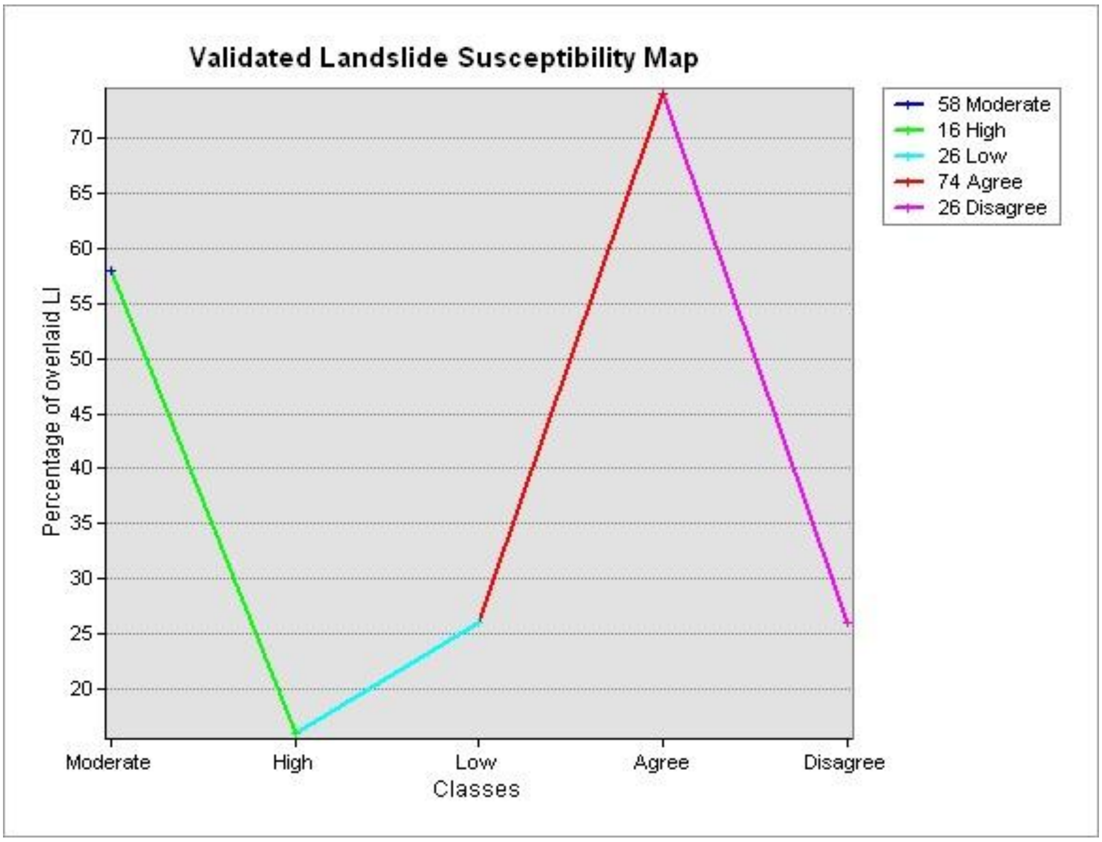


Figure 4.21 Validation of Landslide Susceptibility Map

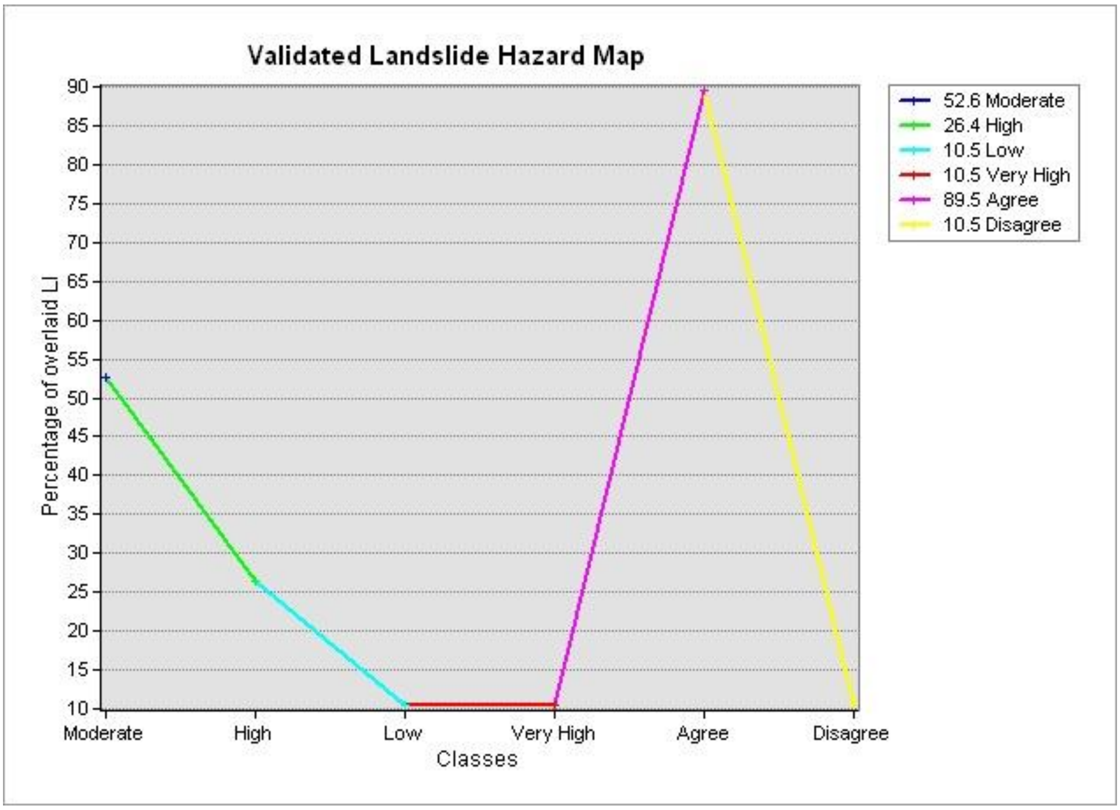


Figure 4.22 Validation of Landslide Hazard Map

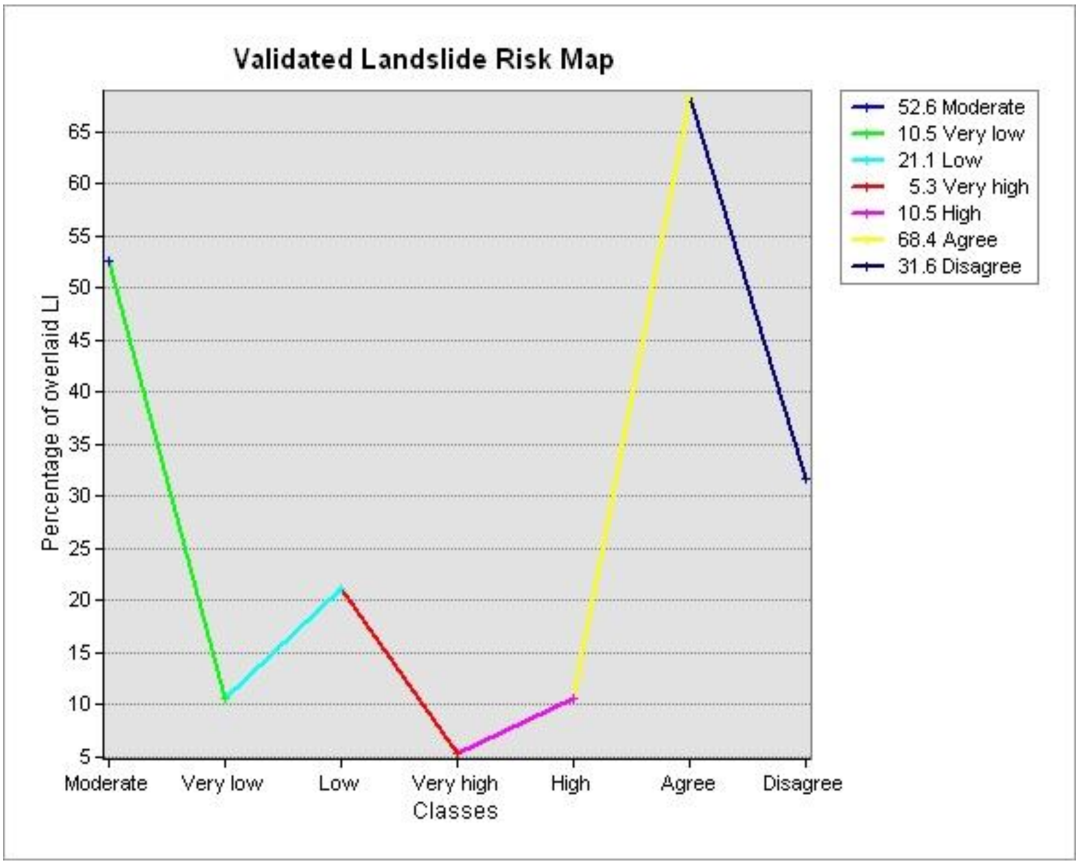


Figure 4.24 Validation of Landslide Risk Map

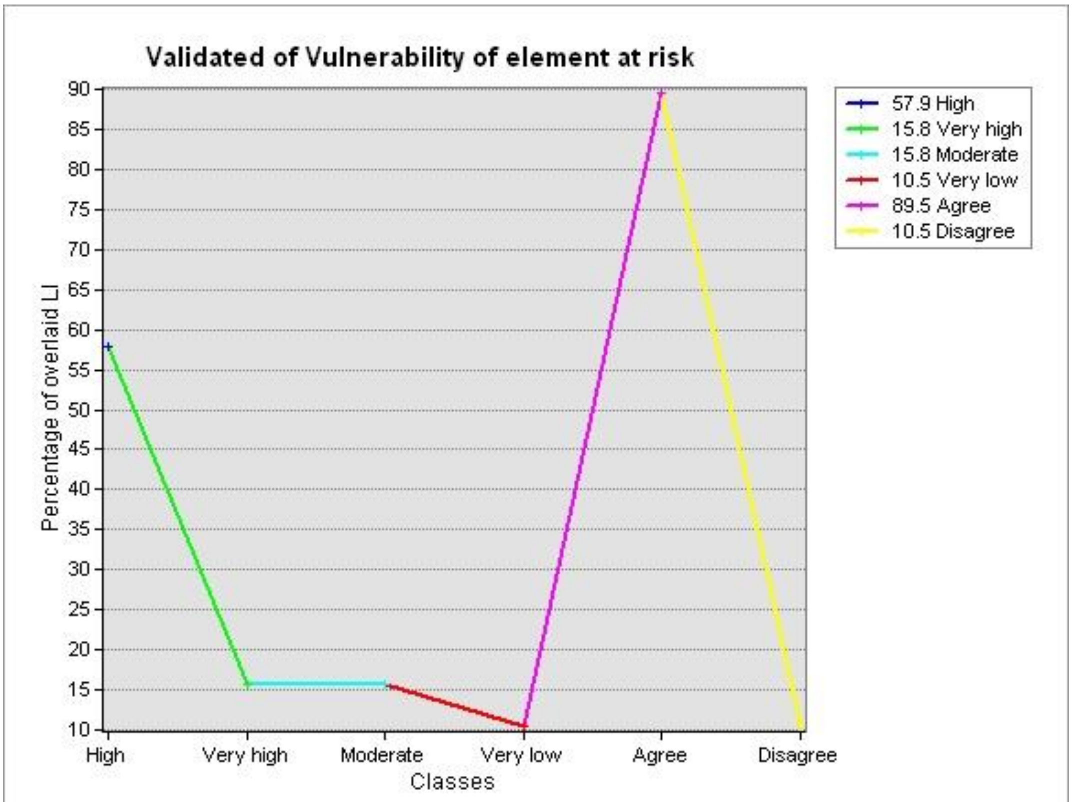


Figure 4.23 Validation of Vulnerability map of element at risk

4. 3 Discussions

4.3. 1 Landslide Hazard Analysis

Landslide susceptibility zonation was produced from eight identified factors, and these data constituted the base of the risk mapping studies. A landslide susceptibility model was created by using Multi-Criteria Decision Analysis, which reflects the relative spatial probability of landslide occurrence. The standardized predictor variable values were aggregated with weights derived from Analytical Hierarchy Process (AHP) in order to evaluate the sensitivity of the landslide susceptibility map to different predictor variables. The analysis indicated that 4.09% of very low susceptible, 30.03% of low susceptible, 44.63% of moderate susceptible, 20.48% of high susceptible, and 0.77% of very high susceptible. To test the predictive capability of this result, an assessment was carried out by comparing the susceptibility map with the existing landslides inventories. Out of nineteen event based landslide records point 26%, 58%, and 16% falls in to low, moderate, and high respectively (Annex 9, Fig. 4.21).

The transformation of landslide susceptibility map into a hazard map requires consideration of landslide triggering parameters (Akgun et al., 2012). This empirical relation was used to map landslide hazard zonation of Gimbi Town. For this purpose, landslide data was used which helps to prepare landslide susceptibility index map, rainfall threshold and landslide hazard zonation. For the purpose of easy visual interpretation, landslide hazard zonation map were classified into five classes (Fig.4.20). Based on this hazard map, 6.17% of the total area is found to have a very low. Low, medium and high hazard zones which constitute 21.5%, 32.73% and 29.22% of the area, respectively. The very high hazard area is 10.38% of the total study area. The comparison of landslide hazard zonation map with landslide inventories shows satisfactory results as 10.5%, 52.6%, 26.2% and 10.5% of the landslides fall in low, moderate, high and very high hazard zones respectively. No landslide event was observed in the very low hazard zone. Overall, the case of the hazard analysis showed that 89.5% of landslide inventories falls in moderate, high and very high hazard zones (Annex 10, Fig. 4.22). As Chimdi et al., (2017) studied on landslide hazard zonation of Gimbi Town and its environment, 36.5% of the area falls in high and very high hazard zonation while in current studied 39.6% falls in high and very high hazard. Therefore, GIS based MCDA techniques is recommended method to map landslide hazard zonation.

4.3. 2 Landslide Risk Assessment

When attempting to assess landslide risk, vulnerability to landslides is often considered as equivalent to complete loss of the assets or total destruction of the elements at risk, for all landslides and landslide types and for all assets or elements at risk in an investigated area (Akgun et al., 2012). In the study area, element at risk due to landslides hazard were identified as: buildings, transportation networks, and agricultural activities. Due to a lack of required information about the direct loss inventory for the study area, all the built up area were evaluated as elements at risk data. The vulnerability of elements at risk or exposure factor was estimated by the combination of land use (buildings, agriculture activities, and road network) data layer. Based on the computed vulnerability of element at risk values, vulnerability of element at risk classes were defined as: very low vulnerability (10.62%), low vulnerability (14.71%), moderate vulnerability (24.67%), high vulnerability (33.10%), and very high vulnerability (16.90%). When existing landslide inventories are overlaid with vulnerability of elements at risk map, 10.5%, 15.8%, 57.9% and 15.6% of them fall in the very low, low, moderate, high and very high vulnerability classes respectively. However, no landslide inventory was overlaid in the very low vulnerability class.

Qualitative (heuristic) landslide risk assessment was computed from product of landslide hazard and vulnerability of elements at risk maps. To aid visual interpretation, the produced risk index map was divided into five categorical risk areas. Thus, the landslide risk classes were clearly identified. When classifying the landslide risk index into categorical classes, a standard deviation method was applied. These were notably divided into very low, low, moderate, high and very high risk zones (Fig. 4.20). According to this risk map, 19.64% (9.11 km^2) of the element at risk areas is very low risk and the low-, moderate- and high-risk zones form 35.09% (16.28 km^2), 25.37% (11.77 km^2) and 17.31% (8.03 km^2) of the element at risk areas, respectively. About 2.59% (1.20 km^2) of the element at risk areas is estimated to be very high risk. According to landslide risk analysis indicated, 68.4% of landslide inventories points falls in moderate, high and very high risk zones. These results build on existing evidence of qualitative risk assessment methods, which are mostly based on integrating a hazard index, and a vulnerability index, using Spatial Multi Criteria Evaluation. Landslide risk assessment of this research comprises scope (range) definition including statistical analysis and area coverage, hazard identification and vulnerability of element at risk evaluation.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5. 1 Conclusion

This research aimed to identify the relevant factors and the methods of mapping landslide hazard and risk assessment. So that, eight environmental factors, and one triggering factor were identified. In addition, two elements at risk maps were also used in this analysis. Based on determined environmental factors landslide susceptibility zonation was produced using Geographical Information System (GIS) based on Multi-Criteria Decision Analysis (MCDA) techniques. The combination of landslide susceptibility zonation map and triggering factor helped to prepare landslide hazard zonation map. The two elements at risk were used to map vulnerability of elements at risk. The landslide risk map was produced from the product of landslide hazard map and vulnerability of elements at risk map.

The verification procedure proved that the produced landslide hazard and risk maps are realistic and acceptable, which may be used for land use, urban planning and management in the study area. Although the MCDA methodology results vary depending on the subjective knowledge of experts, in cases where the quality of the available data is high, and the weighting and rating factors are set correctly the results can be satisfactory. So that, high quality data and determination of suitable parameters for the assessment of landslide risk of a region are very important. In this study field geotechnical data and laboratory test of soil type were not available.

Moreover, the risk assessment is a more dynamic process when compared with the susceptibility or hazard assessments because the risk values and the elements at risks can be changed depending on urban development, infrastructure construction etc. In addition, it is possible that the necessary data for the landslide risk assessments can be collected by simple and applicable methods if the technological facilitates are used. As a final conclusion, the landslide risk assessment tools can be designed as dynamic systems. This idea can be realized because the developments in computer and GIS technologies provide these facilities.

5. 2 Recommendation

This research provides information on landslide susceptibility, landslide hazard and landslide risk at a Town level that could be used by the relevant decision makers to act upon the current land use policy for reducing vulnerability to landslide hazard in Gimbi Town. Thus the responsible bodies of Gimbi Town Administrative Council and land use planners should incorporate the landslide hazard and landslide risk maps in the currently ongoing activities related to landslide disaster, as one of the short term intervention in the Town.

Based on the current study following recommendations are forwarded; the effects of landslides on people and structures can be minimized by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity, develop appropriate policies in consultation with the local people and encourage their participation in an alternative mitigation strategy

A quantitative landslide hazard and risk assessment of the study includes: temporal probability; the probability that a given triggering event will cause landslides, size/volume probability; probability that the slide has a given size/volume/intensity, runout probability; probability that the slide will reach a certain distance downslope as well as Risk estimations like frequency analysis, consequence analysis and their integrations is recommended for further study.

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APPENDIXES

Annex 1 Selected points for field observation and field observation feedback

		Preliminary sample Point generated			Field observations points				
No	Classes	X in m	Y in m	Z in m	X in m	Y in m	Z in m	Code	Description
1	High priority	**811278.4624**	**1012345.949**	**1982**	**811356**	**1012555**	**1994**	**HFP1**	Agriculture area almost near to lineament and bareland, less susceptible to landslide
2		812642.091	1012853.781	2038	812722	1013068	2044	HFP2	Shrubland ,less susceptible to landslide
3		812914.8156	1012599.865	2028	812993	1012810	2023	HFP3	Aggriculture area and very less susceptible to landslide
4		811005.7439	1011330.285	1998	811083	1011542	1995	HFP4	Shrubland and very less susceptiblity of landslide
5		809914.8457	1012345.949	1874	812175	1012049	2015	HFP5	Shrubland and less susceptiblity of landslide
6		811823.9175	1011838.117	2018	811900	1012050	2039	HFP6	Shrubland , near to lineament and highly susceptibility of landslide
7		815369.3363	1012092.033	1827	815447	1012301	1831	HFP7	Bareland near to agriculture area and easy to susceptible by landslide
8		809096.6722	1015139.024	1875	809174	1015349	1882	HFP8	Bareland area and highly runoff sedimentation happened and easily susceptible
9		808823.9476	1015139.024	1861	808901	1015348	1867	HFP9	Bareland area near to lineament and agriculture area
10	Medium priority	**814551.1627**	**1011838.117**	**1865**	**814629**	**1012050**	**1895**	**MFP1**	Aggriculture area near to lineament and shrubland easy to susceptible
11		814278.4382	1011838.117	1923	814356	1012045	1931	MFP2	Aggriculture area near to lineament and easy to susceptible
12		815096.6118	1012092.033	1829	815175	1012302	1846	MFP3	Shrubland and very less susceptiblity of landslide
13		811823.9175	1010822.453	2055	811901	1011031	2065	MFP4	Bareland high probability of landslide,and near lineament
14		812096.642	1011838.117	1999	812172	1012051	2014	MFP5	Aggriculture area and is not at risk
15		813460.2646	1016916.436	1779	813538	1017127	1804	MFP6	Shrub and bareland mixed, near lineament and moderately susceptiblity of landslide
16		813732.989159	1017424.268	1810	813743	1017811	1835	MFP7	Bareland and highly susceptiblity of landslide may occur
17		806914.8759	1016916.436	1844	806993	1017126	1846	MFP8	Bareland area near to agriculture area
18		806642.1514	1016916.436	1801	806719	1017126	1812	MFP9	one side asphalt other side shrubland and very less susceptible
19		806914.8759	1015900.772	1849	806992	1016110	1850	MFP10	Near to foot path road and lineament and less vulnerable to landslide
20		814005.7137	1012853.781	1940	814084	1013065	1932	MFP11	Wetland/ agriculture area land corn area
21		814005.7137	1012345.949	1923	814083	1012559	1927	MFP12	Bareland and very highly susceptible to landslide
22		814551.1627	1013107.697	2007	814628	1013316	1997	MFP13	Bareland and very highly vulnerable to landslide
23		813732.9892	1012599.865	1941	813810	1012810	1949	MFP14	Settlement/ built up area no landslide thus why is not at risk
24		814551.1627	1012599.865	1984	814629	1012811	1977	MFP15	Bareland and erroded area, it may very highly susceptibility of landslide
25		812369.3665	1014631.192	1941	812447	1014847	1934	MFP16	Bareland near to lineament and very highly susceptible
26	Low Priority	**811551.1929**	**1014377.276**	**2024**	**811629**	**1014599**	**2017**	**LFP1**	Settlement/ built up area and less vulnerability but very highly elevated
27		811551.1929	1014885.108	1949	811629	1015096	1974	LFP2	Settlement/ built up area, near to foot path very less vulnerable
28		811551.1929	1015139.024	1949	811628	1015349	1958	LFP3	Settlement/built up area and very vulnerable and moderately elevated
29		811551.1929	1013615..52842	2061	811545	1015602	1965	LFP4	Road/foot path/ built up area and higly elevated
30		811823.9175	1013361.612	2076	811900	1013574	2105	LFP5	Agriculture area near to lineament and very highly elevated as well as highly susceptible
31		812096.642	1014631.192	1952	812173	1014873	1964	LFP6	Road/foot path/ built up area while less vulnerability and moderately elevated
32		811278.4684	1016408.604	1898	811354	1016625	1911	LFP7	Settlement area and less vulnerablity but moderately elevated
33		811551.1929	1017170.352	1895	811625	1017404	1904	LFP8	Built up area, agriculture area, low NDVI
34		810460.2948	1017170.352	1914	810534	1017387	1905	LFP9	Bareland, near built up area and moderately elevated as well as easy to vulnerable
35		809642.1212	1016916.436	1850	809718	1017130	1848	LFP10	Aggriculture area near to foot path & lineament less elevated but moderately susceptible
36		809369.3967	1016916.436	1834	809446	1017127	1840	LFP11	Aggriculture area and less vulnerable
37		809096.6722	1016916.672	1885	809175	1017126	1871	LFP12	Shrubland and very less susceptiblity of landslide
38		807187.6005	1017170.352	1855	807264	1017380	1846	LFP13	Shrubland and less elevated as well as less susceptibility
39		808005.774	1016154.688	1842	808083	1016370	1875	LFP14	Built up area, foot path, and very less susceptible
40		811823.9175	1018439.931	1810	811901	1018653	1831	LFP15	Bareland and highly susceptiblity of landslide and soil erroded
41		811823.9175	1018693.847	1807	811900	1018904	1811	LFP16	Shrubland area, near to bareland less to susceptible
42		809642.1212	1017170.352	1829	809718	1017384	1846	LFP17	Bareland, foot path, near to shrubland & very highly susceptible as well as degraded area
43		806642.1514	1017424.268	1798	806720	1017633	1807	LFP18	Aggriculture after cultivated thus may call as bareland & easily susceptible & erroded
44		807460.325	1016916.436	1851	807544	1017121	1846	LFP19	Lineament belongs to shrubland thus highly vulnerable
45		810460.2948	1018947.763	1859	810537	1019161	1851	LFP20	Shrubland and less elevated as well as less susceptibility
46		809369.3967	1017932.099	1830	809445	1018145	1840	LFP21	Shrubland but highly bareland area and easy to susceptible and degraded
47		808823.9476	1018186.015	1855	808909	1018390	1854	LFP22	Bareland area and very highly susceptible of landslide prone area
48		808005.774	1017424.268	1832	808091	1017628	1849	LFP23	Lowest shrubland with highly bareland and easliy susceptible to landslide
49		807460.325	1017678.183	1814	807537	1017890	1812	LFP24	Bareland and near lineament very highly susceptible at lowest elevated
50		806914.8759	1017678.183	1821	806992	1017889	1803	LFP25	Near to lineament and very highly susceptibleof landslide prone area

Source: Collected and organized by Researcher (Me)

Annex 2 Locations of existing landslide inventories

	Existing Landslide Inventories				
Code	X	Y	Z	located name	Risk element
LI1	810907	1014391	1955	Taba laga	Foot path
LI1	810905	1014383	1954	Taba laga	Foot path
LI2	810900	1014137	1944	Aba sangi	Asphalt road
LI2	810895	1014147	1942	Aba sangi	Asphalt road
LI3	813015	1013586	1983	Sarxe	Asphalt road
LI3	813016	1013563	1980	Sarxe	Asphalt road
LI3	813013	1013603	1978	Sarxe	Asphalt road
LI3	813029	1013601	1976	Sarxe	Asphalt road
LI4	812900	1013414	1982	Sarxe area	Asphalt road
LI4	812899	1013445	1985	Sarxe area	Asphalt road
LI4	812897	1013435	1984	Sarxe area	Asphalt road
LI5	811630	1014799	1956	Masgidi/02 kebele	House/settlement
LI5	811634	1014801	1945	Masgidi/02 kebele	House/settlement
LI5	811633	1014817	1957	Masgidi/02 kebele	House/settlement
LI6	811072	1016295	1934	Gotira	house and asphalt road
LI7	808909	1018390	1854	Not named	Aggriculture area
LI8	813071	1013145	1975	kella area	Asphalt road
LI9	811891	1014662	1942	laga gaba	House/settlement
LI10	806992	1017889	1803	Not named	settlement area

Source: Field observation, collected and organized by Researcher (Me)

Annex 3 Tabular form of Annual rainfall stations in millimeters

Station	Elevation	Geogr1	Geogr2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Anger	**1350**	**36.3333**	**9.26667**	0.2	9.7	34.6	44.1	133.6	259.6	323.3	306.1	271.0	114.5	22.7	9.3	1528.7
Arjo	**2565**	**36.5**	**8.75**	12.6	25.2	66.9	141.1	249.0	383.7	393.2	392.5	334.3	132.9	52.6	30.4	2214.1
Dedessa	**1310**	**36.1**	**9.383333**	6.8	8.7	30.3	47.1	145.6	355.6	326.0	241.9	222.1	86.8	28.2	16.7	1515.6
Gidayana	**1850**	**36.61667**	**9.86667**	2.8	13.1	17.7	31.4	149.8	376.4	355.0	326.8	291.2	101.3	45.0	4.9	1715.3
Gimbi	**1970**	**35.78333**	**9.166667**	6.8	13.1625	28.4	56.675	206.9875	382.4	401.5	329.3	332.4	99.0	15.1	7.9	1879.5
Nekemte	**2080**	**36.46333**	**9.083333**	7.5	20.3	46.3	100.6	222.8	392.9	395.5	384.1	306.8	153.7	43.4	19.7	2093.7
Shambu	**2460**	**37.12117**	**9.5712**	13.3	23.35	53.7	49.3	158.9	258.9	356.9	265.2	261.2	50.9	17.7	15.3	1524.5

Source: Ethiopia Metrological Agency (EMA)

Annex 4: key informant interview attendant of local dwellers in Gimbi Town

School of Civil Engineering and Architecture

Department of Geomatics Engineering

<u>Key informant interview attendant to local dwellers</u>

The principal objective of this key informant interview is to explore the extent to which landslide inventories are increased its area coverage and how it formed, to identified element at risk due to landslide hazard in Gimbi Town. The study is conveyed for academic purpose. Hence, the responses from respondents are confidential and cannot be traced to the persons who provided them.

i. Age of the respondent: ________________ Sex: ___________

ii. What is your level of education? ________________________

iii. Marital status_______________________________________

1. To what extent of landslide invented take place in your zone?
2. After landslide was happened how it enlarged area coverage from the roots?
3. At what time or seasons the landslide happened are start to slide?
4. What are the element at risk due to landslide hazard in your locality?

Thank you for your cooperation and the information you have given!!

Annex 5 Statistical analysis of landslide susceptibility zonation

Zone name	Minim	Maxi	Range	Mean	SD	Sum
Very less susceptible	1	1	0	1	0	2081
Less susceptible	2	2	0	2	0	30382
Moderate susceptible	3	3	0	3	0	66855
High susceptible	4	4	0	4	0	40732
Very high susceptible	5	5	0	5	0	2280

Source: Collected and organized by Researcher (Me)

Annex 6 Statistical analysis of landslide hazard zonation

Zone name	Minim	Maxi	Range	Mean	SD	Sum
Very less hazard	1	1	0	1	0	3225
Less hazard	2	2	0	2	0	22296
Moderate hazard	3	3	0	3	0	50721
High hazard	4	4	0	4	0	59892
Very high hazard	5	5	0	5	0	26895

Source: Collected and organized by Researcher (Me)

Annex 7 Statistical analysis of vulnerability of element at risk zonation

Zone name	Minim	Maxi	Range	Mean	SD	Sum
Very less vulnerable	1	3	2	1.019	0.146	5843
Less vulnerable	1	4	3	2.017	0.199	16172
Moderate vulnerable	1	5	4	3.010	0.187	40268
High vulnerable	2	5	3	4.005	0.175	71838
Very high vulnerable	3	5	2	4.968	0.193	45912

Source: Collected and organized by Researcher (Me)

Annex 8 Statistical analysis of landslide risk zonation

Zone name	Minimum	Maximum	Range	Mean	SD	Sum
Very less risk	1	1	0	1	0	10122
Less risk	2	2	0	2	0	35896
Moderate risk	3	3	0	3	0	39546
High risk	4	4	0	4	0	35488
Very high risk	5	5	0	5	0	6745

Source: Collected and organized by Researcher (Me)

Annex 9 Statistical analysis of validated landslide susceptibility map

LS Zone	Min	Max	Range	Mean	Median	SD	Sum	Overlaid LI	%
Low	5	10	5	6.7	5	2.4	20	5	26
Moderate	1	9	8	3.4	3	2.2	31	11	58
High	6	8	2	7	7	0.9	42	3	16

Source: Collected and organized by Researcher (Me)

Annex 10 Statistical analysis of validated landslide hazard map

LH Zone	Min	Max	Range	Mean	Median	SD	Sum	Overlaid LI	%
less	5	5	0	5	5	0	10	2	10.5
Moderate	3	10	7	5.1	4	2.8	36	10	52.6
High	1	8	7	3.25	2	2.8	13	5	26.2
Very high	6	7	1	6.5	6	0.5	13	2	10.5

Source: Collected and organized by Researcher (Me)

Annex 11 Statistical analysis of validated Vulnerability map

VM Zone	Min	Max	Range	Mean	Median	SD	Sum	Overlaid LI	%
Very less	2	2	0	2	2	0	4	2	10.5
Moderate	1	10	9	6.5	7	3.4	26	3	15.8
High	3	9	6	4.5	3	2.1	27	11	57.9
Very high	4	6	2	5	5	0.8	15	3	15.8

Source: Collected and organized by Researcher (Me)

Annex 12 Statistical analysis of validated Landslide Risk map

LR Zone	Min	Max	Range	Mean	Median	SD	Sum	Overlaid LI	%
Very less	2	2	0	2	2	0	4	2	10.5
Less	5	10	5	7.25	5	2.3	29	4	21.1
Moderate	1	8	7	4.125	3	2.2	33	10	52.6
High	6	7	0	6.5	6	0.5	13	2	10.5
Very high	6	6	0	6	6	0	6	1	5.3

Source: Collected and organized by Researcher (Me)

Annex 13 Event based Landslide observed area in the Town

Source: Collected and organized by Researcher (Me)

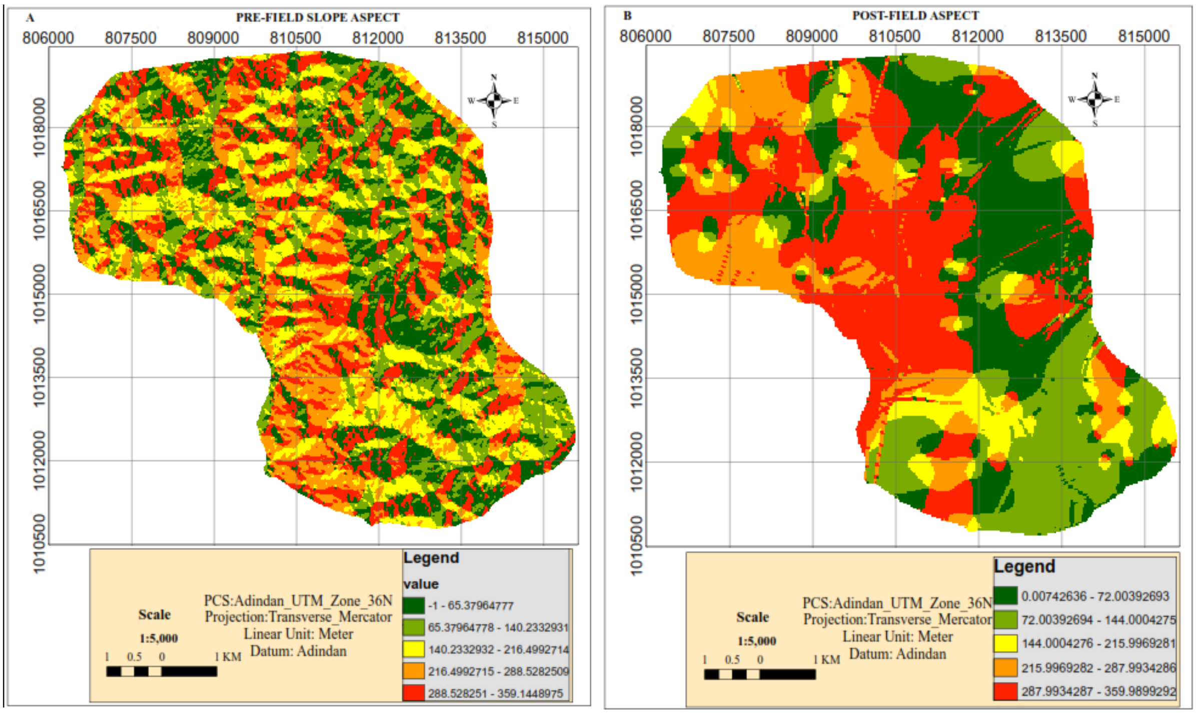
A) Laga Gaba settlement at risked, B) Laga Gaba foot path at risked, C) Gaba Malifu asphalt and settlement at risked, D) Taba Laga settlement at risked, E) Taba Laga foot path and settlement at risked, F) Abba Sangi foot path at risked.

Annex 14 Monthly Temperature & Rainfall of Study area

No	Months of the year	Temperature per month in °c	Rainfall per in mm
1	January	15	20
2	February	25.4	40
3	March	16.1	65
4	April	15.2	95
5	May	15.3	115
6	June	13.9	160
7	July	13.8	263
8	August	13.6	268
9	September	13.9	283
10	October	14.1	56
11	November	14.5	17
12	December	14.9	13

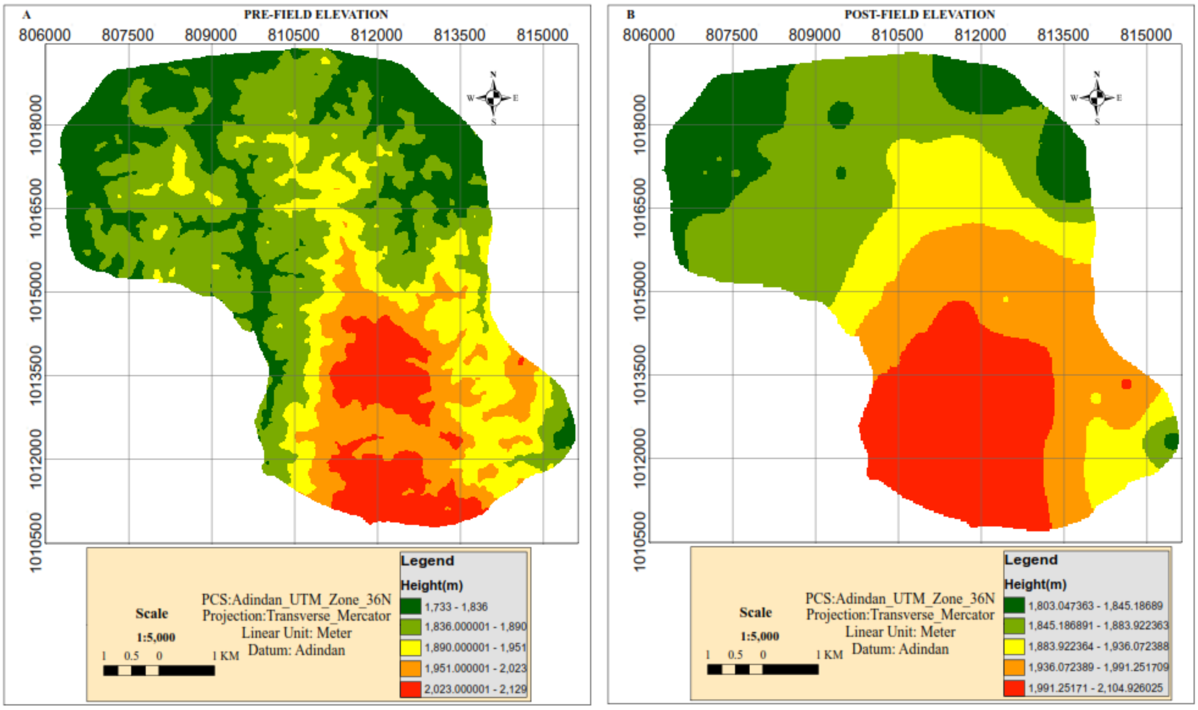
Source: (Ali, et al., 2017)

Annex 15 Aspect from Existing DEM (A) and from Field (B)



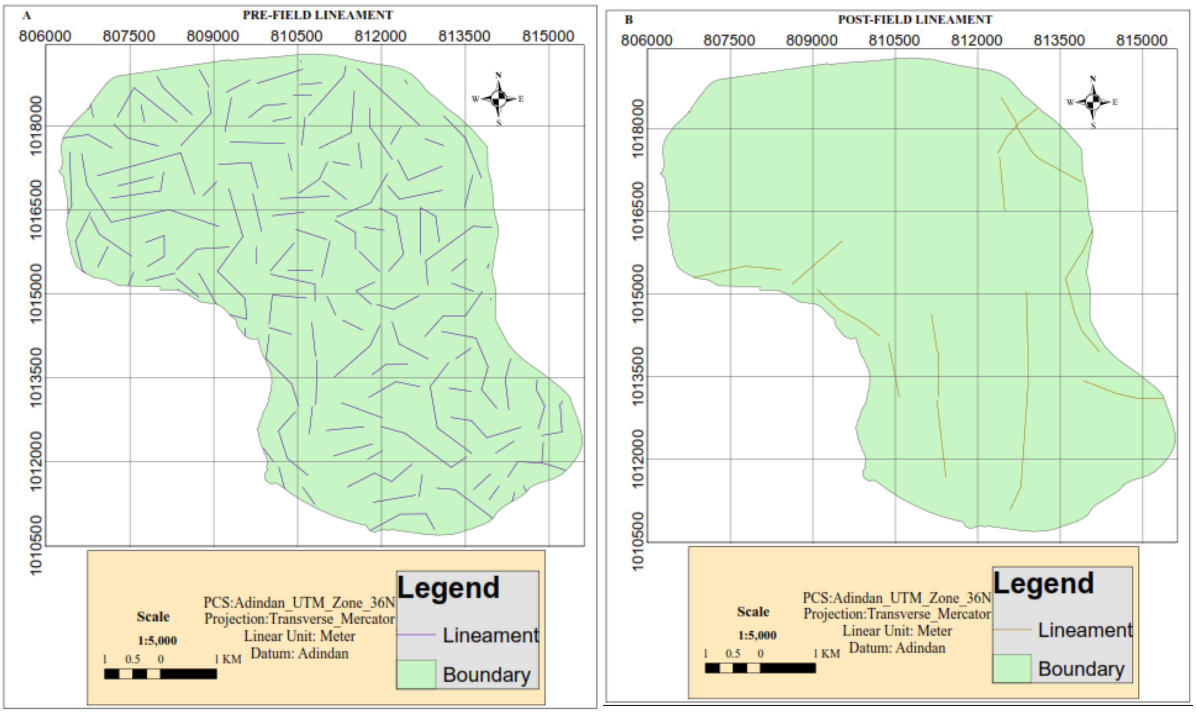
Source: Collected and organized by Researcher (Me)

Annex 17 Existing Elevation Map (A) and from Field (B)



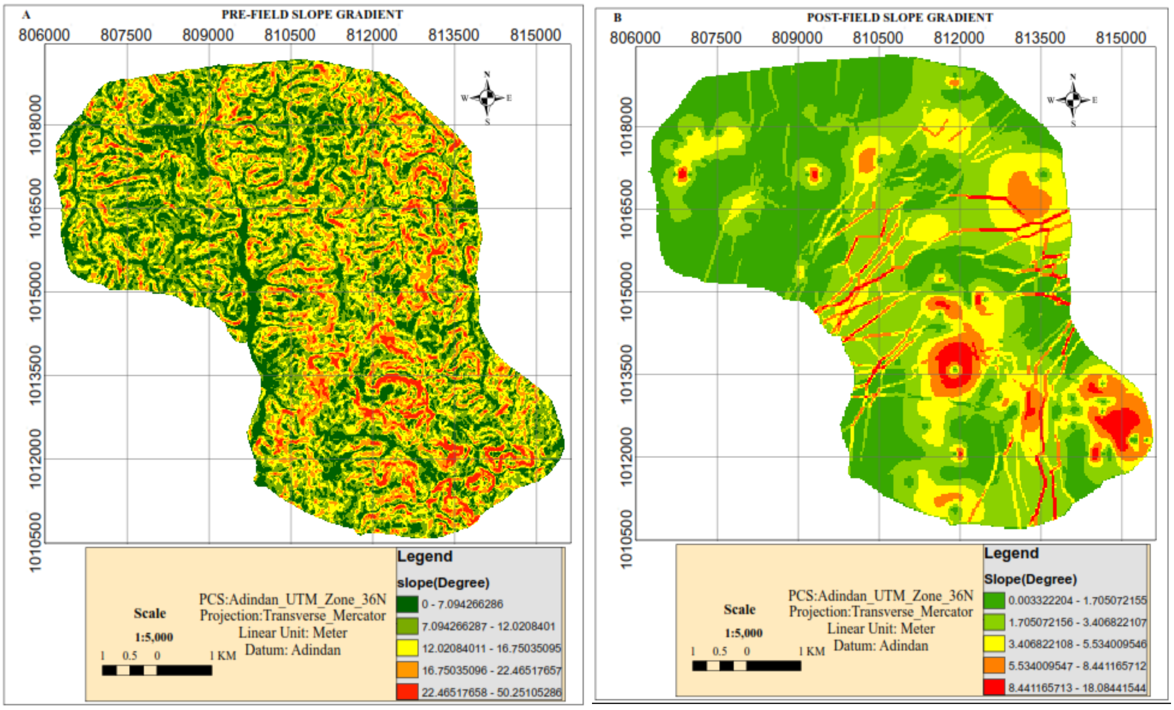
Source: Collected and organized by Researcher (Me)

Annex 16 Lineament extracted from Existing DEM (A) and from Field (B)



Source: Collected and organized by Researcher (Me)

Annex 18 Slope gradient generated from Existing DEM (A) and from Field (B)



Source: Collected and organized by Researcher (Me)