LANDSLIDE HAZARD MAPPING USING GIS AND REMOTE SENSING TECHNIQUES: THE CASE OF JIMA GENETI WOREDA, HORO GUDURU WOLLEGA ZONE, ETHIOPIA

A Thesis submitted to school of Civil and Environmental Engineering, Addis Ababa Institute of Technology in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Geodesy and Geomatics (specialization in Geomatics)

BY: LACHISA BUSHA

ADVISOR: DANIEL ALEMAYEHU (PhD)

October 2019

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Civil and Environmental Engineering

This is to certify the Thesis prepared by **Lachisa Busha** Entitled as “Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Jima Geneti Woreda, Ethiopia”. Submitted in Partial Fulfillment of the Requirements for The Degree of Master of Science in Geomatics Engineering Compiles with the Regulations of the University and Meets the Accepted Standards with its Originality and Quality.

Approved by board of examiners:

________________	__________	__________
Advisor	Signature	Date
________________	__________	__________
Internal Examiner	Signature	Date
________________	__________	__________
External Examiner	Signature	Date
________________	__________	__________
Chairperson	Signature	Date

DECLARATION

I hereby declare that the thesis entitled "Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Jima Geneti Woreda, Ethiopia" has been, carried out by me under the supervision of Dr. Daniel Alemayehu. School of Civil and Environmental Engineering respectively, Addis Ababa University during the year 2018-2019 as a part of Master of Science in Geomatics Engineering. I further declare that this work has not been, submitted to any other University or Institution for the award of any degree or diploma.

______________________	__________	______________
Student Name	Signature	Date
______________________	__________	______________
Advisor	Signature	Date

CERTIFICATE

This certified that the thesis entitled “Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Jima Geneti Woreda, Ethiopia is benefited work carried out by Lachisa Busha under our guidance and supervision. This is the actual work done by Lachisa Busha for the partial fulfillment of the award of the Degree of Master of Science in Geomatics Engineering from Addis Ababa University, Addis Ababa.

Acknowledgments

First, Above all, I would like to thanks the “Almighty God” who helped and guided me in all aspect of my life especially to accomplish this work successfully. Glory to his Almighty for His care and smoothening challenges in doing this research.

Secondly, among all, I wish to express my wholehearted thanks to my Advisor, Dr. Daniel Alemayehu for his constructive, fruitful and valuable comments and guidance throughout the research work. His supervision, patience, wisdom, insight, guidance motivation and kindness in every stage of this thesis. His guidance was most helpful during the development process of this thesis. I am grateful for his continuous support. He was not only a supervisor but also a friend, who will always be close to me in my future life.

Third, I also appreciate Ethiopian Geologic Survey (EGS), Ethiopian ministry of Agriculture for their provision of data and documents free of charge. Finally, I appreciate all my family and friends, whom I did not mention their name here, for their support, encouragement and care.

Table of content

List of Table

List of Figure

List of Equation

Acronyms

AHP	Analytical Hierarchy Processes
ANN	Artificial Neural network
Arc GIS	Aeronautical Reconnaissance Coverage Geographic Information System
AUC	Area under Curve
BIS	Bureau of Indian Standard
DEM	Digital Elevation Model
EGIA	Ethiopian Geospatial Information Agency
EGS	Ethiopia Geologic Survey
EIA	Environmental Impact Assessment
EMA	Ethiopia Mapping Authority
EO	Earth Observation
ERDAS	Earth Resource Data Analysis system
ETM+	Enhanced Thematic Mapper Plus
FR	Frequency Ratio
GPS	Global Positioning System
IVM	Information Value Model
LHEF	Landslide Hazard Evaluation Factor
LHZ	Landslide Hazard Zone
LU/LC	Land use land cover
MCA	Multi-Criteria Analysis
MCE	Multi-Criteria Evaluation
ROC	Receiver operating characteristics
SRTM	Shuttle Radar Topographic Mission
USGS	United States Geological Survey
WLC	Weighted Linear Combination

Abstract

The main purpose of this study is to assess landslide hazard zones for Jima Geneti Woreda using Geographic Information system (GIS) and remote sensing by applying multi criterial analysis. The causative factors considered to landslide analysis in the area was, slope, aspect, drainage density, lineament density, geology, land use land cover and soil type. The thematic data layer representing various factors were, generated by using GIS and remote sensing techniques. Using Analytical Hierarchy Processes the weight of each factor were calculated and assigned in GIS. To add these factors and produce landslide hazard map weighted linear combination was, used. Landslide hazard map prepared was, categorized in to very high, high, low and very low hazard zone. The result of analysis were verified using landslide inventory data. The result showed that the landslide hazard map agreed with areas that had recently experienced landslide and using this mode was very suitable in predicting landslide hazard and generating landslide hazard maps. The landslide hazard map shown that southwestern region of study area was prone to landslide. The correlation between landslide occurrence and causative factors was, correlated to examine their relationship. Based on landslide hazard zone various mitigation measure was, taken for stabilization of unstable slope. The present study determine that multi criterial analysis with GIS is a powerful tool in predicting landslide hazard mapping in the area. The future landslide hazard analysis and landslide intervention in Jima Geneti Woreda suggested for further researcher, land management and concerned body should have based on the present finding

Key word: *Landslide, Jima Geneti Woreda, GIS and remote sensing**,** multi-criteria analysis*

CHAPTER ONE: INTRODUCTION

1.1. Background

Landslides are geological hazard that cause damage to life and infrastructures. Many authors and researchers dealt the concept of landslide differently. According to Varnes and IAEG (1984), landslide are all varieties of mass movement on slope that contain slight or no true sliding. These mass movements may cause loss to property and life when it happen around settlement and infrastructure area. Although, Landslide are a process of mass transport without transportation medium like water, air and ice (Brusden, 1984)). According to Hutchinson (1988), landslide is a rapid mass wasting process that causes the down slope movement of mass of rock, debris or earth caused by variety of external stimulus. Moreover, landslides considered as mass movement on slope without any transporting agent. A recent definition given by (Courture, 2011) states that; landslide is movement of soil mass or earth materials (debris or rock) down a slope. This definition of landslide encompass types of materials that move down a slope.

Subsequently, landslide categorized as one of the most significant natural hazard throughout the world (Crozier and Glade, 2005 Varnes, 1996). The United Nations International Strategy for Disaster Reduction (UNISDR) and the Centre for Research on the Epidemiology of Disasters (CRED) for 2006 shows; landslide is the third most frequently occurring natural disastrous among top 10 natural hazard (Ramakrishnan, 2002). Landslide have been frequently problem in Ethiopia mainly in highland areas in most parts of the north, south and western region of the country and parts of the rift valley escarpment (Ayele *et al*.2014). According to Ayalew (1999), the Ethiopian highland has established significant instability in both superficial materials and the bedrocks. Jima Geneti Woreda was, characterized by steep topography and high precipitation. As a result, slope failures shown in the form of landslide and rock fall in the area. All most all common types of landslide problem happen in the area. Therefore, there is a great need for effective landslide hazard mapping to save property destruction and loss of life. However, landslide happens commonly and can symbolize most critical force on earth and it need understanding to what causes them and how to prevent or escape it. Even though, landslides are more manageable and predictable than other natural disastrous (Reni, 2018).

To minimize the impact of landslide hazard, it is necessary that the area, which have susceptible to landslide, should be, identified and mapped (Girma, *et al.,* 2015). According to Brabb (1993) reported, at least 90% of landslide loss can be avoided if the problem is recognized before the landslide event. Moreover landslide hazard analysis and mapping can offer, useful evidence for disastrous damage reduction and it contribute in viable land-use planning (Chen, *et al*., 2007). This can indicate landslide hazard zonation is an important step in landslide investigation and landslide risk management.

The analysis is used to categorize the factors that are related to landslides, evaluate the comparative influence of factors affecting slope failures, establish a relation between the factors and landslides, and to forecast the landslide hazard in the upcoming based on such a relationship (Chen, *et al.,* 2007). Extraction of relevant spatial information related to landslide occurrence is an integral part of hazard assessment. Nevertheless, integrating remotely sensed (RS) data with Geographic Information System (GIS) are, proved to effective tools for generating and processing spatial information. Integration of remote sensing (RS) and Geographic Information system (GIS) play vital role in natural disaster management particularly in landslide studies by integrating various factors and selected as a best tool to, locate landslide hazard zones with accurate precision, cost and time effective.

Moreover, a number of studies were, conducted on landslide hazard zonation using GIS and remote sensing techniques (Aulitzky, 1980, Carrara *et al.,* 1991; Fell, 1994; Neelakantan and Ramasamy, 2002). GIS deals a superior technique for landslide analysis since it offers capabilities of integrating multi sector, multi-level and multi period database. As many variables are involved, it is imperative to overlay the various layers of data to develop a full and precise depiction of what is taking place on the Earth's surface. However, the main importance of GIS techniques in landslide analysis is to generate extremely detailed maps that show past events and future events which have the potential to save lives, property, and money. Moreover, Cardenas (2008), reports illustrate the evidence on the exhaustive use of GIS in combination of uncertainty modeling tools for landslide mapping. Remote sensing techniques are also highly employed for landslide hazard assessment and analysis.

Remote sensing technology is capable of providing up to date geographic information and is the main source of input data for assessing and monitoring the environment in information system environment. The current land use land cover information of the study area where extracted, mapped from satellite images, and used as an input data for the study.

Therefore, remote sensing serves as a tool for environmental resource assessment and monitoring (Metternicht, *et al.* 2005). Before and after aerial photographs and satellite imagery are used to gather landslide characteristics, like distribution and classification, and factors like slope, lithology, and land use/land cover to be used to help predict future events (De la ville *et al*, 2002). Conversely, before and after images helps to show, how the landscape changed after an event, what may have triggered the landslide, and shows the process of regeneration and recovery (Fabbri, *et al.* 2003).

However, it is possible to generate maps of likely occurrences of feature landslide using satellite image in combination with GIS and on the ground studies. Such maps should show the locations of previous events as well as clearly indicate the probable locations of future events. In this study, seven main parameters were used to analysis probability location of landslide hazard in Jima Geneti Woreda including slope, aspect, lineament density, drainage density, land use land cover, geology and soil type. Landslide related factor data have been, extracted and overlaid, and landslide hazard map have been, made and verified.

1.2. Statement of Problem

A few decades ago, land surface was highly covered by forest (Girma *et al.,* 2015). However, soil erosion and run off process increased significantly due to deforestation, road cutting and urbanization. Conversely, this has intensified the landslide process (Girma *et al.,* 2015) and its effect on human life and property due to increment of slope instability (Martha and Kerle. 2008). As resulted from those human and natural factors the overall roughness of terrain and steep slopes where at risk in the rainy seasons. Although, Jima Geneti Woreda is, characterized by a steep topography and subjected to heavy precipitation. Due to these adverse effects, the area is prone to extensive and severe landslides (Ercanoğlu and Gökçeoğlu, 2002). Moreover, historical accounts and geologic evidence show that hazards of various types and scales have been occurring at Jima Geneti Woreda frequently for many years.

Although, the area is covered significant cultivated land, this increase the disintegration of alluvo-colluvial materials and facilitate percolation of rainwater during rainy season. This makes the area prone to landslide, so as it needs to be, analyzed for landslide hazard. As previous year, due to heavy rainfall there were many landslides resulting in damage and human casualties in the Area. Therefore, there is a great need to develop selected factors that are, related to landslide in the area and preparing landslide hazard map that can contribute in viable land use planning and risk management.

Since researchers did not tried so far to prepare susceptible landslide hazard map for the Woreda. Conversely, GIS and remote sensing did not fully utilized and various factors have not considered. Consequently, it is mandatory to determine the comparative influence of factors affecting slope failures and establish a relation between the factors and landslides in the area. Although, presenting mitigation measure for landslide hazard zone in the area were, needed. The present study dedicated on to assess landslide hazard zones for Jima Geneti Woreda using GIS and remote sensing by applying multi criterial analysis.

1.3. Research Question

1. Which correlating factors highly contribute to landslide in the Area?

3. Which area is more prone to landslide?

4. Which mitigation measures are required?

1.4. Objectives

1.4.1. General objective

The general objective of the study is to assess landslide hazard zones using GIS and remote sensing at Jima Geneti Woreda.

1.4.2. Specific objective

- ✓ To develop selected factor maps for landslide hazard analysis in the area.
- ✓ To identify and map the landslide hazard hot spot sites in the area

- ✓ To examine correlation between landslide occurrence and causative factors in the area.
- ✓ To identify appropriate mitigation measure in the study area

1.5. Significance

The study is extremely significant and plays a vital role to the following concerns:

- ➢ It will contribute to understand the science of landslides and factors associated with them.
- ➢ It is applicable in terms of providing future landslide hazard information for the status of social stability
- ➢ It is applicable to understand nature of unstable slope and their potential to landslide.
- ➢ It will enable how cities towns and countries can plan for land use, engineering of new construction and infrastructure that will reduce the costs of living with landslide hazards.

1.6. Scope

The present study was, developed for local scale by considering seven parameters for the occurrence of landslide hazard. While the methodology was developed, it focus on GIS and Remote sensing techniques and multi criterial evaluation for landslide hazard mapping. The study where delimited to physiography, geology, land use land cover and soil type of the area and does not consider population status.

1.7. Limitation

The present study was attempted with all possible effort in acquiring required inputs in the form of primary data for validation and ancillary data, data collection interpretation, data preparation and data analysis. The most challenging limitation of present study are resource limitation, unavailability of high-resolution digital elevation model and unavailability of recorded landslide inventory data. Even though, Jima Geneti Woreda is one of the highly affected area by landslide, but its implication on the landslide hazard analysis and management were, not studied in any reliable journal this case challenges the researcher to cite better on the study area.

1.8. Organization of the Thesis

The present thesis study was, organized in five main chapters as follows; the first chapter introduces introduction, statement of the problem, objectives, scope, significance and limitation. In this chapter frequency and status of landslide through the world, in Ethiopia and in the study area was, discussed based on different literatures. In addition, the problem based on the issue that exist in literature, theory and practice that need for the study was, presented.

The second chapter discuss literature review. This chapter introduce various literatures that are, related to the present study title that are, used to give brief review of theoretical basis of landslide hazard zonation and different approach for landslide hazard mapping. Although, the application of remote sensing, geographic information system (GIS) and integration of geographic information system and remote sensing for landslide hazard mapping was discussed.

The third chapter discuss general description of study area, data source, data collection, data preparation and general methodological steps. In this chapter, detail description of the study area, in terms of location, geology, and climate and all information about the data and step taken to achieve stated objective was, presented.

The fourth chapter introduce data analysis method performed in the present study, the result obtained from the analysis and interpretation of the result in perspective of literature review or discussion section. In this chapter, data analysis procedure and thematic data layer maps were, presented. Although, weight derivation of causative factors, landslide hazard validation, correlation between landslide occurrence and causative factor class was discussed. The fifth chapter discuss the work in the output of the work accomplished or conclusion and give further research direction and suggestion or recommendation. In this chapter, the indication of the study and additional model and data needed for further analysis of landslide hazard in the area were, presented.

CHAPTER TWO: LITERATURE REVIEW

2.1. Landslide Hazard and Zonation

Landslide hazard is the probability of occurrence within a given period and within a specified area of potentially destructive phenomena (Guzzetti, 2002). Even though there are a number of approach to define landslide hazard. According to Varnes and IAEG, 1984, Guzzetti *et al*., (1999) landslide hazard refers to the probability of landslide occurrence within a specified period of time, area and magnitude. This definition can indicate that, landslide hazard integrate three basic element, magnitude (area, volume velocity), geographical or spatial location and time or period of the expected landslide.

Landslide hazard zonation is a basic and necessary step in landslide analysis and landslide risk management. The term zonation in landslide hazard analysis is, defined by different authors differently. According to Varnes and IAEG (1984), zonation is a division of land surface into areas and ranking these areas according to the degree of hazard from landslides or other mass movements'. Moreover, Courture (2011) described landslide hazard zonation as a division or partition of land into slightly homogeneous areas and ranking according to degrees of actual or potential landslide vulnerability, hazard or risk or applicability of certain landslide related regulations. Howe ever, there has significant increase in both landslide events and landslide studies in different part of the world (Gutierrez *et al*., 2010). Furthermore the statistical assessment of international landslide literature approved by Gokceoglu and Sezer (2009), illustrate that publication of landslide related articles in the international journals has experienced exponential growth. Subsequently, after the topical natural disasters around the world, landslide monitoring and providing early warning have gained enormous interest (Nadim *et al.*, 2006).

For a long period, landslide hazard zone, mapping has been, carried out in different parts of the world by various techniques and approach. A number of techniques and approaches have been, developed for, landslide hazard zone mapping. Generally, those approaches are; landslide inventory mapping, heuristic approach, probabilistic assessment, deterministic approach, statistical analysis and multi criteria decision-making approach (Leroi, 1997; Fall *et al*., 2006). Nevertheless the, effectiveness of one method over other depends on several factors like; scale of the study area, the accuracy of the predictable outcomes, the availability of data, parameters measured etc. (Fall *et al.*, 2006).

Inventory analysis is one of the simplest qualitative approaches of landslide hazard mapping. Landslide inventory mapping is collection of information on the spatial and temporal pattern of landslide distribution and displaying them on a map. According to Dai and Lee, 2001; Dai *et al.*, 2002; Fall *et al.*, (2006) Landslide inventory mapping is identification and compilation of details of each landslide. Therefore, information collected during inventory analysis may include all about landslide pattern, location, magnitude, types of mass movement and so on. Thus, information collected are obtained through field survey using GPS, Historical records or interview of witness, satellite image, google earth and aerial photograph interpretation. However, landslide inventory maps used to show slope failure caused by single events or cumulative effect of many event over long period (Guzzetti *et al*., 2000).

Landslide hazard map play a vital role in landslide studies and landslide risk management. Even though, the quality and extensiveness of landslide inventory map influence the reliability of landslide analysis. Galli *et al*., (2008) compared landslide inventory maps prepared for different part of Italy, by establishing relationship between geomorphological landslide maps and multi-temporal landslide inventories. The result show the complete landslide inventory map have highly useful for landslide analysis. Similarly, Guzzetti *et al*., (2003) compared three-landslide inventory using universal frequency-area statistics. The result indicate, the number of landslide events increased proportionally with increasing landslide area and decreased with decreased landslide area. They discussed on the importance of completeness and resolution of landslide inventory maps in the landslide studies. The incompleteness of landslide inventory map is happen during field-based collection of information due to loss of evidence of the existence of landslide removed by erosion, cultivation or other factor. Therefore, historical records and interview of witness are more significant for complete landslide inventory mapping (Guzzetti *et al*., 2003).

To minimize subjectivity in weightage assignment procedure and produce more objective and reproducible results, techniques toward landslide hazard zonation has been, changed from heuristic to statistical approach (Kanungo *et al.,* 2009). According to Dai and Lee (2001) stated, statistical approach emphasis on identifying relationship between past landslide and causative factor. Even though, in statistical approach various causative factors has been, analyzed by univariate or multivariate statistical methods (Fall *et al.,* 2006; Dai and Lee. 2001).

Conversely, the limitation of statistical approach is the collection of data on landslide distribution and causative factor over large area for considerable prolonged period (Girma *et al*., 2015) and the result are dependent on quality of data and details of landslide frequency data (Fall *et al*., (2006). There are two types of statistical approach in landslide hazard zonation they, are bi-variate and multi-variate statistical analysis.

This analysis has been, applied for landslide hazard zonation to compere each data layers of causative factor to the existing landslide distribution (Kanungo *et al.,* 2009). Its main objective is to identify the density of landslide occurrences within each causative factor data layer and parameter of data layer classes and to derive weights of data based on class distribution and landslide density (Suzen and Doyuran, 2004). However, weight of the landslide causative factor assigned based on landslide density. The major bi-variate statistical model used in landslide hazard mapping are; Weights of Evidence Model, Weighted overlay model, Frequency Analysis approach, Information Value Model (IVM) and Fuzzy Logic method (Piacentini *et al.* 2012; Parise 2002; Lee and Pradhan 2006; Sarkar *et al*., 2006; Chung and Fabbri. 1998, 1999;).

Multivariate statistics is a form of statistics containing more than one statistical variable of actual observation and analysis. While, multivariate statistical analysis for landslide hazard zonation reveals the relative influence of each thematic data layer to the total landslide susceptibility (Kanungo *et al.* 2009). Moreover, the analysis related to landslide susceptibility determine the weights of landslide causal factors based on the relative contribution in the occurrences of past landslide event with in a defined land unit area (Dai *et al.,* 2010; Suezen and Doyuran 2004b; Ayalew and Yamagishi 2005; Nandi and Shakoor 2009).

According to Sudhakar *et al.,* (2013) stated, multivariate statistical method is, used to determine the percentage of landslide area for each pixel and to produce landslide absence or presence data layer for the given area. Moreover, it also concerns to understand the objective and background of various form of multi-variate statistical analysis and how they are, related to each other (H.shahabi *et al*. 2012). Logistic regression model, Discriminant analysis, multiple regression models, conditional analysis, Artificial Neural Networks (ANN) are commonly used methods of multi-variate statistical analysis for Landslide Hazard Zone mapping (Tolga *et al.* 2005; Guzzetti *et al*., 2005b; Clerici *et al.* 2002; Chang and Liu. 2004).

Probabilistic approach is a method that can identify location, time and magnitude of landslide event. Guzzetti *et al.,* (2005b) stated, probabilistic approach in landslide hazard analysis has, applied to determine spatial, temporal and size probability of landslides. Moreover, this approach bring objectivity in assigning weight (Sudhakar *et al.*, 2013) but certain degree of subjectivity exists in weight assignment process (Kanungo *et al.*, 2009). Guzzetti *et al.,* (2005b) carried out landslide hazard assessment at the Basin scale using probabilistic model. They determined probability of landslide size, temporal and spatial probability of landslides using, frequency area distribution function. Although, Jaiswal *et al.*, (2010a) approved, quantitative landslide hazard assessment along transport route in Nilgiri Hills, India. They performed Frequency-volume statistics to get probability of landslide magnitude for different return period. Several studies have attempted apply probabilistic approach for quantitative landslide hazard zonation in recent time (Ghosh 2011; Floris and Bozzano 2008; Das 2011; Jaiswal and Van Westen 2013; Guzzetti *et al.* 2006; Polemio and Sdao 1999; Chelboard *et al.,* 2006)

2.2.1. Analytic Hierarchy Process Approach

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice (Chakhar and Mousseau, 2008). MCDA consists of a series of techniques (such as weighted summation or concordance analysis) that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by, experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/siting a particular facility/service (Malczewski, 2004).

AHP (Analytical Hierarchy Process) is, considered as relevant to derive the weights of multi-criteria by comparing the relative importance of criteria using pair wise comparison. It depends on the principle of, decomposition, comparative judgement and synthesis of priorities (Malczewski, 1999). Subsequently, this technique involve multi criteria decision making and multi objective approach to allows the active participation of decision maker in reaching an agreement (Sahnoun, H *et al.* 2012). Weighted linear combination (WLC) is a combination between qualitative and quantitative approach (Ayalew *et al*., 2005). It is characterized by full trade off among all factors, average risk and offers much flexibility than the Boolean in the decision making process.

2.2.2. Application of Remote Sensing for landslide hazard Mapping

Remote sensing is the science, art and technology of acquiring data about any physical object or entity without physical contact**.** Remote sensing assist as a tool for environmental resource assessment, monitoring and management. The development of remote sensing technology to provide multi-spectral, multi-temporal and multi-spatial images is very helpful to increase the speed and frequency with which one can analyze a landscape (Idowu and Ukoje, 2009). Moreover, remote sensing contributes to the development of impartial and complete assessments over larger geographic extents and remote area than is possible with fieldwork alone (Steininger and Horning, 2007). Remotely sensed data is the main source of input data for analyzing, and interpreting any natural resource on the earth surface. The recent developments in the application of satellite RS data in landslide studies in Europe has been, discussed by Tofani *et al.*, (2013). The study showed that over 70% of the total applications of RS data for landslide studies are, owned by landslide detection, mapping and monitoring.

Good quality aerial photographs help in accurate landslide detection and mapping. However, aerial photographs may not be, used in continuous landslide monitoring, since it does not prove repetitive coverage of the same area. Conversely, the availability of remotely sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions has made remote sensing as one of the best source of data for large-scale applications and study (Assefa *et al*., 2007). According to Dai *et al.*, (2001), the most common inputs data to GIS are remotely sensed data from satellites or aircrafts. Therefore, remote sensing serves as one of the main source data for GIS and prepare for further analysis in GIS environment.

2.2.3. Application of Geographic Information System (GIS) for landslide hazard Mapping

Geographic Information System is a computer system deigned to store, retrieve, manipulate, analyze and display geographical referenced data. GIS in science view; defined as science used to analyze locational-based information. This makes it possible to take data stored in one form and combine with data entered and stored in some other form (Church, 2002). It has become possible to efficiently collect, manipulate and integrate a variety of spatial data such as geological, structural, surface cover and slope characteristics of an area, which can be used for hazard zonation using GIS techniques. The data layer can well integrate using GIS and weighted analysis is helpful to find Landslide prone area. By the help of GIS we can do risk assessment and can reduce the losses of life and property. It also helps to answer questions and solve problems by looking at your data quickly and easily.

Moreover, GIS integrate different data source stored in different format to display all forms of geographically referenced information. Geographical Information System is widely used in landslide hazard assessment especially for generation of thematic data layers, computation of different indices, weight assignment, data integration and generation of LSZ maps. In hazard assessment, GIS provided to model and rank hazard risk occurrence according to its distribution or intensity and output visualization in various format. However, geographic information system supports as geo-database, geo-visualization and geo-processing views to support decision-making process.

2.2.3. Integration of GIS and Remote Sensing for landslide hazard Mapping

GIS and remote sensing techniques applied in several scientific disciplines like in Environmental Science (Akar, 2009). Integration of GIS, Remote sensing and GPS provide timely and useful information about natural resource and the change appear on earth. Moreover, integrations of geospatial technology can process and evaluate locational-based data to locate and predict hazard risk. This technique plays a key role for monitoring and prediction of disasters like landslide through evaluating, manipulating and analyzing geo-spatial data. The review of few studies on landslide hazard assessment using RS data indicate that aerial photographs are widely used in landslide detection and mapping (Galli *et al.,* 2008).

Although, the advancement in earth Observation (EO) techniques facilitate effective landslide detection, mapping, monitoring and hazard analysis (Tofani *et al.,* 2013). Several landslide hazard zonation, methods such as ANN, Decision Tree model, Weighted Overlay, AHP, MCDA, IVM and physically based landslide hazard models are GIS and remote sensing based models to predict landslide probability (Chang and Liu. 2004).

CHAPTER THREE: METHODOLOGY

3.1. Description of Study Area

3.1.1 Geographic Location

The study area is located in western part of Ethiopia and western region of Oromia. Its geographical location is between 37^0 3'and $37^0$17' East and 9^0 13'30"and 9^0 32'30"North. The gross command area is approximately 411.49 km^2 in areal extent. Most part of the area where covered by water body particularly, plain area located at North East of the study area. Topography of the area is varies from chains of mountain around southwest to North West and plain and racked surface where observed around South East and North East. The elevation ranges from 2209 to 3184 m with an average elevation of 2696.5m above mean sea level.

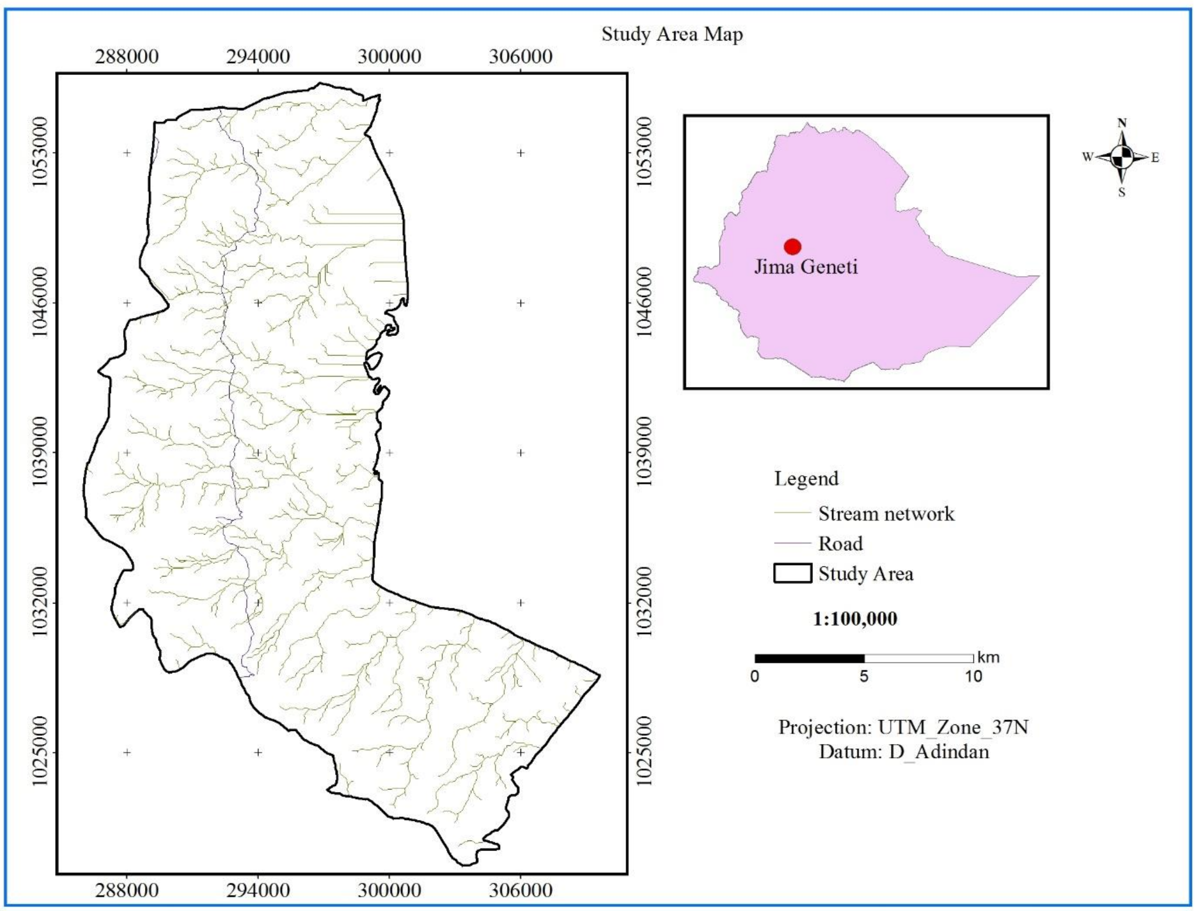


Figure 3. 1 Geographic location of study area

3.1. 2. Geology of the Area

The regional and local Geological characteristics of study area and its surrounding has been, described by Solomon Gerra and Mulugeta Haile Mariam (2000). The description of geology of the study area mainly taken from the geologic map of the area at scale 1:250,000 prepared by Geological survey of Ethiopia (GSE). It consists of Mesozoic sandstone, quaternary sediment, lower basalt, trachytic plugs and flows, upper basalt and upper trachyte flows and pyroclastic rocks. The study area is highly complex with several thrusts and folds. Several irregularly oriented faults are also present in the area.

Mesozoic sandstone

This unit, exposed at north and northeastern part of the study area. It cover 9% of the study area. The rocks of Mesozoic sandstone are, correlated with Gohaseon formation Getaneh Assefa (1979). Strati graphically, it is bounded by Paleozoic sandstone and tertiary volcanic rocks or locally by few erosion remnants of Mesozoic siltstone. The composite of section of this unit shows it has maximum thickness of 770 meters. Generally, the succession consists of two subunit, which have slightly thickness of 470 m and 300 m. .

Quaternary sediment

Quaternary sediment occur extensively at the southeast and northeast of the study area and at the central part of the area. It covers approximately 20% of the total area. This unit consists three types of sediment: black cotton soil, reddish sandy soil and fluvial soil. Since this sediment occur mixed with one another, it is impossible to map separately.

Lower basalt

The unit of lower basalt is the most abundant unit of the volcanic rocks in the study area. It covers 34% of the total area. It is located by covering from south to north of the study area. The unit has a maximum thickness of 600 m.

Trachytic plugs and flows

Trachytic covers 1.2% of the study area. It crops randomly in many localities as isolated plugs and flows. Some trachyte plugs shows banking effect on the surrounding rocks. The rock is dark gray to dark green on fresh out crop and weathers to, light gray, fine to medium grained and shows columnar jointing. There is vertical and lateral variation in color grain size and composition within the same rock. It is light gray and medium to coarse grained at the bottom and pinkish gray and fine grained at the top of the plug. Generally, these rocks is composed of 55% sanidine, 20% augite, aergirine augite and pegeonite, 15% plagioclase and minor amount of orthoclase, secondary calcite, opaque minerals and quartz. The mineral occur as phenocrysts in the cryptocrystalline and glassy groundmass.

Upper basalt

The upper basalt covers 15.8% of the study area. It consists alternating layers of augite and olivine-augite phyric, fine grained and aphanitic basalt. Olivine augite basalt is dark to dark gray and shows columnar jointing. It is composed of 20-30% augite, 15-20% olivine, 10-15% plagioclase, 5-10% opaque minerals and minor amount of hematite and biotite. These minerals occur as phenocrysts and microphenocrysts within cryptocrystalline and glassy ground mass. Augite shows an hourglass zoning. Olivine is, altered to chlorite and iddingsite. This rock is locally composed of secondary minerals such as zeolite and magnetite. The augite phyric basalt is composed of 30-35% augite, 5-40% plagioclase, 5-10% opaque minerals, 0-10% glass, 0-5% olivine and minor amount of chlorite serpentine, calcite, iddingsite and zeolite. It is, characterized by porphyritic with varieties of intersertal when glass is present. The phenocrysts are mainly augite and sometimes olivine and plagioclase. These phenocrysts range in size from a few millimeter to 0.02m.

Upper trachyte flows and pyroclastic rocks

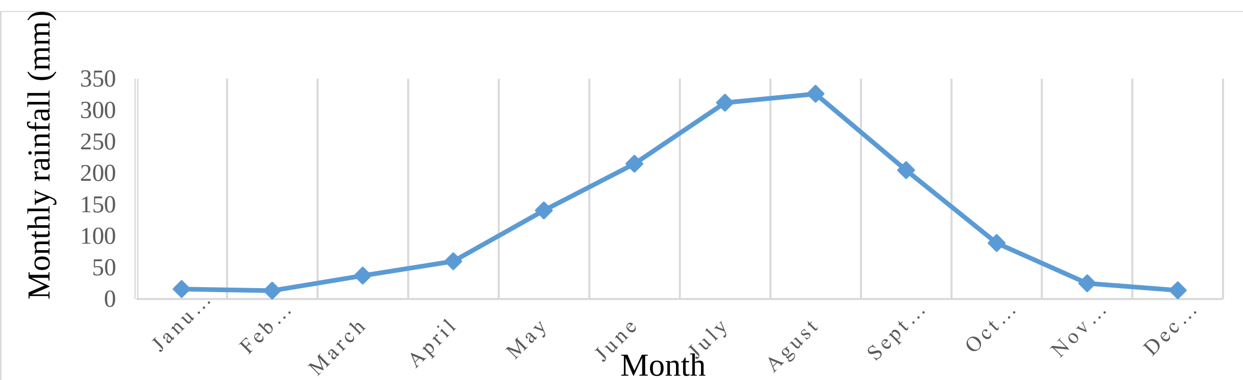
The upper trachyte flows and pyroclastic rocks cover 7% of the total area. This unit consists 45% trachyte flow, 40% of pyroclastic rocks of various such as ignimbrite, ash fall, lithic tuff, crystal tuff, volcanic breccia and lahar 10% plagioclase phyric basalt. Trachyte flows is light, medium grained, porphyritic and shows flow layering.

This rock is composed of 60% sanidine, 25% plagioclase, 10% opaque minerals and 5% augite, aegirine augite and biotite. These minerals occur as microphenocrysts and microlites within cryptocrystalline and glassy matrix.

3.1.3. Climate

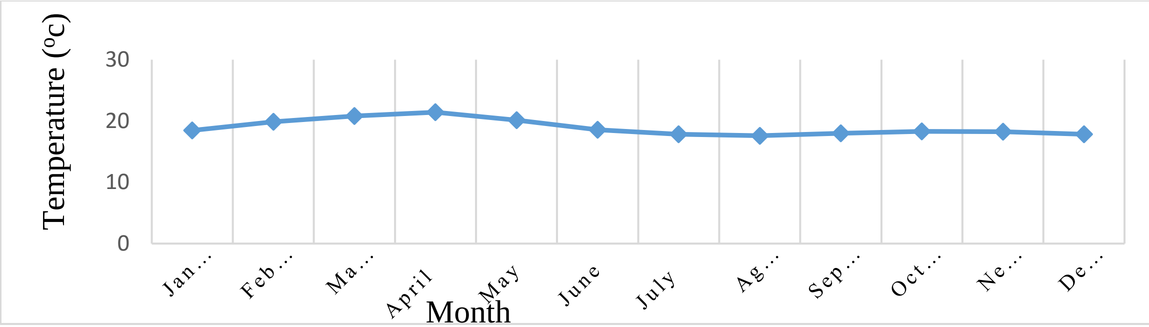
The climatic condition of the study area is part of the tropical humid climatic region. The main rainy and dry seasons in the area are from June to August and between October and January respectively. Most part of the study area have high altitude particularly South West and North West, those parts have low temperature and South East and North East have medium and high temperature. This variation in temperature of the study area is happen due to elevation variation of the area, the area located at higher elevation have low temperature value and the area located at low elevation have high temperature value. On the other hand, type of vegetation and crops to be grown in the study area where vary and they are dependent on the climate of the environment. However, the climate of the study area is comfortable with optimum temperature and rainfall.

The land use and land cover in the study area is mainly forest and agricultural land. The monthly mean historical rainfall and temperature data can be, mapped to show the baseline climate and seasonality by month, for specific years, and for rainfall and temperature. The chart below shows mean historical monthly rainfall and temperature for the study area during the period 1991-2016. The dataset was, produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA).



Source Climatic Research Unit (CRU)

Figure 3. 2 Monthly rainfall of the study area recorded by climatic research unit



Source Climatic Research Unit (CRU)

Figure 3. 3 Maximum and minimum temperature of the study area recorded by climatic research unit

3.2. Materials used

The materials and software used in data collection and thematic data generation to produce final out put in the present study was, reported in Table 3.1.

Table 3. 1 Materials used.

	Materials and software	Purpose	Version/type
1	ERDAS IMAGEN	To perform, image processing, land use land cover classification and accuracy assessment.	2014
2	ArcGIS	To implement, data generation and preparation, overly analysis and map layout preparation.	10.5
3	IDRISI selva	To execute weight derivation for each factor.	17
4	Google Earth pro	Ancillary data.	2019
5	Hand held Global positioning system (GPS)	To collect landslide inventory data for validation and for accuracy assessment.	

3.2.1. Data Sources

In this study, the necessary data for the study were, identified. Because of the nature of the study proposed number of data are, used for the present study. The availability of data were, recognized with relative sources. Most of data source in the present study is internet source and some data source are organization office.

Thus, the data used in the present study were secondary data. Table 3.2 present the main data source with their type and scale.

Table 3. 2 List of data and sources

s/no	Type	Description	Source
1	Maps	Geology map (1:250,000)	EGS(Ethiopia Geologic Survey)
		SRTM (30*30m resolution)	USGS (United States Geological Survey)
2	Row data	ETM+ images(year 2019, path 169 row 54)	USGS (United States Geological Survey)
3		Soil data by Ethiopia shape file (vector format)	Ministry of Agriculture

3.3. Methods

3.3.1. Data Collection

Collecting reliable and accurate data is the most predetermining factor for the final output of the proposed study. While collecting data it is better, first to introduce the data requirement. In this study before collecting data, the purpose of data were recognized. For the present study, data was, collected from different governmental office and downloaded from internet. As part of data collection different data formats, projections and types were, collected. Therefore, Geology map was, collected from EGS (Ethiopian Geological Survey) to extract and characterize geology and lineament. SRTM image (30*30 resolution) from USGS to derive digital elevation model of the study area. To extract slope, aspect and drainage network digital elevation model were, used as input source data. Soil data was, collected from Ministry of Agriculture to extract soil type and soil texture. ETM+ images from USGS to map land use land cover of the area.

3.2.3. Data Preparation

The selection of conditioning factors and preparation of corresponding thematic data layers is a crucial component of any landslide hazard analysis. In this study, before the preparation of factor datasets from raw data, all datasets converted into the same projection system and Universal Transverse Mercator (UTM) projection of Adindan datum was, used for all the data set. The datasets include geology map and soil map, which were represent by polygon future. This discrete form of data was not suitable to be, used in landslide hazard mapping. For this reason, it was converted into continues surfaces (Süzen and Doyuran, 2004). Then the raw data were, used for the production of input data with the same data type.

Preparation of Land use Land cover dataset: the downloaded ETM+ images of 2019 was layer stacked by using seven band and sub setting the image were performed by the shape file of the study area (Appendix figure A.5). Radiometric enhancement technique like, haze reduction, and atmospheric noise reduction were, applied to enhance image appearance. The dataset containing 5, 4, 3 Red, Green, Blue band respectively were prepared for land use land cover classification of the study area (Appendix figure A.5).

Preparation of Geology dataset: To prepare geology datasets of the study area, geology map of Nekemte was, acquired from geological survey of Ethiopia in soft copy. The geology Map incorporates the geological units and the faults lines in the area (Appendix, figure A.1). The geology map has a database concerning the geologic unit names. The map was georeferenced and saved in tiff format. This is, done with the geo-referencing tool bar in ArcGIS Environment. As part of this dataset preparation, the shape file of the study area and georeferenced geology map was, projected to the same coordinate system. By editing and digitizing technique within shape file of the study area, the geology dataset of the area were prepared.

Preparation of Soil dataset: Soil dataset were, acquired from ministry of agriculture of Ethiopia. The soil datasets was, obtained in vector data form by Ethiopia boundary shape file based on soil survey of 2008. Soil dataset of the study area were, clipped from Ethiopia soil dataset. The most relevant attribute for deriving soil texture information was soil class, which captures the type of soil in terms of texture. As part of preparation of this datasets vector datasets of the study area soil was, converted to raster datasets and prepared for further analysis.

Preparation of DEM datasets: The downloaded SRTM (30*30-resolution) image of the study area and its surrounding from USGS (United States Geological survey) were, imported into 3dem software. 3dem were, used to fill missing SRTM values. As part of preparation this datasets, the digital elevation model (DEM) of the study area were, extracted by shape file of the study area (Appendix, figure A.3)**.** The extracted digital elevation model of the area prepared was, used to determine the elevation of the area and for extraction of slope, Aspect, stream network and drainage density datasets of the study area.

Preparation of Slope dataset: Digital elevation model of the area was, used to generate the slope datasets. To prepare slope datasets, digital elevation model were, processed under arc toolbox of GIS environment. The generated slope datasets were prepared for further reclassification of slope angle.

Preparation of Aspect dataset: Aspect datasets were prepared from digital elevation model of the area. Digital elevation model was, processed under arc toolbox of GIS environment. The generated aspect datasets were, prepared for further analysis and reclassification.

Preparation of Stream network datasets: stream network datasets, were extracted from Digital elevation model data of the area by performing various process. The preparation of stream network datasets was, performed under spatial analysis toolbox of hydrology tool. The stream network prepared datasets was used generate drainage density of the area.

Preparation of Drainage density datasets: Drainage density datasets were prepared from stream network of the area (Appendix, figure A.4). Frist, stream datasets were, converted to vector data format by using conversation tool (raster to polyline). The polyline vector format of stream network were, used to generate drainage density dataset by line density tool.

Preparation of Lineament datasets: lineament dataset are line features generated from georeferenced geology map of Nekemte map (Appendix, figure A.2)**.** The generated layer feature were, converted to line under data management tool. The prepared lineament datasets were, used to produce lineament density map.

Preparation of Lineament density datasets: lineament density datasets were prepared from lineament datasets of line features. By Calculating, a magnitude-per-unit area from polyline features that fall within a radius around each cell (line density) lineament density datasets was, generated. The general methodology adopted in the present study was, shown in flowchart of landslide hazard mapping (Figure 3.4).

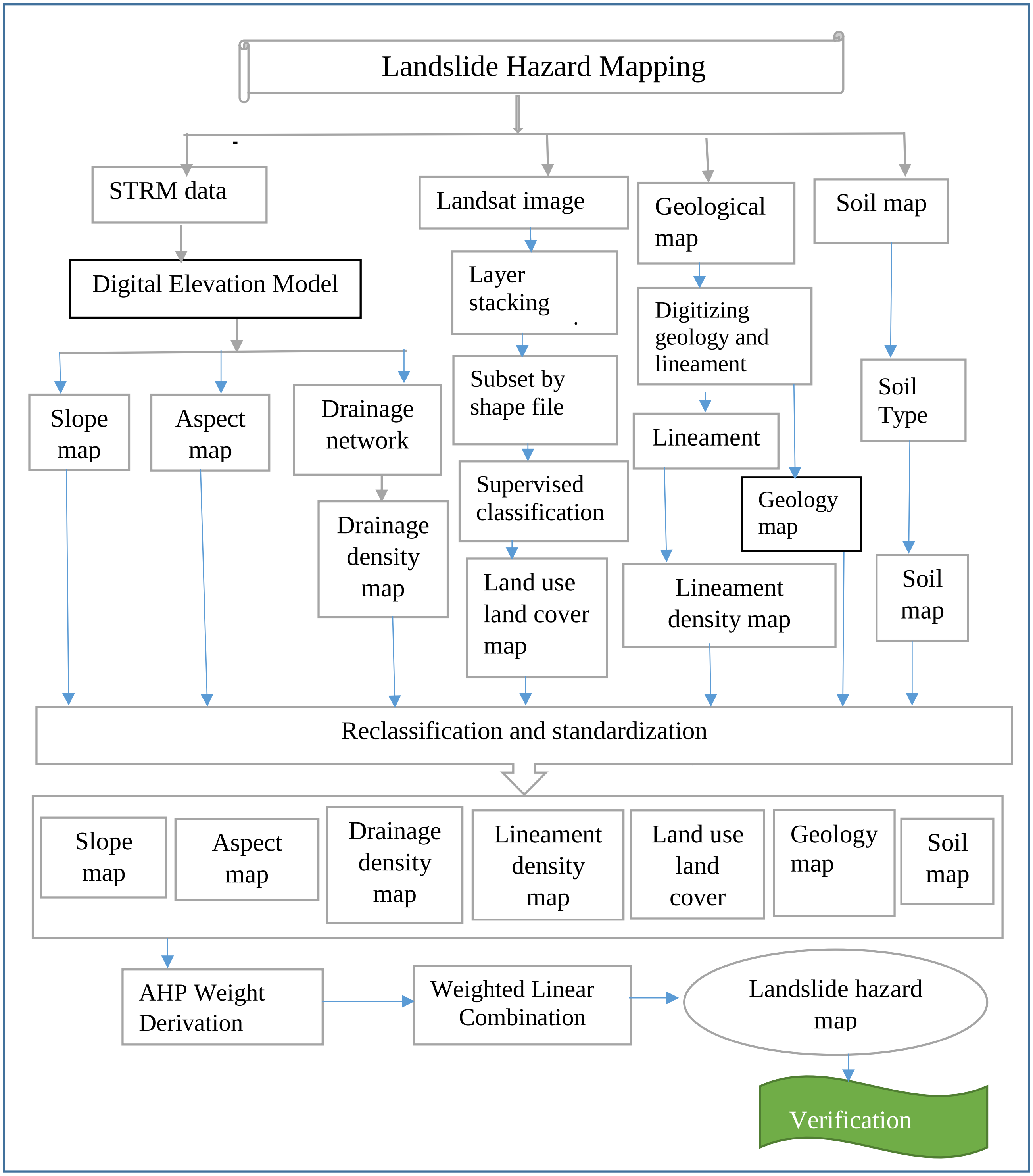


Figure 3. 4 Flowchart of methodology used for landslide hazard mapping

CHAPTER FOUR: DATA ANALYSIS, RESULTS AND DISCUSSIONS

4.1. Data Analysis

Data analysis method employed in the present study depend on the qualitative data collection and analysis. The analysis of qualitative data collected was accomplished through integrated use of ERDAS IMAGE and ArcGIS software packages along with, excel and Microsoft office tools. The input data in the form of geology maps, soil maps and satellite image were, used to extract the variables that may have consequence on landslide occurrence. In the present study, slope, aspect, drainage density, lineament density, geology, land use land cover and soil type was, selected as the conditioning factors for landslide hazard mapping in the study area. It was, assumed that these causative factors were probably responsible for landslide in the area.

However, there are no standard guidelines for selecting these parameters (Ayalew *et al.,* 2005). One parameter may be an important controlling factor for landslide occurrence in a certain area but not in another one. Therefore, the nature of the study area, the scale of the analysis, and data availability were, taken into account (Yalcin. 2008). Collectively, the seven factors used in current study were, selected based on the above-mentioned criteria while literature outputs and general guidelines for GIS-based studies was also considered (Magliulo *et al*., 2008). Generation and production of thematic data layers are the most important and time consuming task in present study. A various number of thematic maps stated were, generated.

4.1.1 Slope

Slope is the first derivative of elevation with each pixel denoting the angle slope at particular location. The slope is an important factor, which influences the landslide process (Ayalew and Yamagishi, 2003). If the slope is steeper, the increment in shear stress is high and the tangential component of the weight of the mass increase while the perpendicular weight will decreases. Therefore, when the shear stress is higher than the resisting force, the slope mass get tendency to slide down the slope (Ahmed. 2009). Slope angle is an essential component of the landslide influencing factor set, which indicates how steep the ground surface.

Because of its relationship with landslides, slope angle is a crucial factor in landslide Hazard assessment as such it is frequently, used in creating landslide hazard maps (Clerici *et al*. 2002; Lee *et al*. 2004 and Lee 2005). For the present study area, slope was, divided into five categories classes: (0-10), (10-20), (20-30), (30-40) and (greater than 40). Slope class and area coverage are, listed in Table 4.1.

Table 4. 1 Slope class and area coverage

s.no	Slope class (degree)	Area(km^2)	Area (%)
1	0-10	323.68	78.7
2	10-20	78.29	19.03
3	20-30	8.73	2.12
4	30-40	0.71	0.17
5	>40	0.078	0.02
Total		411.49	100

As indicated in the table, most part of the area was, dominated by gentle topography. Among the part of study area, northeastern, southwestern, and western part of the area were, characterized by gentle slope topography. In addition, to the area was, characterized by northwest and southwest facing gentle range, which are, divided by numerous river valleys. However, when the slope is steeper the thickness of the colluvial material decrease. Conversely, very small topography of the area was, dominated by steep slope. Village have moderate and high slope occurs in agricultural land.

As shown from the table topography of the area were, dominated by gentle slope with $<10^0$, which cover 78.7 % of the total area. Which is mainly found at northwester of the area. The second dominant toppography of the area is slope with $10\text{-}20^0$ found at northwestern, southwester and northeastern by covering 19.03% of the total area. Much of the cultivated lands falls with in this slope class. The third dominant topography of the area is slope with $20\text{-}30^0$ covering 2.12% of the total area. In this slope class, agricultural and grassland were found as relatively genteler slopes favor agriculture practice. However, only 0.02% of the area is slope with >40^0 which is mostly found at northeaster and southeastern of the area. Much of forest and agricultural land were found in this slope class.

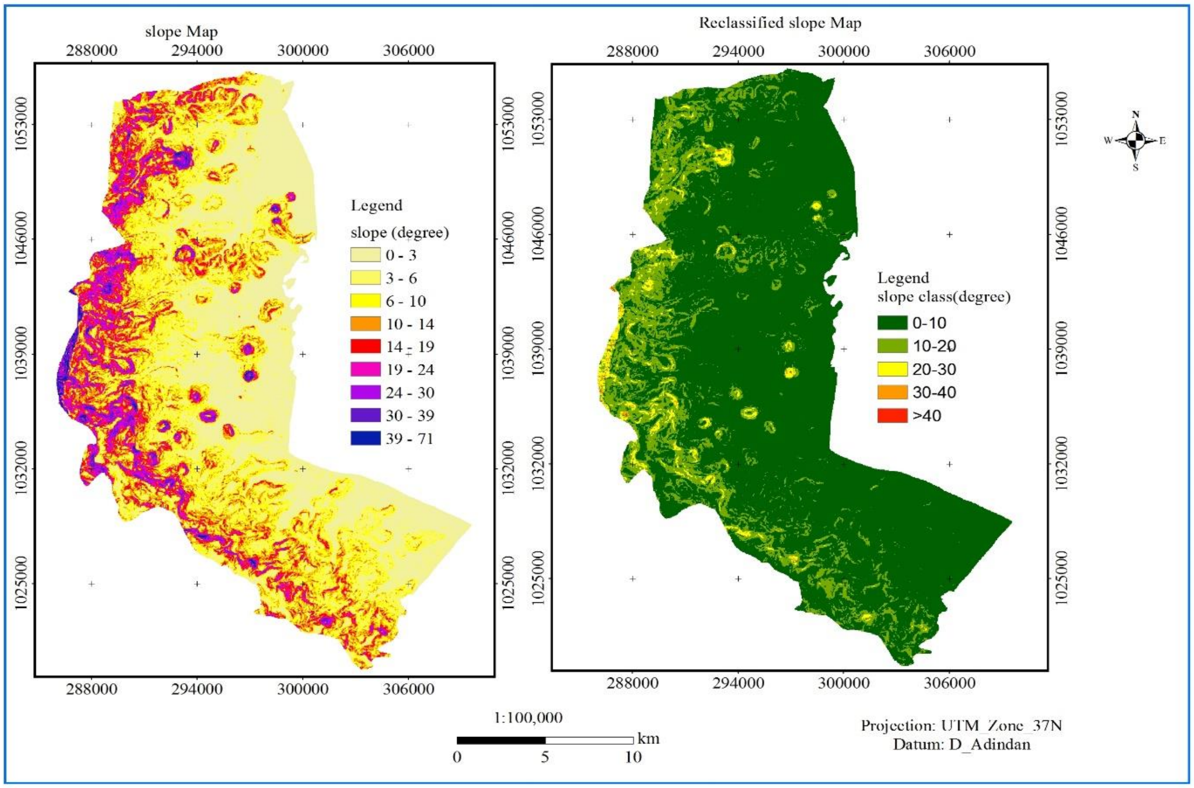


Figure 4. 1 Slope Map of study area

4.1.2. Geology

It is widely recognized that geology greatly influences the occurrence of landslides, because lithological and structural variations often lead to a difference in strength and permeability of rocks and soils. Thus, landslide activity is highly influenced by the nature and type of regolith material (Thomson. 1971). This is due to the stability of the slope is greatly influenced by the type and nature of underlying bedrocks (Negi *et al.,* 2012). The various mechanical properties influencing the stability of the slope are entirely dependent on the rock formation and the type soil that constitutes the slope (Raghuvanish *et al*., 2014a).

For the present study Geology were, considered as a basic contributing factor. Accordingly, six different geologic unit were, observed in the study area. The list of units and their respective total area was, summarized in Table 4.2.

Table 4. 2 Geology unit and area coverage

s.no	Geology Name	Area(km^2)	Area (%)
1	Quaternary sandstone	82.36	20.02
2	Water	49.96	12.14
3	Lower basalt	141.6	34.41
4	Trachytic plugs and flows	5.03	1.22
5	Upper basalt	65.28	15.87
6	Upper trachyte flow and pyroclastic rocks	29.93	7.27
7	Mesozoic sandstone	37.33	9.07
Total		411.49	100.00

According the table 4.2 most part of the study area covered by lower basalt, which cover 34.4% of total area. This type of geology was, found from south to north central part of the study area. However, this type of rock have high porosity and have a tendency to produce unusually mobile flows (Hutchnison. 2000). The second most dominant geologic type in the area is quaternary sandstone, cover 20.02% of total area. It was, found extensively at the southeast and northeast of the study area. It was located around water body. The third dominant geologic type in the study area is upper basalt, which cover 15.8% of total area. This rock found continuously from southwester to northwester of the study area. It was, characterized by high porosity and rapid weathering because it is pyroclatic rocks (Hutchnison. 2000). The fourth dominant geology type in the area is Mesozoic sandstone. This unit, exposed at north and northeastern part of the study area by covering 9.07% of total area. Trachytic plugs and flows covers 1.22% of the total area. This unit found at northwestern and southwestern part of the area. This type of rock characterized by high degree of weathering (Hutchnison. 2000). From the total area around 12.14% of the area was, covered by water body. Due to the depth of water, information about geology of the area was, not recorded. This area is located at northeastern part of the area. Figure 4.2 shown the geology type and its distribution in the study area.

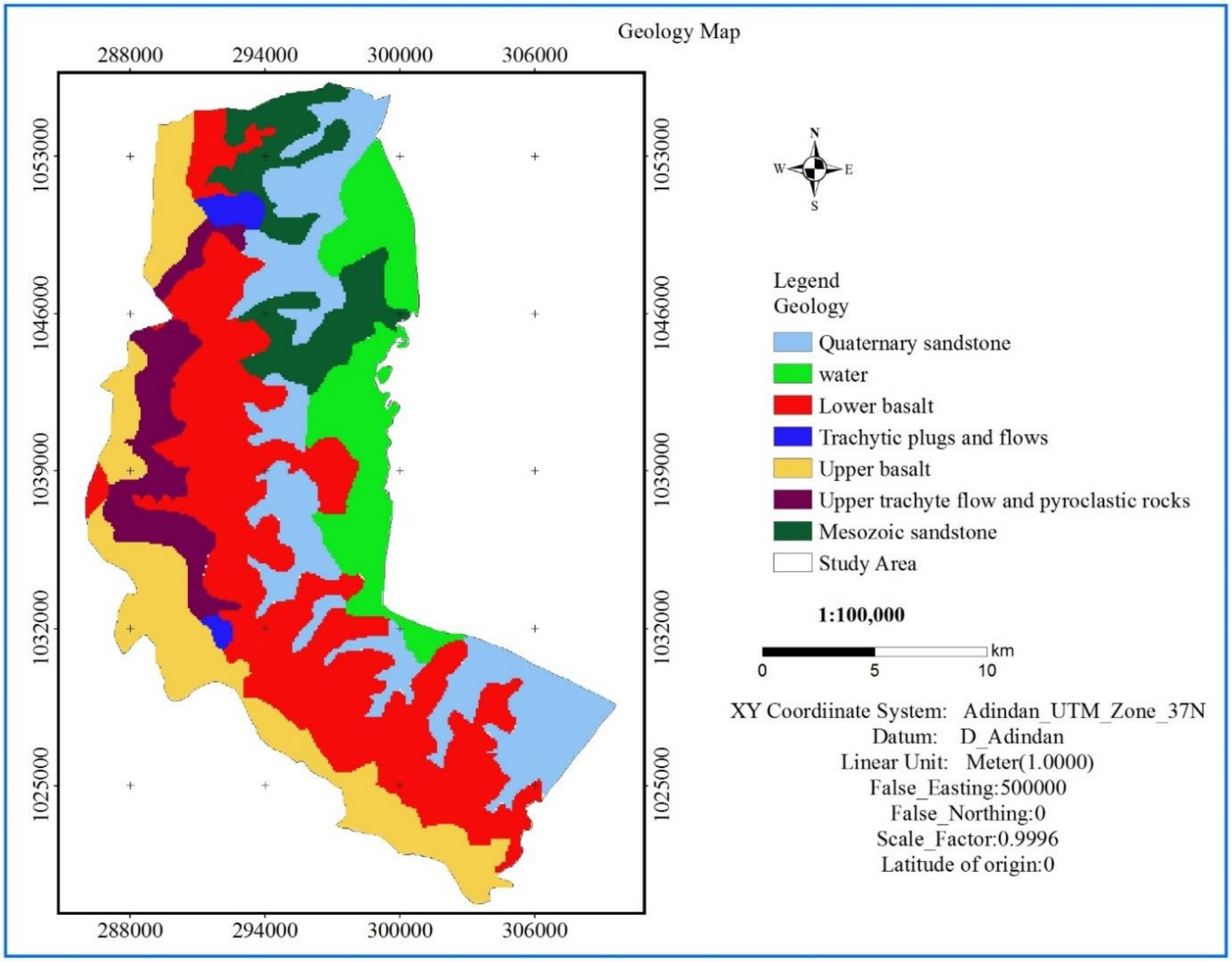


Figure 4. 2 Geology map of the study area

4.1.4. Lineament Density

Lineament is a map able simple or composite linear feature of the surface whose parts are, aligned in a straight or slightly curved and which differ distinctly from the pattern of adjacent feature and reflect a subsurface phenomenon. Such linearly oriented fracture controlled zones can be, interpreted as lineament. Hence, lineament with open fracture allow more water to infiltrate, increase pore water pressure and trigger slides along such weaker zones.

Therefore, landslide are more prone in the fractured, fault and jointed zone (Anbazhagan *et al.*, 2013). Although, the probability of landslides occurring is greater in highly fractured areas compared to those with a lower fracture density (Cortes *et al*., 2003). Conversely, lineament density are, used in landslide hazard assessment (Atkinson and Massari. 1998). However, it would seem that utilizing both lineament density and lineament buffer were, produce a more accurate landslide hazard assessment and introduce more uncertainty. The significance either using one or both factors when undertaking hazard mapping would be useful issue for further study. Several lineament in the study area occur tendency of, almost parallel to each other, implying that the stresses, which produce these features, were not local but acted in a large region to produce a number of failure or weak zones parallel to a particular direction. A number of parallel lineament was, observed in different part of the study area especially at southeastern region (figure 4.3). Based on the Lineament density the area was, divided into five category zone as very low density (less than 0.001 km/km^2), Low Density (0.001-0.003 km/km^2), moderate density (0.003-0.005 km/km^2), high density (0.005-0.007 km/km^2) and very high density (greater than 0.007 km/km^2).

Table 4. 3 Lineament density class and area coverage

s.no	Lineament Density Class(km/km^2)	Lineament density	Area(km^2)	Area (%)
1	<0.001	Very low	21.34	5.19
2	0.001-0.003	Low	17.65	4.29
3	0.003-0.005	Moderate	16.13	3.92
4	0.005-0.007	High	16.62	4.04
5	>0.007	Very High	339.75	82.57
Total			411.49	100

According to the table, the study area was, characterized by very high lineament density. Lineament density of the area were, high at southern part of the study area. The area which have greater than 0.007 km/km^2 dominated by very high lineament density which cover 82.57% of total study area. This show that large part of the area falls under very high lineament density. The second dominated lineament density is very low lineament density, which account 5.19% of total area. It was, found mainly at northern and central part of the study area. The third dominant lineament density in the area is low lineament density, the area between 0.001-0.003 km/km^2. It was, distributed at the northern, central and southern part of the area. Moderate lineament density cover only 3.92% of the total area. It was, mainly found at norther, central, and part of the area. It is, found between the area 0.003-0.005 km/km^2.

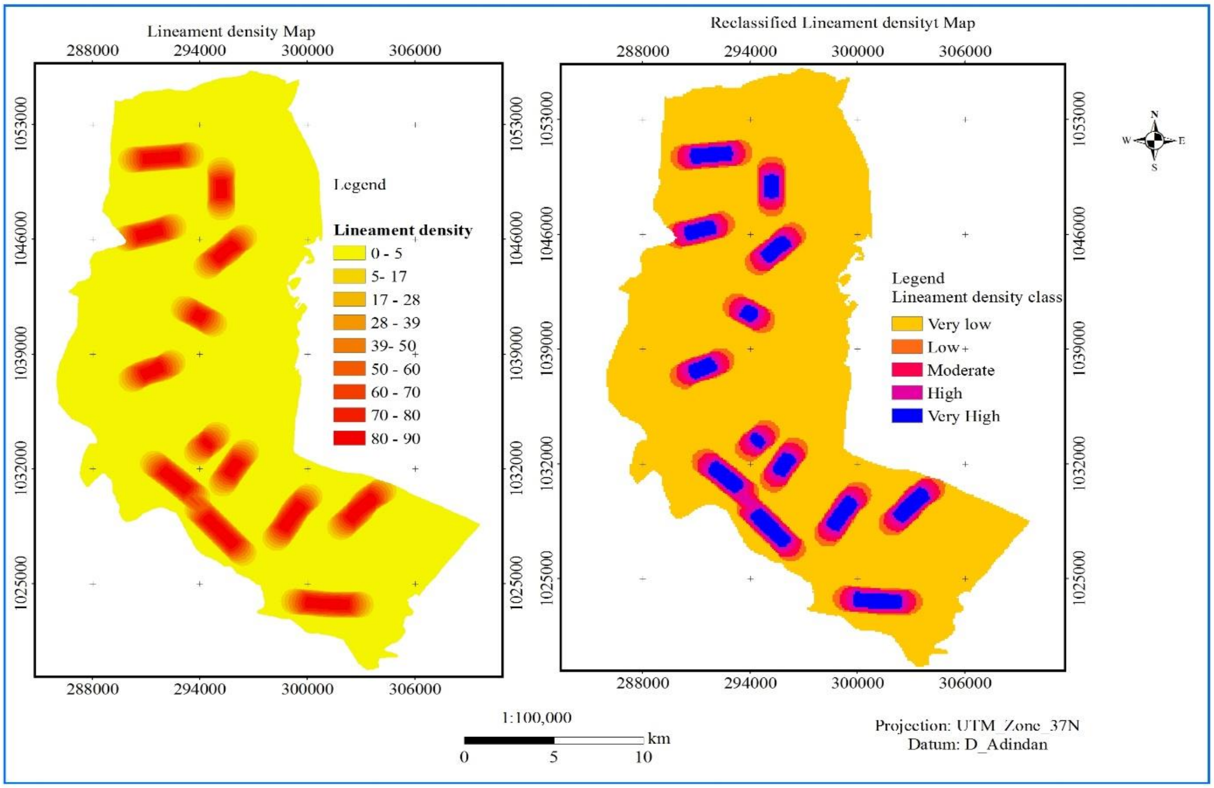


Figure 4. 3 Lineament density map of the study area

4.1.5. Soil Type

Soil type is important parameter in landslide analysis because type of soil determine the tendency of soil particle to resist sliding across each other. The nature of the movement is, controlled by the earth materials involved (Peter. 1970). Soil type with large particles such as sandy soils are the most cohesive while clayey soils with fine particles almost cohesiveness.

Friction force are dependent on the load placed on soil surface. The greater the load the greater the likelihood the force of friction will overcome. This result in the movement of soil particles within the soil layer and potential to slope failure (Ramakrishinan *et al.* 2002). Three different soil type exist in the study area. Although, the presence of different soil type in the area determine the nature of mass movement and slope failure. The soil type observed in study area have different soil property and area coverage. The total area coverage and soil type exist was, presented in table.

Table 4. 4 Soil type and area coverage

s.no	Soil Type	Area (km^2)	Area (%)
1	Humic Nitisols	298.28	72.5
2	Chromic Luvisols	0.17	0.04
3	Water Bodies	85.25	20.72
4	Fibric Histosols	27.79	6.75
Total		411.49	100

From the table above, the most common soil type in the area is Humic Nitosols covers (72.5%) of total area. This type of soil was, Deep, dark red, brown or yellow clayey soils having a pronounced shiny, nut-shaped structure (HWSD). In addition to, this type of soil have loam texture, it comprise comprises particles, or granules, ranging in diameter from 0.0625 mm (or 1⁄16 mm) to 2 millimeters. It was, found at southwestern, central, northern and northwestern of the study area.

The second most common is Fibric Histosols, which account (6.75%) of the study area. This type of soil composed of organic materials (HWSD). However, this type of soil have clay texture. Clay is naturally occurring firm earthy material, composed primarily of fine-grained (diameter less than 0.002mm) that is plastic when wet and hardens when heated and that consists primarily of hydrated silicates or aluminum. It was, mainly exposed at southeastern of the study area. The third soil type dominate the area was chromic luvisols which account only 0.04% of total area. This soil type located at western part of the study area by covering small area. This soil type have loam texture.

It was, dominated by medium texture. Most part of the area found at northeastern have no information about soil type. This is because of the presence of water in the area information about soil was not recorded.

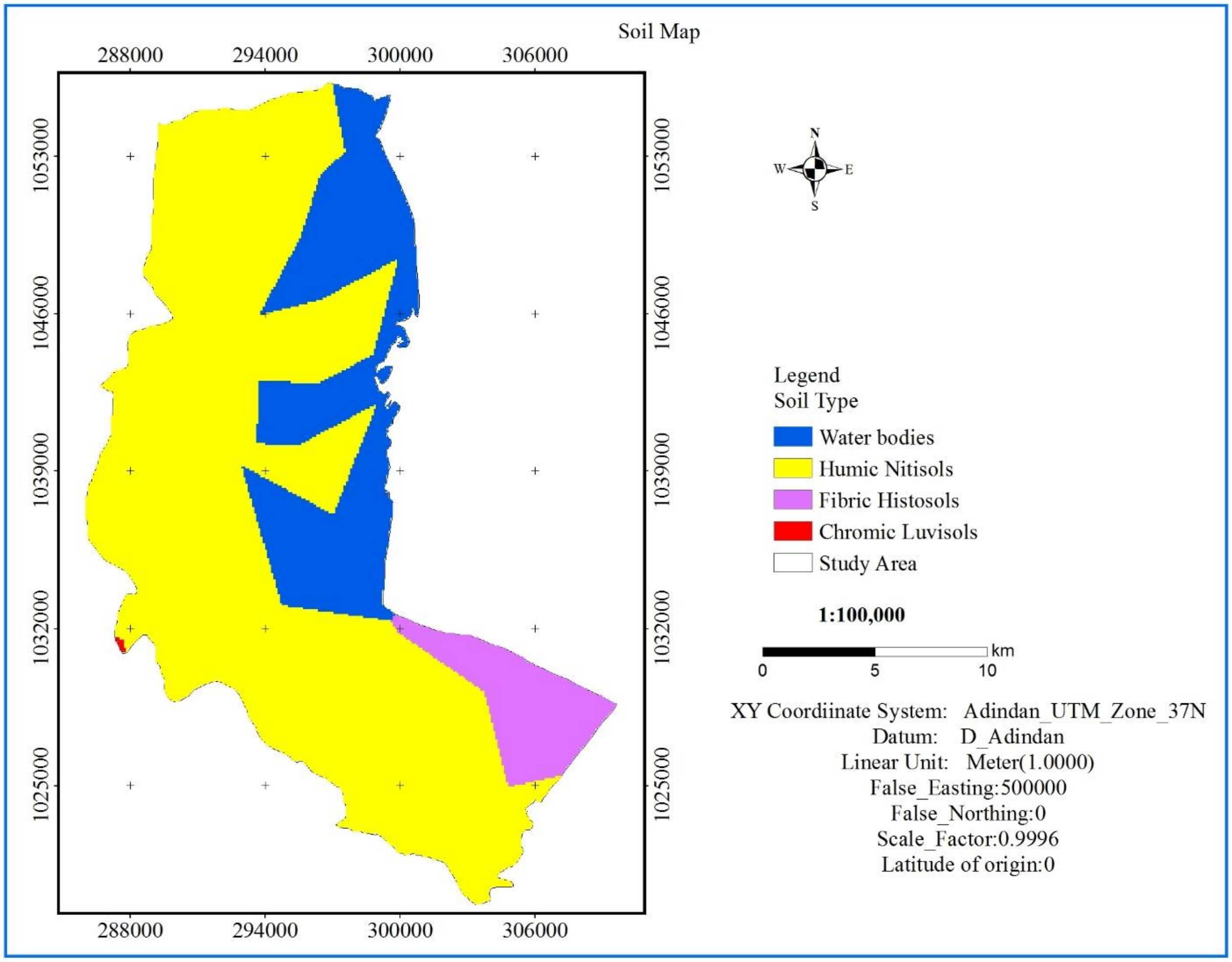


Figure 4. 4 Soil map of the study area

4.1.6. Aspect

Aspect show the inclination or orientation of slope in a given area. Although, aspect strongly influences potential direct incident radiation and thus temperature. Therefore, the moisture of the soil on the ground may alter. Aspect as a landslide-conditioning factor has been, considered in various studies (Ercanoglu and Gokceoglu. 2004). Aspect gravely affects hydrological processes such as evapotranspiration, weathering, and vegetation growth particularly in arid environments and areas with weak soil types (Sidle and Ochiai. 2006). As a result, this parameter was, also considered as a conditioning factor for the present study area. The slope aspect for the study area was, divided into five categories: North, Northeast, Northwest, Southwest and south.

Table 4. 5 Aspect class and area coverage

s.no	Aspect class	Area (km^2)	Area%
1	North	52.75	12.82
2	Northeast	68.38	16.62
3	Northwest	32.45	7.88
4	Southwest	59.21	14.4
5	South	198.68	48.28
Total		411.49	100.00

From the table most of the area was, dominated by slope facing to south, which account 48.28% of total area. This aspect class commonly covered southeastern part of the study area. The second aspect class dominate the area was, northeast facing slope, which cover 16.62% of total area. It was, distributed in all part of the study area except northeastern. However, various researcher prove that slope facing to north and northeaster have high probability to failure. In present study area, this aspect class falls on high topography and agricultural land. Slope facing to southwest in the study area was, cover 14.4% of total area. This aspect class mainly distributed at northwestern and scattered at all part of the study except northeast. It was the third dominating aspect class in the area. The fourth dominant aspect class in the area was, aspect class aspect facing to north direction. It cover 12.82% of total area. This aspect class in the study area mostly falls on highly elevated area located at western and northwester of the study area.

Slope facing to northwestern of the study area was, scattered in all part of the study area by covering 7.88% of total area. It is located on terrain covered by forest. This aspect class cover small area of the study area among aspect class. However, this aspect class have a contribution for slope instability; because of partially the slope was face to the north direction as proved by various researcher. Fig 4.5 Shown aspect class with their distribution in the study area.

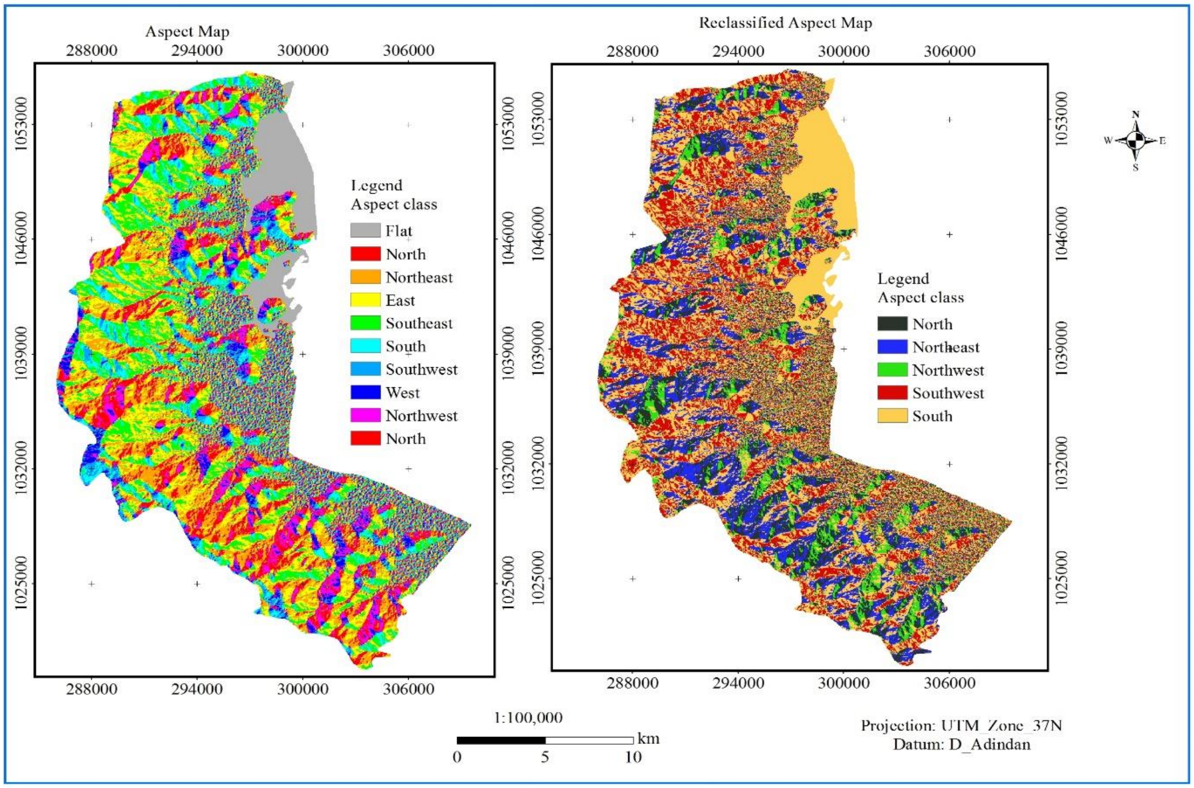


Figure 4. 5 Aspect map of the study area

4.1.7. Land Use Land cover

Land use and land cover play a significant role in influencing landslides**.** Many landslides occur mainly due to the improper activities such as deforestation and increase in the urbanization over a period. Areas with little or no vegetative land cover and areas degraded by inappropriate logging, pastoral, agricultural or construction practices are predisposed to landslides and mass-wasting events (Varnes. 1978). Although, Rapid changes in land use and land cover, as well as land degradation processes, are precursors to mass movement events (Alcántara *et al*. 2006). Therefore, for the present study land use land cover was, considered as a contributing factor for landslide hazard analysis. The Identified land cover types that were, reclassified included the following: Agriculture, Wetland, Grassland, Forest, and water body.

Table 4. 6 Land use land cover type and area coverage

s.no	LuLc Type	Area (km^2)	Area (%)
1	Agriculture	251.71	61.17
2	Wetland	40.58	9.86
3	Grassland	14.85	3.61
4	Forest	33.83	8.22
5	Waterbody	70.52	17.13
Total		411.49	100.00

As indicated in the table, large parts of the study area were, covered by agricultural land, which account 61.2% of total area. It was, found at southern to northern and western direction. Agricultural land in the area were, observed in different range of slope angle. Due to suitability of soil type for different crops, large area was, used for cultivation. The second land cover dominate the area were water body, which account 17.13% of total area. This is mainly located at northeastern of the study area. Although, most part of the study area was, dominated by water body, cover 17.13% of total area. Water body that mainly dominated southeastern part of the area is Lake and others were, distributed in all part of the area with small area coverage. Because of gentle slope topography of the area, accumulation of water is high.

The area also characterized by wetland which account 9.86% of total area. It was, mainly found at southeastern of the area and northeaster along water body. In addition, forest have significant contribution to characterize the area. Forest the area cover 8.22% of total area. Mostly forest in the area is located on terrain. Area, which are unsuitable for agricultural purpose and other activities were, covered by forest. Forest was, found mainly in western and norther highland of the area. Forest in the northern part of the area were, planted by community environment, while forest scattered in other part of the area was natural forest.

Grassland in the area, which account only, 3.6% of total area. It was, found around wetland and water body, southeastern, eastern and northeastern of the area.

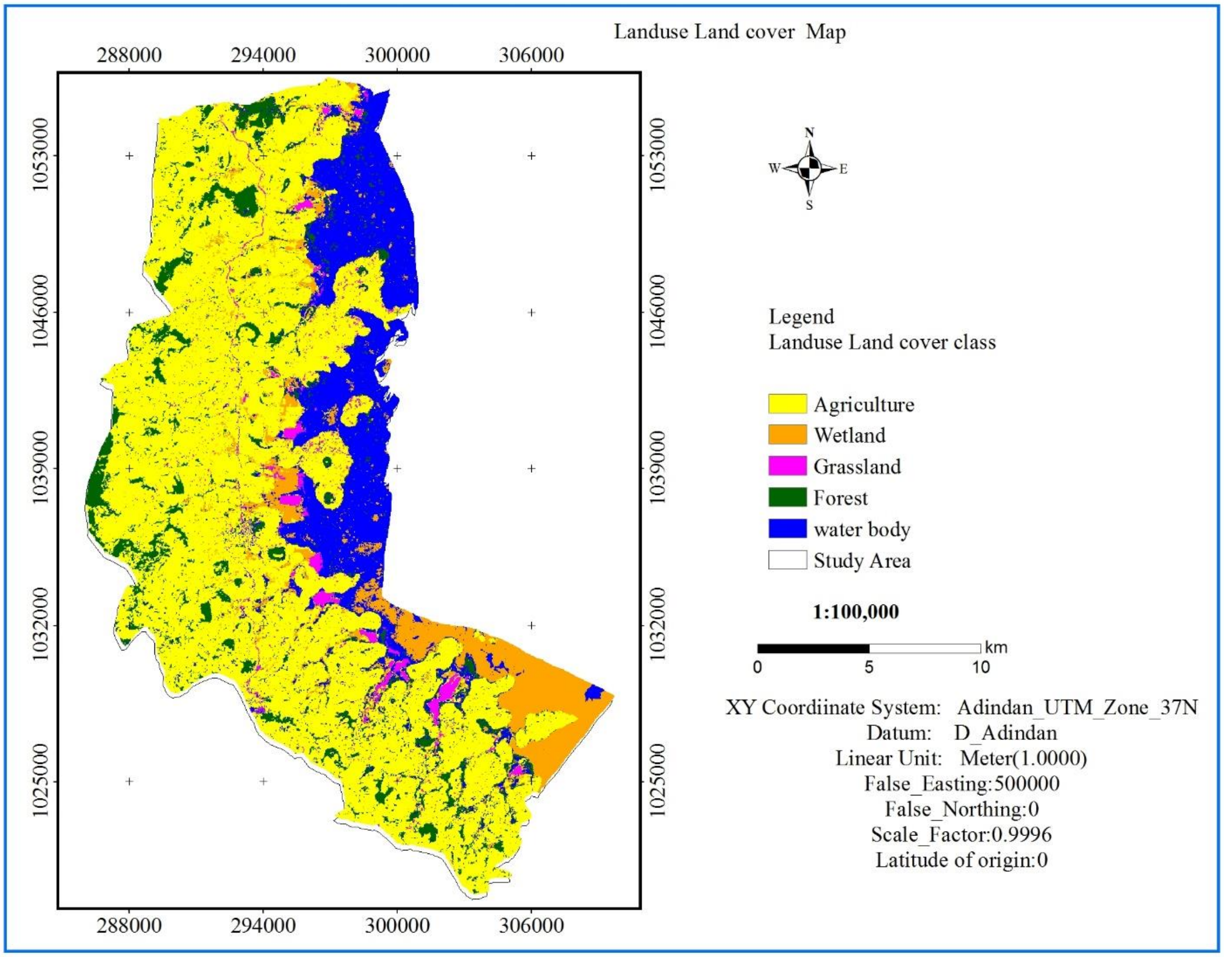


Figure 4. 6 Land use land cover map of the study area

Accuracy Assessment

To know the exactness of the prepared land cover map, accuracy assessment should be, done for the classified image. This is because image classification without accuracy assessment is inadequate (Lillesand *et al*. 2004). Land cover maps derived from remote sensing imagery always contain some sort of errors due to several factors, which range from classification technique to method of satellite data capture. Therefore, accuracy assessment performed for image classification was, used to tell how accurately the land use /land cover maps were, classified correctly. The present study used 252 randomly selected pixels for the 2019 land use /land cover map, were, also checked with reference data (ground data collected by hand held GPS) to assess the accuracy of the classification. The current study revealed on an overall accuracy 85.3% and a kappa index of agreement of 0.816. The kappa coefficient implies that the classification process is avoiding 81% of the errors that a completely random classification generates.

Table 4. 7 Accuracy assessment of the classified land use/land cover map

CD	Ag	Wtl	Grsl	Frt	Wb	ROT	RT	CLT	NOCC	PA	UA
Ag	45	1	2	1	2	51	54	51	45	83.3%	88.2%
Wtl	3	39	4	1	3	50	44	50	39	88.6%	78.0%
Grsl	1	2	41	3	3	50	51	50	41	80.4%	82.0%
Frt	2	0	2	46	0	50	51	50	46	90.2%	92.0%
Wb	3	2	2	0	44	51	52	51	44	84.6%	86.3%
CT	54	44	51	51	52	252	252	252	215		

Ag=Agriculture, Wtl=Wetland, Grsl=Grassland, Frt=Forest, Wb=Water body, RT=Reference total, ROT=Row total, CLT=Column total, CD= Classified data, CLT= Classified total, PA=Producer Accuracy, UA=User Accuracy.

4.1.8. Drainage Density

Drainage density is the drainage by streams of the watershed into the main stream. It indicates the closeness of spacing of channels, providing a quantitative measure of the average length of stream channel for the basin. Moreover, drainage density is highly affected by physiography of the particular area and an important factor for landslide occurrence. This is a result of on steep slope; surface water accelerates and rock erosion increase, while on lower slope surface flow decrease and sediment accumulation increase, and therefore, probability of landslide occurrence increase (Samy *et al*. 2012).

Although, impermeable rocks were, exposed to the runoff resulted in poor drainage density and high ragged terrain have more drainage density (Ankit Sharma & Prafull Singh 2014). High Drainage density erode the soil and tend to break the rock resulting in landslide. The drainage density of the study area was, produced from stream network of the area (Appendix, figure A.4).

In the study area, two types of stream network were, observed they are dendritic and longitudinal stream network. Dendritic stream network reflects areas with steep slopes, low precipitation and high rate of rock erosion. Longitudinal stream network reflects areas with gentle slopes, high precipitation and accumulation. Based on the drainage density the area divided into five category zones as very low density (less than 0.006 km/km^2), low density (0.006-0.012 km/km^2), moderate density (0.012-0.018 km/km^2), High density (0.018-0.024 km/km^2) and very high density (greater than 0.024 km/km^2). Closer investigations of the processes responsible for drainage density variation have revealed that a number of factors like climate, topography, soil infiltration capacity, vegetation, and geology collectively influence stream density (Pidwirny. 2006).

Table 4. 8 Drainage density class and area coverage

	Drainage Density class(km/km^2)	Density	Area(km^2)	Area (%)
1	<0.006	Very low	0.86	0.21
2	0.006-0.012	Low	5.31	1.29
3	0.012-0.018	Moderate	63.7	15.48
4	0.018-0.024	High	181.61	44.13
5	>0.024	Very High	160.01	38.9
Total			411.49	100

The table shown, most part of the study area was, characterized by high drainage density, which cover 44.13% of total area. It was, found at southern and central part of the study area. High drainage density in the area is the result of weak or impermeable subsurface material, sparse vegetation and high relief. Although, high drainage density gives rise to a fine drainage texture (Strahler. 1964). Even though, high drainage density in the area may indicate, areas of high precipitation, low infiltration, greater flood and thin vegetation cover.

The second dominant drainage density in the area is very high drainage density, it cover 38.9% of total area. It is located on very high elevation and distributed in all part of the study area. In addition to, low and very low drainage density in the area covers only 1.3% of total area and located at southern, northern, northeastern and scattered in all part of the area. According to Nag (1998), low drainage density is generally characteristics areas of highly resistant or permeable subsoil material, dense vegetation and low relief.

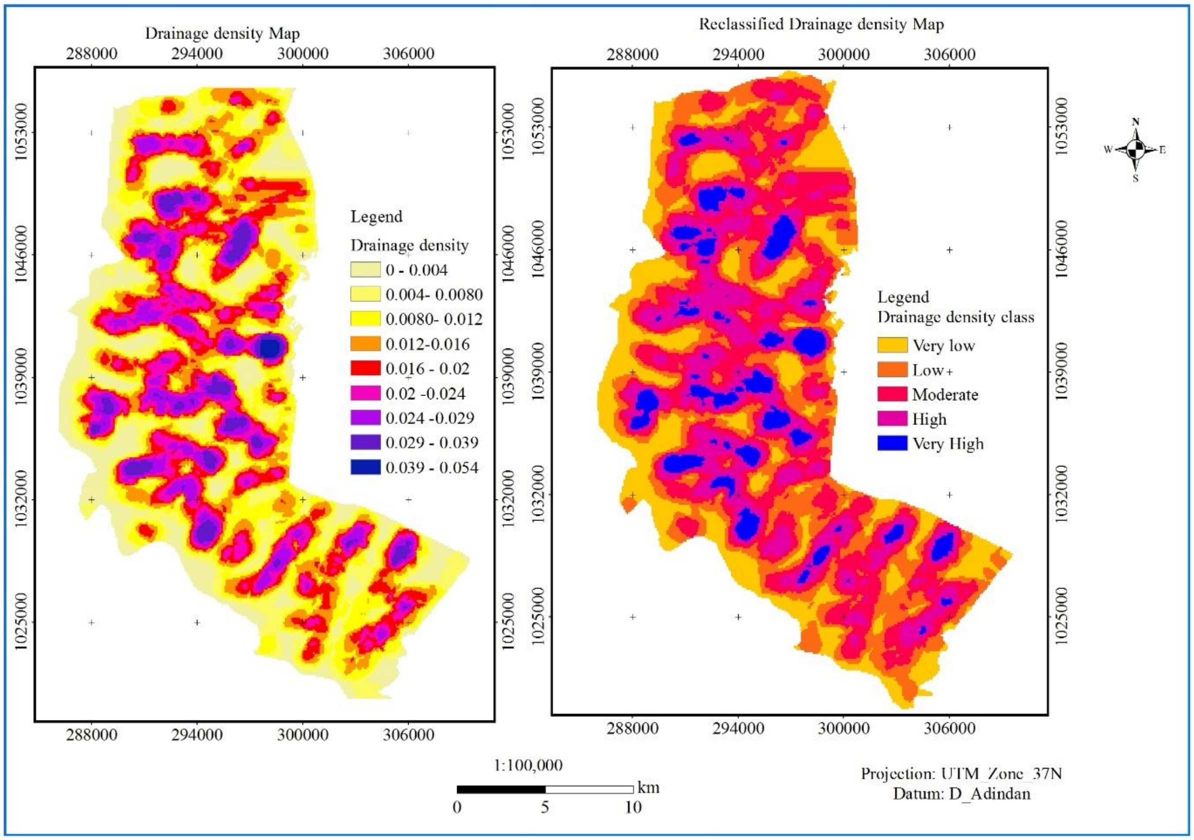


Figure 4. 7 Drainage density map of the study area

4.2. Assigning Criteria Weight

After the standardization to common scale (30*30m) of each causative factor, weight is, given for each layer based on pairwise comparison of two data layers at the same time, using pairwise comparison of 9-point continuous rating scale in IDRISI selva 17. Moreover, weight module is, used to develop a set of relative weights for a group of factors in a multi-criteria evaluation.

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. Consequently, 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. Although, the factors and their resulting weights can be, used as input for the MCE module for weighted linear combination or for other MCE modules.

Accordingly, the weights developed to each factor are, given based on the analytical hierarchy process proposed by Saaty (1994) by means of providing a series of pairwise comparisons of the relative importance of factors. In each cell of the matrix, the relative significance of the row variable to its corresponding column variable was, considered and the appropriate rating was, given. The resulting consistency ratio of the pairwise comparison matrix is 0.08 that indicate acceptable consistency range because the acceptable consistency ratio of the pairwise comparison matrix is less than 0:10).

Table 4. 9 Analytical Hierarchy Process weight derivation module

Factors	Aspect	Drainage Density	Land use Land cover	Soil	Slope	Lineament Density	Geology	Weight
Aspect	1							0.12
Drainage Density	1/5	1						0.3
Land use Land cover	1/5	1/3	1					0.15
Soil	1/7	1/3	1/3	1				0.07
Slope	1/9	1/3	1/3	1/7	1			0.17
Lineament Density	1/5	1/5	1/5	1/5	1/3	1		0.03
Geology	1/7	1/5	1/7	1/3	1/5	1	1	0.16

Consistency ratio: 0.09

The weights calculated indicate the relative significance of the factors in contributing mass movement. From obtained result, highest weight was, given to drainage density. The next highest weight has been, given to slope, geology and land use land cover.

Finally, less weight has been, given to lineament density and aspect as compare to others although they play a reasonable contribution to the existing mass movements in the study area.

4.3. Weighted Linear Combination

Through a Multi-Criteria Evaluation, these causative factors (aspect, drainage density, land use land cover, geology, lineament density, slope and soil maps) representing are combined to form a single hazard map. The weighted linear combination (WLC) method presented by (Drobne and Lisec. 2009) was, used to obtain a linear combination of weighted parameters for landslide hazard map. Each causative factor was, multiplied by its derived weight and then the results added to produce the landslide hazard map.

Landslide hazard zone of the study area was prepared was reclassified using spatial analysis tool, available in ArcGIS 10.5. Conversely, the hazard rating selection was somewhat subjective. The rating of hazard indicate that the likelihood of a landslide occurrence. For the present study due to limited landslide inventory data records were, made available during the analysis, the hazard class were, first reclassified by equally dividing the maximum score to four class; namely very low, low high and very high hazard zone.

4.4. Results and Discussions

4.4.1 Results

4.4.2. Landslide Hazard Map

The landslide hazard map prepared for the present study area revealed that, very high hazard zone cover 63.45 km^2 or 15.42% of total area. Very high hazard zone consists of forest and agricultural land, which is located on more than 20^0 slope angle and nitisols soil type and lower basalt and Trachytic plugs and flows geologic type. The drainage density found on very high hazard zone is high drainage density. High percent of very high hazard zone is located on steep slope and forest area. High hazard zone cover 241.893 km^2 or 58.78% of total area. High hazard zones located at various land use land namely forest, agricultural land, grassland and wetland. The slope is vary from 0^0 to 40^0. Low hazard area cover 92.674km^2 or 22.52 % of total area. Low hazard zone located on slope less than 10^0 and greater than 40^0. The land use land cover located on low hazard zone are mainly wetland and forest. The distribution of low hazard zone in the area is predominately on gentle slope and on steeper slope. Very low hazard zone cover 13.473km^2 or 3.27% of total area. Land use land cover type located on very low hazard zones is water. Very low hazard zone is located on very gentle slope in the study area.

Table 4. 10 Landslide hazard class and area coverage

s.no	Landslide Hazard zone	Area(Km^2)	Area (%)
1	Very High	63.45	15.42
2	High	241.89	58.78
3	Low	92.67	22.52
4	Very Low	13.47	3.27
Total		411.49	100.00

Distribution of different landslide hazard zone in the study area produced in present study was, presented in figure 4.8. Very high hazard zone are, distributed in the central part from southern to northern of the study area and highly concentrated in southwest. High hazard zone are, distributed in the northern, southern, southwestern, northwestern, and mainly concentrated in the central part of the study area. Low hazard zone are highly distributed in the northeast, southeast and eastern regions and have scattered distribution at southern part of the study area. Very low hazard zone are mainly concentrated in the northeastern region and scattered at southeastern region of the study area. The hazard map shows, the areas of very highest hazard represented by the highest elevation, forest area and agricultural land. Especially, agricultural land on terrain and high drainage density in the area are more prone to landslide.

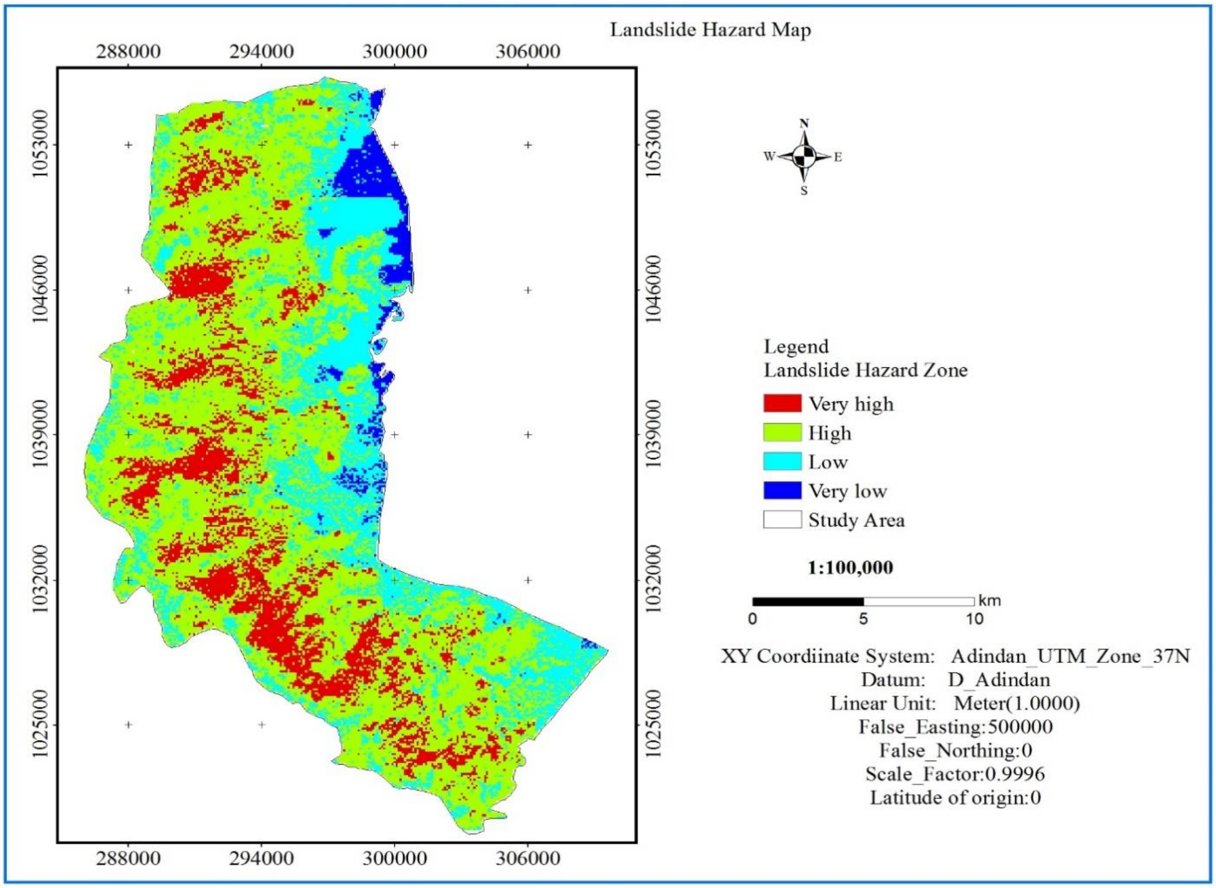


Figure 4. 8 Landslide hazard map of the study area

4.5. Verification of Landslide Hazard

Databases of historical landslide events are essential for the calibration and the confirmation of the model results. Although, landslide inventory data is, considered as the initial tool for landslide hazard evaluation (Dai and Lee. 2002). Thus, for the present study landslide inventory data was, collected through field investigation using hand held GPS and landslide on inaccessible areas like gorges, high cliff and in dense vegetated areas were, identified on Google Earth image (Google Earth pro 2019). The data include location of landslide, landslide location coordinate, landslide triggering event, landslide type and land use of each slide present. The classification of landslide was, offered based the definition given by Varnes (1978). Thus, most of the landslides or slope failures identified were, related to rotational slides, transitional slide, debris flow, earthflow and rock fall (Appendix Table A.1). Accordingly, 40 point of landslide inventory data was, collected. The verification was, performed by comparison of existing landslide data (inventory data) with the prepared landslide hazard map. The analysis results were validated using the Relative landslide density index (R-index) and receiver operating characteristic (ROC) analysis to evaluate the correlation between the landslide hazard maps and landslide inventory points. Relative landslide density index (R-index) used in this study was to assess the relationship between landslide hazard map and landslide inventory points. Relative landslide density index (R-index) were, performed with a formula defined by, Baeza, &Corominas. (2001) as follows.

$$R = \left(\frac{ni}{Ni}\right) / \sum \left(\frac{ni}{Ni}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4. 1}$$

Where: ni the number of landslides occurred in the sensitivity class i.

Ni the number of pixels in the same sensitivity class i.

The R-index result class of very high, high and low hazard zone shown that, 54%, 21% and 25% respectively. A standard validation analysis was, additionally performed, using the validation datasets in order to estimate the overall performance of landslide hazard in the study area. For the validation of the output from analysis, the receiver operating characteristics (ROC) curve was drawn, and the area under curve (AUC) value was calculated. (ROC) curves in the present study. The ROC curve technique was, based on plotting model sensitivity, true positive fraction values calculated for different threshold values versus model specificity, true negative fraction values on a graph (Deleo. 1993). Model sensitivity true positive fraction is the ratio between correctly classified presence data and all presence data, while model specificity true negative fraction is the ratio between correctly classified grid cells with landslides and all grid cells without landslide (Pradhan and Lee 2010). When calculating the ROC value, AUC values close to 1.0 indicate high levels of accuracy of the model while results close to 0.5 indicate inaccuracies in the overall model, Yilmaz (2010). Comparison result of present result study shown in figure 4.9. When the validation landslide data was, overlaid onto the landslide hazard map 0.81 AUC value were, achieved.

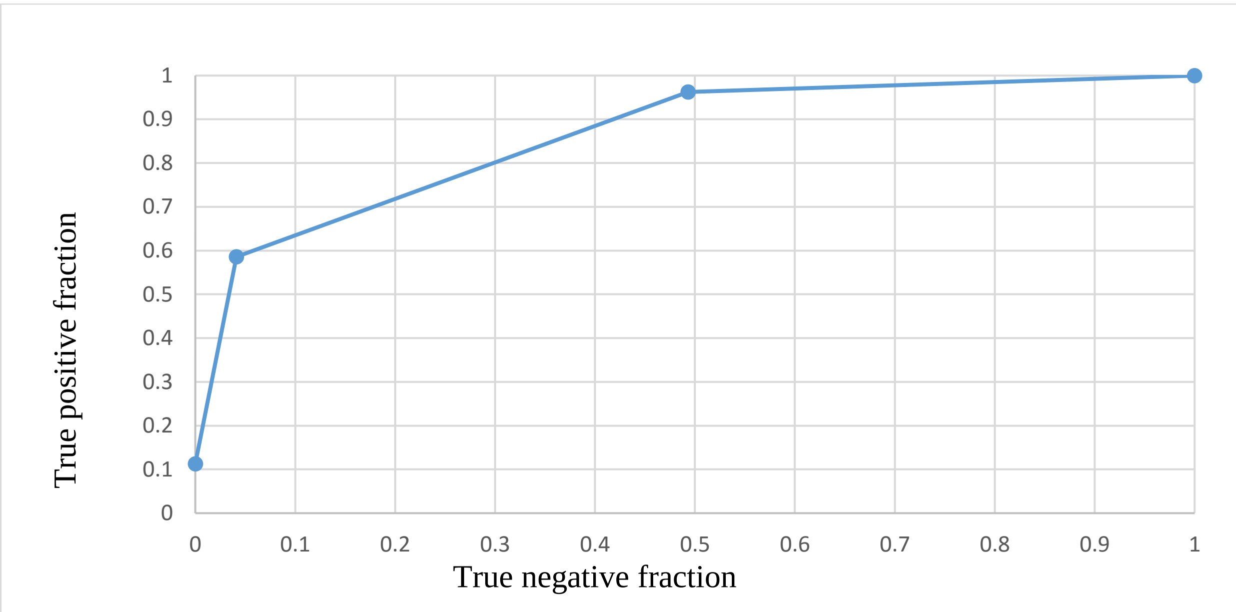


Figure 4. 9 Receiver operating characteristic curve

The overall verification of (Relative landslide density index (R-index) and receiver operating characteristic (ROC) showed a satisfactory agreement between the landslide hazard map and existing data from landslide inventory data.

4.6. Correlation between Landslide Occurrence and Causative Factors

Landslide occurrence is, determined by landslide-related factors, and that future landslides will occur under the same conditions as the past landslides. The assumption behind landslide hazard zone is that future landslides will occur under similar conditions as past and present landslides

(Lee and Talib. 2005). The relationship between landslides occurrence in an area and the landslide related factors can be, distinguished from the relationship between landslides not occurring in an area and the landslide-related factors. This relationship can be, computed using frequency ratio quantitatively. Landslide frequency ratio can be calculated by the ratio of percent domain of a factor class and percent landslide in that class (Lee and Sambath 2006; Poudyal *et al.* 2010; Pradhan 2010; Pourghasemi *et al*. 2013). The ratio value indicates how strong the spatial relationship is between a landslide occurrence and landslide-related factor's classes. Thus, frequency ratio value shows the correlation between landslides and causative factors in a specific area (Meten *et al.* 2015). Moreover, when, the frequency ratio value is greater than one, the percentage of the landslide area in the class is higher than the percentage of the class in the total area; it indicates a strong relationship between landslides and the factor's class. While, when the value is less than one, it means a weak relationship and if the value is one, it means an average correlation (Lee and Sambath 2006; Pradhan 2010a). In the current study landslide factors namely drainage density, lineament density, slope, aspect, land use land cover, soil and geology) were, converted into raster map with a pixel size of 30 m. Landslide point data and each causative factor were, overlaid. Using zonal tool in ArcGIS from landslide inventory data, landslide distribution area relative to each causative factor class were, calculated. Based on pixel count of causative factor class and landslide area corresponding to causative factor class, the frequency ratio of each factor class was, obtained by rationing landslide percentage to area percentage.

The frequency ratio defined as:

$$\mathrm{FR_i} = \frac{\mathrm{N_{pix(s_i)}}/\mathrm{N_{pix(N_i)}}}{\sum \mathrm{N_{pix(s_i)}}/\sum \mathrm{N_{pix(N_i)}}} \quad \text{Equation 4. 2}$$

Where; $\mathrm{FR_i}$ is the frequency ratio of class 'i' of causative factor 'j',

$N_{pix(s_i)}$: The number of pixels containing landslide in class 'i',

$N_{pix(N_i)}$: Total number of pixels having class (i) in the whole area of the study area,

$\sum \mathrm{N_{pix(s_i)}}$: Total number of pixels containing landslide,

$\sum \mathrm{N_{pix(N_i)}}$: Total number of pixels in the whole area of the study area

Table 4. 11 Calculation of frequency ratio value

Factors	Class	No of pixel in class	Class (%)	No of landslide pixel within the class	Landslide (%)	FR
Drainage density	very low	97624	21.3	3600	10	0.46
	Low	115943	25.3	3600	10	0.39
	Moderate	122605	26.8	13500	37.5	1.39
	High	87827	19.2	9900	27.5	1.43
	very high	33463	7.3	5400	15	2.1
Total		457462		36000		
Slope	0-10	176048	38.5	9000	25	0.64
	10-20	133359	29.15	13500	37.5	1.28
	20-30	89176	19.49	8100	22.5	1.15
	30-40	45242	9.9	3600	10	1.01
	>40	13637	2.98	1800	5	1.67
Total		457462		36000		
Land use land cover	Agriculture	287671	62.88	27000	75	1.19
	Wetland	42384	9.26	900	2.5	0.26
	Grassland	10497	2.29	900	2.5	1.09
	Forest	38660	8.45	4500	12.5	1.48
	Water	78250	17.1	2700	7.5	0.44
Total		457462		36000		
Geology	Quaternary sandstone	91403	19.98	27000	75	3.75
	Water	55415	12.1	900	2.5	0.21
	Lower basalt	157166	34.36	900	2.5	0.07
	Trachytic plugs and flows	5599	1.22	4500	12.5	10.21
	Upper basalt	72501	15.85	2700	7.5	0.47
	Upper trachyte flow and pyroclastic rocks	34113	7.46		0	0
	Mesozoic sandstone	41265	9.02		0	0
Total		457462		36000		

Table 4.11 Calculation of frequency ratio value (*continued*)

Aspect	North	58641	12.82	5400	15	1.17
	Northeast	70990	15.52	9000	25	1.61
	Northwest	58190	12.72	1800	5	0.39
	Southwest	94971	20.76	6300	17.5	0.84
	South	174670	38.18	13500	37.5	0.98
Total		457462		36000		
Lineament density	very low	372692	81.47	28800	80	0.98
	Low	19428	4.25	900	2.5	0.59
	Moderate	20161	4.41	900	2.5	0.57
	High	21287	4.65	900	2.5	0.54
	Very High	23894	5.22	4500	12.5	2.39
Total		457462		36000		
Soil type	Humic Nitisols	331458	72.46	32400	90	1.24
	Chromic Luvisols	197	0.04	0		0
	Water Bodies	93859	20.52	0		0
	Fibric Histosols	31948	6.98	3600	10	1.43
Total		457462		36000		

The correlation analysis by frequency ration presented in the table 4.11 indicate the importance of causative factor class on the landslide occurrence. Accordingly, frequency ratio of drainage density indicate that very high and high drainage density shown strong correlation with landslide occurrence in view of frequency ratio, value is 2.1 and 1.43 respectively. Thus, the area that have very high and high drainage density in the study area have high probability to landslide occurrences. The frequency ratio in other class of drainage density is low and it implies the probability of landslide occurrence in those classes is also low.

Frequency ratio result of slope class greater than 40^0 indicate strong correlation with landslide occurrence, the value is 1.67. Thus, slope in the study area that have an inclination of greater than 40^0 are most prone to landslide. Conversely, slope below 10^0 shows frequency ratio 0.64 and for slope class 10^0-20^0, 20^0-30^0, 30^0-40^0 the frequency ratio value is greater than one that also indicate the probability of landslide occurrence in those class is high.

Within land use class, forest frequency, ratio result have shown strong correlation with landslide occurrence, value is 1.48. Although, the frequency ratio of agriculture and grassland is 1.19 and 1.09 respectively. The value is greater than one that also shows the probability of landslide occurrence in these classes has be, high. The remaining land use class show the probability of landslide occurrence is low as frequency ratio indicate the value is less than one.

Frequency ratio of geology layer reflected that, in the trachytic plugs and flows the highest frequency ration was, recorded. It indicate that in the study area the area that have trachytic plugs and flows geologic type have strong correlation with landslide occurrence. Type of rock showed a very robust influence on landslide event in the study area. Although, the frequency ratio of quaternary sandstone is 3.75 the value is greater than one. Which shows the probability of landslide occurrence is high in the area covered by quaternary sandstone. The occurrence of landslide in the remaining geologic type of the study area, is low as the frequency ratio indicate, the value is greater than one.

In a case of aspect, frequency ratio of northeast and north facing slope showed a strong correlation with landslide. The remaining class of aspect have weak correlation with landslide occurrences because the frequency ration value is less than one. From lineament density class, very high lineament density showed strong correlation with landslide occurrence as frequency ration indicate. The occurrence of landslide in the remaining class of lineament density is low as frequency ration indicate, it show weak correlation. In a case of soil type class, frequency ratio of histosols and nitisols are high and it indicate strong correlation with landslide occurrence. The remaining class of soil type have no correlation with landslide occurrence.

4.7. Mitigation Measures

Mitigation is action taken to prevent or reduce the risk of life, property, social and economic activities, and natural resource from natural hazard. Mitigation of landslide hazard can be successfully undertaken when detailed information about frequency, magnitude and character of slope failure within a particular area are, known (Vijith *et al*. 2009; Liu *et al*. 2006). For these reasons the identification of landslide-prone areas represents a cheap and fast method in understanding this hazard and in ensuring that appropriate mitigation strategies are implemented (Bai *et al*. 2009).

Landslide hazard can be, mitigated by both physical countermeasures such as slope stabilization, reforestation and water management and non-physical countermeasures such as evacuations and road closures. Nevertheless, every class has some distinct characteristics and mechanism of failure, therefore mitigation measure are, proposed to overcome the effect of each class on slope stability (Bhim *et al*. 2017).

The landslide hazard map of the study area was, generated from the most predominating factors causing landslide hazard in the area. Landslide hazard class was, analyzed by considering slope morphology, stream network, drainage density and land use land cover of the area corresponding to hazard class. Landslide hazard information contained in this study provide a solid practical, policy and legal foundation which will enable local government planners to avoid or mitigate landslide hazard and help to build sustainable, hazard resilient communities in the study area. Therefore, selection of the most appropriate mitigation measures to be adopted in hazard zone take into account the factor that affect the hazard in terms of the probability occurrence of movement or landslide such as the morphology of the area, the actual or potential causative processes affecting the geosystem, which can determine the occurrence of movement or landslides.

Thus, mitigation measures proposed was, based on different predominating factors are overlapped in each and every cell unit of landslide hazard map by considering topography of the area relative to hazard zone. When landslide hazard map was, overlapped with causative factors, landslide hazard class was, observed in different class of causative factors. Depending on causative factor class with landslide hazard class the concise mitigation representation of hazard zone in the study area was, presented. Table 4.12 present mitigation measures given for specific zones with suggestion action.

Table 4. 12 Mitigation measures per class

Hazard zones	Suggested action	Mitigation measures
Very High	• Construction and other activity should be restricted. • Existing property owners in this zone should be, notified of the landslide hazard.	✓ Avoid excavating on or at the base of steep slopes ✓ Avoid placing fill soil on or near steep slopes ✓ Warning signs ✓ Stop cultivation on steep slope ✓ Slope Netting ✓ Channelizing the surface and sub-surface runoff ✓ Vegetative turfing ✓ Plant native ground cover on slopes
High	• Construction and other activity should be restricted. • Consult with a professional before significantly altering existing slopes uphill or downslope. • Existing property owners in this zone should be notified of and educated about the hazard	✓ Channelizing the surface and sub-surface runoff ✓ protecting the base of the slope from erosion ✓ Slope Netting ✓ Check Dams ✓ Retaining wall
Low	• Construction and other activities need only consider landslides as a minor threat	✓ Spraying ✓ Channelizing surface drainage.
Very Low	Construction and other activities need not take landslide hazard into account	✓ Vegetation ✓ Channelizing the surface and sub-surface runoff

Mitigation measure taken in this study are used to increase resisting forces and retaining potentially unstable material, decrease pore pressure, reduce soil saturation and weathering, avoid erosion and reinforce soil and protect the hillside foot in the area.

4.8. Discussions

In the study area, it was, observed that even though the slope is steep, especially in the case of slope, which have Quaternary sandstone the slope is almost stable. Thus, it approve that stability might be, controlled by the factor such as, slope deposit type, discontinuity orientation and shear strength (Girma *et al*. 2015). In present study area, the area covered by forest and agricultural land are more prone to landslide. This would be the result of existing steep slope morphology and the shallow rooted nature of different evergreen vegetation type in the area. However, the presence of vegetation increase the rate of infiltration (Meten *et al*. 2015) and increase the accumulation of water by decreasing the stability of the slope (Farrokhnia *et al*. 2010).

Conversely, Ashish Pandey *et al*. (2007) prepared landslide hazard zone and they suggested that landslide hazard map is the immense use to planner and designer in selecting suitable route paths. In this study, landslide hazard maps can help local developers, community planners, and slope management engineers by providing them with efficient, effective, cheap and readily replicable landslide hazard maps of high-resolution. In addition, this hazard map can change the community's approach to landslide from mitigation and response to prevention by creating landslide predictive maps ahead of hazardous events as opposed to localized site-specific geotechnical analysis after a landslide has occurred.

Moreover, Siddan and Veerappan (2014) prepared hazard zonation map for a highway section. They have proposed some general mitigation measures like concrete ditches, slope flattening, benching, anchoring etc., which are either expensive or not suitable for the area having high relative relief like the present study area. Still there is a few literature about the use of hazard map for mitigation aspect. Anbalagan *et al.* (2008) prepared a meso-scale landslide hazard zonation, mapping and suggested that planner should avoid the high hazard area or take precautionary measures during implementation. This study was fill the existing gap for the use of hazard zonation for site-specific mitigation measures.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study available spatial datasets were, used as inputs into GIS to map landslide hazard zone in the area by using multi criterial analysis. This method demonstrate that landslide hazard was, caused by the collective effect of the event controlling parameters. In present study seven landslide-conditioning factor namely, drainage density, lineament density, soil type, geology, aspect, land use land cover and slope were, identified. The weight derived by analytical hierarchy process show that the contribution of each factor for landslide occurrence in the area. Based on obtained weight result the most contributing factor to landslide occurrence in the area is drainage density. This showed that drainage density should have a greater degree of influence in causing landslides.

The obtained hazard map indicate that southwestern region of the area were more prone to landslide. However, the result were still reasonable since the predicted landslide hazard coincided with areas that had recently experienced landslide. This reveal that multi criterial analysis with GIS is a powerful tool in predicting landslide hazard and landslide hazard mapping in the area.

The conducted correlation analysis between landslide occurrence and causative factor, reveal that causative factor class of trachytic plugs and flows geologic type, high and very high drainage density, slope facing to north and northeast, slope angle greater than 10^0, histosols and nitosols soil type, forest, agriculture and grassland causative factor class have strong correlation with landslide occurrence. While the remaining causative factor class have, weak and others have no any correlation with landslide occurrence. This indicate that each class of different causative factor have different contribution in landslide occurrence in the area.

The landslide hazard map shown, mainly very high and high hazard zones are located on steep topography, and low and very low hazard zones were, located on steep to gentle slope. This shown that these hazard zones are potentially dangerous for any future habitation and development. Thus, there is an immediate need to implement mitigation measures in these hazard zones. Therefore, the mitigation measures required for landslide hazard zone in the study area contain; slope stabilization, reforestation and water management.

5.2. Recommendations

Based on the present study finding the following recommendation were, forwarded.

- ✓ Mapping landslide hazard zone, particularly in Jima Geneti Woreda advised for researcher and concerned body should be, based on the use of multi criterial analysis with GIS, and comparative studies of factors that influence landslide occurrence.
- ✓ Further researchers, needed to improve landslide area prediction should have to use factor such as, characteristics of discontinuity surfaces, interrelationships of discontinuities, pore water pressure in soil mass, water forces acting within the discontinuity surfaces, shape factor of particles in coluvial material.
- ✓ The future landslide interventions in Jima Geneti Woreda suggested for land management and concerned body should be, based on the findings of the current study.

References

Ahmed, S. (2009). slope stability analysis using GIS and numerical modeling techniques. *unpublished Msc Thesis, Vrije Universiteit, Brussel*.

Akar, I. (2009). How geographical information systems and remote sensing are used to determine morphometrical features of the drainage network of Kastro (Kasatura) Bay hydrological basin. *International Journal of Remote sensing*, 30:7,1737-1748.

Alcántara-Ayala, I. E.-C. (2006). Landsliding is related to land-cover change: A diachronic analysis of hillslope instability distribution in the Sierra Norte, Puebla, Mexico. Catena. *Catena*, *65(2)*,, pp.152-165.

An, P. M. (1991). Application of fuzzy set theory to integrated mineral exploration . *canadian Journal of exploration geophysics*, *27(1)*, pp.1-11.

Anbalagan, R. D. (2008). Landslide hazard zonation mapping on meso-scale for systematic town planning in mountainous terrain. *Journal of Scientific & Industrial Research*, 67: 486–497.

Arora M, D. G. (2004). An artificial neural network approach for landslide hazard zonation in the Bhagirathi (Ganga) Valley, Himalaya. *Int J Remote Sensing*, 25:559–572.

Assefa Melesse, M. W. (2007). Remote Sensing Sensors and Applications in Environmental Resources Mapping and Modelling. 7:3209-3241.

Atkinson PM, M. R. (1998). Generalised linear modelling of susceptibility to landsliding in the Central Apennines, Italy. *Journal of Disaster Risk Studies, vol. 3, no.1*, Comput Geosci 24(4):373–385.

Aulitzky, H. (1980). Preliminary two fold classification of debris torrets. *Interprevent ,Bad ISCHL, Austria (translated to English by G>Eisbacher,)*, 4:285-309.

Ayalew, L. (1999). The effect of seasonal rainfall on landslide in the highlands of Ethiopia. *Bulletin of Engineering and Environment*, 58, 9-19.

Ayalew, L. a. (2003). slope failures in the Blue Nile basin, as seen from landscape evaluation perspective. *Journal of Geomorphology*, 61, 1-22.

Ayalew, L. a. (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in Kakuda-Yahiko Mountains, central Japan. *Geomorphology*, 65:15–31.

Ayalew, L. Y. (2005). Landslide in sodo island of Japan: part II. GIS based suceptibility mapping with comprasion of result from two method and (Yalcin catena 2008) verification. *Eng.Geology*, 81,432-445.

Ayele, S. T. (2014). Application of Remote Sensing and GIS for Landslide Disaster Management: A Case from Abay Gorge, Gohatsion–Dejen Section, Ethiopia. *Landscape Ecology and Water Management: Proceedings of IGU Rohtak Conference Vol. 2, Advances in Geographical and Environmental Sciences,Springer Japan*, 15-32.

B, P. (2010a). Landslide susceptibility mapping of a catchment area using frequency ratio, fuzzy logic and multiple logistic regression approaches. *J Indian Soc Remote Sens*, 38:301–320.

Baeza, C. &. (2001). Assessment of shallow landslide susceptibility by means of multivariate statistical techniques. *Earth Surf. Process. Landf*, 26, 1251–1263.

Bai SB, W. J. (2009). GIS based and data driven bivariate landslide-susceptibility mapping in the Three Gorges Area, China. *Pedosphere*, 19(1):14–20.

Balsubramani K, K. K. (2013). Application of geospatial technology and information value technique in landslide hazard zonation mapping: a case study of Giri Valley, Himachal Pradesh. *Disaster Advances.*, 6:38–47.

Benesty J., C. J. (2009). Noise Reduction in Speech Processing: Pearson Correlation Coefficient. *Volume 2*.

Bhim Kumar Dahal and Ranjan Kumar Dahal. (2017). Landslide hazard map: tool for optimization of low-cost mitigation. *Research*.

Blahut J, V. C. (2010). Analysis of landslide inventories for accurate prediction of debris-flow source areas. *Geophys J Roy Astron Soc*, 119:36–51.

Brabb, E. (1993). Proposal for worlide landslide hazard maps. *proceedings of 7th international Conference and field workshop on landslide*, (pp. 15-27). Czech and Slovak Republics.

Brusden, D. (1984). Mudslide in slope instability. 363-418.

Cardenas, I. (2008). "Landslide susceptibility assessment using Fuzzy Sets, Possibility Theory and Theory of Evidence. Estimación de la susceptibilidad ante deslizamientos: aplicación de conjuntos difusos y las teorías de la posibilidad y de la evidencia.". *Ingenieria Investigecion*, 28:1-26.

Cardinali M, R. P. (2002). geomorphological approach to estimation of landslide hazards and risks in Umbria, Central Italy. *Natural Hazards Earth Syst Sci*, 57–72. doi: 10.5194/nhess-2-57-2002.

Carrara, A. M. (1991). GIS techniques and stastical model in evaluating landslide hazard. *Earth surface and land forms*,, 16:427-445.

Chakhar, S. a. (2008). GIS Based multi-criterial spatial modeling generic framework. *International Journal of Geographic Information Science*, 22:11,1159-1196.

Champatiray P, D. S. (2007). Fuzzy based methods for landslide hazard assessment in active seismic zone of Himalaya. *Landslides*, 4:101–110.

Champatiray, P. (2000). Perationalization of cost-effective methodology for landslide hazard zonation using RS and GIS: IIRS initiative. In: Roy P, Van Westen C, Jha V, Lakhera R, editors. *Natural Disasters and their mitigation; Remote Sensing and Geographical Information System Perspectives. Dehradun, India: Indian Institute of Remote Sensing;*, pp. 95–101.

Chang K, L. J. (2004). Landslide features interpreted by neural network method using a high resolution satellite image and digital topographical data. *Proceedings of 20th ISPRS Congress.* Istambul: Geo-Imagery Bridging continents.

Chang K, L. J. (2004). Landslide features interpreted by neural network method using a high resolution satellite image and digital topographical data. *Proceedings of 20th ISPRS Congress.* Istambul: Geo-Imagery Bridging continents.

Chelboard F, B. R. (2006). *Rainfall Thresholds for Forecasting Landslides in the Seattle, Washington, Area- Exceedance and Probability.* Reston, Verginia: U S Geological Survey Open file report −2006-1064.

Chen, Z. &. (2007). Landslide Hazard Mapping Using logistic regression model in mackenzie Valley, Canada. *Natural Hazards*, 42:75-89.

Chen, Z., & Wang, J. (2007). "Landslide hazard mapping using logistic regression model in Mackenzie. *Natural Hazards*, 42: 75–89.

Chung and Fabbri. (1998). Three Bayesian prediction models for lanslide hazard. In Bucciantti, ed.,. *Proceedings of International Association for Mathematical Geology Annual Meeting(LMG 98) october 3-7*, (pp. pp.204-211). Ischia, Italy .

Chung, C. F. (1993). The representation of geoscience information for data integration . *Nonrenewable Resource, 2(2)*, pp.122-139.

Chung, C. F. (1999). probabilistic prediction models for landslide hazard mapping. *photogrammetric Engineering and Remote sensing*, pp.1389-1399.

Church, R. (2002). Geographical information systems and location science. *Computers and Operations Research*, 29:54-562.

Clerici A, P. S. (2002). A procedure foe landslide susceptibility zonation by the conditional analysis method. *Geophys J Roy*, 48:349–364.

Clerici, A. P. (2002). A procedure for landslide susceptibility zonation by the conditional analysis method. *Geomorphology*, 48(4), pp.349-364.

Courture, R. (2011). Landslide Terminology- national technical guidelines and best practices on landslide. *Geological survey of canada*, 12.

Crozier, M. a. (2005). Landslide Hazard and Risk: Issues and concepts. *Landslide Hazard and Risk*, 1-40.

Dai FC, X. C. (2010). Spatial distribution of landslides triggered by the 2008 Ms 8.0 Wenchuan earthquake. *J of Asi Earth Scie 40(3): doi:10.1016/j.jseaes.2010.04.010*, 883–895.

Dai, F. a. (2001). Terrain based mapping of landslide susceptibility using a geographical information system: A case study Canadisn. *Geotechnical Journal*, 38,911-923.

Dai, F. C. (2002). landslide risk assessment and managment: An overview. *Journal of Engineering Geology*, 64,65-87.

Das, I. (2011). Spatial Statistical Modelling for assessing landslide hazard and vulnerability. *University of Twenty, International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands*.

De La Ville, N. C. (2002). Remote Sensing and Gis Technologies as a tool to support sustainable Management of Areas Devastated by landslides. *Environment, Development and sustainability.*, 4(2):221-229.

Deoja, B. M. (1991). Mountain Risk Engineering. *Part I, International Center for Integrated Mountain Development*.

Drobne, S. L. (2009). Multi-attribute Decision Analysis in GIS: Weighted Linear combination and ordered weighted averaging. *Informatica, vol.33*, 459-479.

Ercanoglu M., a. G. (2004). Use of fuzzy relations to produce landslide susceptibility map of a landslide-prone area (West Black Sea Region, Turkey). *Engineering Geology*, 5:229–250.

Fabbri, A. G.-J. (2003). "Is prediction of future landslide is possible with a GIS?". *Natural Hazards*, 30(3): 487-503.

Fall, M. A. (2006). A multi method approach to study the stability of natural slopes and landslide susceptibility mapping. *Journal of Engineering Geology*, 82,241-263.

Farrokhnia A, P. S. (2010). A recent scenario of mass wasting and its impact on the transportation on Albroz mountains, Iran using geo-information technology. *Arab J Geosci*, doi:10.1007/s 12517-010-0238-7.

Fell, R. (1994). landslide Risk assessment and acceptable risk. *can.geotech J.*, 31:-261-272.

Fikre Girma, Tarun Kumar Raghuvanshi, Tenalem Ayenew and Trufat Hailemariam (2015). Landslide hazard zonation in Ada Berga District, Centeral Ethiopia - A statistical based Approach. *Journal of Geomatics Vol.9 No*. 1. 25-36.

Floris, M. a. (2008). Evaluation of landslide reactivation: a modified rainfall threshold model based on historical records of rainfall and landslides. *Geophys J Roy Astron Soc*, 94:40–57.

Galli M, A. F. (2008). Comparing landslide inventory maps. *Geophys J Roy Astron Soc.*, 94:268–289.

Ghosh, S. (2011). Knowledge Guided Empirical Prediction of Landslide Hazard. *University of Twente, Netherland*.

Glade, C. a. (2005). landslide Hazard Risk; issues, concepts and approachs. *landslide hazard risk*, 1-40.

Gokceoglu C, S. E. (2009). A statistical assessment on international landslide literature. *(1945–2008) Landslides*, 6:345–351. doi: 10.1007/s10346-009-0166-3.

Goswami R, M. N. (2011). Distribution and causes of landslides in the eastern Peloritani of NE Sicily and western Aspromonte of SW Calabria, Italy. *Geophys J Roy Astron Soc.*, 132:111–122.

Gutierrez F, S. M. (2010). Recent advances in landslide investigation: issues and perspectives. *Geophys J Roy Astron Soc*, 124:95–101.

Guzzetti F, A. P. (2003). Comparison of three landslide event inventories in Central and Northern Italy. Spain. *Universitat de les Ilies Balears*, Proceedings of 4th EGS Plinius Conference held at Mallorca.

Guzzetti F, G. M. (2006). Landslide Hazard assessment in the Collazzone area, Umbria, Central Italy. *Nat Hazards Earth Syst Sci*, 6:115–131.

Guzzetti F, R. P. (2005b). Probablistic landslide hazard assessment at the basin scale. *Geophys J Roy Astron Soc*, 72:272–299.

Guzzetti F., C. M. (2000). Comparing landslide maps: A case study in the upper Tiber. *Environmental Management*, 25:3, 247-363.

Guzzetti, F. (2002). Landslide Hazard Assessment and Risk Evaluation:Limitis and Prospective. *Proceedings of the 4th EGS Plinius Conference held at Mallorca, Spain.* spain: by Universitat de les Illes Balears.

Guzzetti, F. C. (1999). 'Landslide hazard evaluation: an aid to a sustainable development'. *Geomorphology, vol. 31,*, pp. 181-216.

H, S. &. (2012). Evaluation and comparison of bivariate and multivariate statistical methods for landslide susceptibility mapping (case study: Zab basin). *Arab J Geosci (2013) 6:3885–3907: DOI 10.1007/s12517-012-0650-2*.

Howell, J. (1999). Roadside Bioengineering. *Reference Manual,*, 81–102.

Hutchison., J. (1988). Mass Movement in Faibridge R (ed(. *the encyclopedia of Geomorphology. Reinold*, pp.688-695.

Idowu, I. a. (2009). Application of Remote sensing(RS) and Geographic Information systems (GIS) to Environmental impact Assessment (EIA) for sustainabel development. *Research journal of Environmental and Earth sciences.*, 1:1,11-15.

Jaiswal P, v. W. (2010a). Quantitative assessment of landslide hazard along transportation lines using historical records. *Landslides*, 8:271–291.

Jaiswal P, V. W. (2013). Use of quantitative landslide hazard and risk information for local disaster risk reduction along a transportation corridor: a case study from Nilgiri District, India. *Nat Hazards*, 65:887–913, Published online on 20 Sep 2012) doi:10.1007/s11069-012-0404-1.

Jibson, R. H. (1998). Amethod to produce probabilstic seismic landslide hazard maps. In A. Bucciantti, ed.,. *proceedings of International Association for Mathematical Geology Annual Meeting (LAMG 98) october 3-7,* (pp. pp.211-217). Ischia, Italy.

JM, D. (1993). Receiver operating characteristic laboratory (ROCLAB): software for developing decision strategies that account for uncertainty. In: Proc. 2nd Int. Sym. uncertainty modelling and analysis. *Computer Society Press*, 318–325.

Kanungo D, A. M. (2009). Landslide Susceptibility Zonation (LSZ) mapping-a review. *J South Asia Disaster Stud*, 2:81–105.

Kanungo D, A. M. (2009). Landslide Susceptibility Zonation (LSZ) mapping-a review. *Journal of South Asia Disaster Stud.*, 2:81–105.

Kumar, K. S. (2018). Hazard assessment of landslide disaster using information value method and analytical hierarchy process in highly tectonic Chamba region in bosom of Himalaya. *Journal of mountain science*, pp.808-824.

Landslide Hazard Zonation in Ada Berga District, centeral Ethiopia -A GIS Based statistical Approach. (2015). *Journal of Geomatics,Vol 9* , 25-36.

Lee S, P. B. (2006). Probabilistic landslide hazard and risk mapping on Penang Island, Malaysia. *J Earth Syst Sci.*, 115:661–672.

Lee S, S. T. (2006). Landslide susceptibility mapping in the Damrei Romel area, Cambodia using frequency ratio and logistic regression models. *Environ Geol*, 50:847–855.

Lee, S. (2005). Application of logistic regression model and its validation for landslide susceptibility mapping using GIS and remote sensing data. *International Journal of Remote Sensing*, 1477–1491.

Lee, S. a. (2000). development of spatial landslide information system and application of spatial landslide information. *The journal of gis association of Korea*, 8,141-153.

Lee, S. a. (2001). statistical analysis of landslide susceptibility at yongin, Korea. *Environmental Geology 40(9)*, pp.1095-1113.

Lee, S. a. (2005). Probabilistic landslide susceptibility mapping in the Lai Chau province of Vietnam: focus on the relationship between tectonic fractures and landslides. *Environmental Geology*, 48(6), pp.778-787.

Lee, S. R. (2004). Determination and application of the weights for landslide susceptibility mapping using an artificial neural network. *Engineering Geology*, 71(3-4), pp.289-302.

Leroi, E. (1997). landslide risk mapping:problems,limitation and development (F.Cruden: Editor). *Proceedings landslide Risk Assessment, Balkema, Rotterdam*, pp.239-250.

Liu YS, W. J. (2006). GIS based assessment of land suitability for optimal allocation in the Qinling Mountains, China. *Pedosphere*, 16(5):579–586.

Magliulo, P. L. (2008). Geomorphology and landslide susceptibility assessment using GIS and bivariate stastitics: A case study in southern Italy. *Natural Hazard*, 47,3,411-435.

Malczewski, J. (1999). *GIS and multicriterial analysis decision analysis.* New york: John and sons.

Malczewski, J. (2004). Integrating multicriterial analysis and geographic information systems; the ordered weighted averaging(OWA) approach. *international journal of environmental technology and managemennt*, 6:1/2,1-13.

Martha T, v. C. (2013). Landslide hazard and risk assessment using semi-automatically created landslide inventories. *Geophys J Roy Astron Soc*, 139–150.

Martha, R. a. (2008). segment optimization for object based landslide detection. *International Archieves of the photogrammetry, Remote sensing and spatial information sciences*, vol.XXXVIII-4/C7.

Matebie Meten*, N. P. (2015). Effect of Landslide Factor Combinations on the Prediction Accuracy of Landslide Susceptibility Maps in the Blue Nile Gorge of Central Ethiopia. *Geoenvironmental Disasters*, 2:9 DOI 10.1186/s40677-015-0016-7).

Metternicht, G. H. (2005). Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments'. *Remote Sensing of Environment*, 98(2-3): 284-303.

Nadim, F. K. (2006). 'Global Landslide and Avalanche hotspots'. *Landslides, vol.3, no.2,*, pp. 159-174.

Nandi, A. a. (2009). A GIS based landslide susceptibility evaluation using bivariate and multivariate statistical analyses. *Eng Geol*, 110:11–20.

Neelekanta, R. A. (2002). GIS based lineament analysis for landslide zonation mapping. *international conference on IT enabled spatial data services* (pp. pp.346-380 pJ). Nilgri, Tamil Nadu, south India: Tiruchirappalli, indian: proc.

Neuhausev B, D. B. (2012). GIS based assessment of landslide susceptibility on the basis of weights of evidence model. *Landslides*, 9:511–528. doi: 10.1007/s10346-011-0305-5.

Panikkar S, S. V. (1997). Landslide hazard analysis of the area around Dehra Dun and Mussoorie, Uttar Pradesh. *Curr Sci*, 73:1117–1123.

Parise, M. (2002). Landslide hazard zonation of slopes susceptible to rock falls and topples. *Natural Hazards Earth Syst Sci.*, 37–49.

Peter, T. (1970). *Environmental Geology: Conservation Land-use Planning and Resource.* New York: Horper and Row.

Piacentini D, T. F. (2012). Statistical analysis for assessing shallow-landslide susceptibility in South Tyrol (south-eastern Alps, Italy). *Geophys J Roy Astron Soc*, 151–152:196–206.

Polemio M, S. F. (1999). The role of rainfall in the landslide hazard: the case study of the Avigliano Urban area (Southern Apenniens Italy). *Engineering Geology*, 53:297–309.

Pourghasemi HR, G. J. (2013). Landslide susceptibility mapping using support vector machine and GIS. *J Earth Syst Sci*, 122:349–369.

Preuth T, G. T. (2010). Stability analysis of a human-influenced landslides in eastern Belgium. *Geophys J Roy Astron Soc*, 120:4–98.

R.S. Negi, M. P. (2012). Landslide Hazard Zonation using Remote Sensing and GIS: A Case Study of Giri Valley, District Sirmaur Himachal Pradesh(. *International Journal of Environmental Sciences Vol.1 No.1.*, pp. 26-39.

Raghuvanshi, T. J. (2014a). slope stability susceptibility evaluation parameter (SSEP0 rating scheme An approach for landslide hazard zonation . *Journal of African Earth Sciences*, 99, 595-612.

Rai, S. 2. (2010). conventional engineering & bioengineering approach for slope stabilisation on rural roads.A case study:Nepal.

Ramakrishnan, S. K. (2002). Landslide Zonation for Hill Area Development. *GIS Development.net*, Viewed March 19th 2013.

Ramakrishnan, S. K. (March 29th 2013). ‘Landslide Zonation for Hill area Development’. *GIS development.net*.

Reni Bibriven Lila, B. M. (May 2018). landslide hazard modeling in ventura and santa barbara counties, california using multi-tiered geospatial. *A dissertation submitted to the Graduate Council of Texas State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a Major in Environmental Geography*, 1-107.

S.Anbazhagan, A. C. (2013). Remote Sensing and GIS for Landslide Hazard Mapping – Case Study from Mumbai, India . *landslide and Environmental Degradation*, 89-106.

Saaty, T. L. (1980). *The analytical heriarchy proccess, planning, priority setting, resource allocation.* New York: McGraw-Hill.

Sahnoun, H. S. (2012). GIS and multicriterial analysis to select potential sites of agro industrial complex. *Environmental. Earth science* , 66,2477-2489.

Sarkar S, K. D. (2006). Disaster mitigation of debris flows, slope failures and landslides. GIS based landslide susceptibility mapping- a case study in Indian Himalaya. Tokyo, Japan. *Universal Academy Press*, pp. 617–624.

Schicker R, M. V. (2012). Comparison of bivariate and multivariate statistical approaches in landslide susceptibility mapping at a regional scale. *Geophys J Roy Astron Soc.*, 161-162:40-57.

Shiferaw Ayele, T. K. (2014). Application of Remote Sensing and GIS for Landslide Disaster Management: A Case from Abay Gorge, Gohatsion–Dejen Section, Ethiopia.

Siddan, A. a. (2014). Landslide hazard zonation mapping in Ghat road section of Kolli Hills, India. *Journal of Mountain Science*, 11(5): 1308–1325.

Singh, A. S. (2014). Landslide Susceptibility Mapping of North Sikkim Himalaya using Geospatial Techniques. *Esri India User Conference.*

Standards, B. o. (1998). Preparation of landslide hazard zonation maps in mountainous terrain. *Guidelines (Part2-Macrozonation), vol 14496. 2. New Delhi: BIS; 1998.*, pp. 1–19.

Steininger, M. &. (2007). NASA-NGO Biodiversity Working group and UNEP-WCMC to support implimentation of the convention on biodiversity. In *Sourcs Book on Remote sensing and Biodiversity Indicators.*

Suezen ML, D. V. (2004b). Data driven bivariate landslide susceptibility assessment using geographical information systems a method and application to Asarsuyu catchment, Turkey. *Eng Geol*, 71:303–321.

Suzen, M. a. (2004). A comparison of the GIS based landslide susceptibility assessment methods: Multivariates versus bivariate. *Journal of Environmental Geology* , 45,665-679.

Thomson, S. (1971). Analysis of a failed slope. *Canadian Geotechnical Journal*, 8, 596-599.

Tolga C, H. A. (2005). Susceptibility assessment of shallow earth flows triggered by heavy rainfall at three catchments by logistic regression analyses. *Geophys J Roy Astron Soc*, 72:250–271.

Varnes D, I. (1984). Landslide hazard zonation. *United Nations Scientific and Cultural Organization* (pp. pp. 1–6.). Paris: a review of principles and practice.

Varnes D, I. (1984). Landslide hazard zonation: a review of principles and practice. *Paris: United Nations Scientific and Cultural Organization;*, pp.1-6.

Varnes, D. J. (1978). *Slope movement types and processes.* Washington D. C.: Transportation and Road Research Board, National Academy of Science.

Vijith H, R. P. (2009). Using Info Val Method and GIS techniques for the spatial modelling of landslides susceptibility in the Upper catchment of River Meenachil in Kerala. *Indian Soc of Remote Sens*, 37:241–250.

Westen, V. (1993). Application of Geographic Informaion systems to landslide hazard zonation. *Ph.D Thesis, technical university of Delft, International Institute fo Aerospace survey and earth science, the Netherland ITC publication*, 15(1) 245p.

Woldaregay, K. (2013). Review of the occurrences and influencing factors of landslides in the highlands of Ethiopia. *J. Sci. (MEJS)*, 5 (1), 3–31.

Yadav, A. P. (2007). Landslide Hazard Zonation using Remote Sensing and GIS: a case study of Dikrong river basin, Arunachal Pradesh, India.

Yalcin, A. (2008). GIS Based landslide suceptibility mapping using analytical proccess and bivariate stastitics in Ardesen(Turky). *comparisons of Result and confirmation*, 72,1-12.

Zadeh, L. (1965). Fuzzy sets. *IEEE Information and control, 8(3)*, pp.338-353.

Zimmermann, H. (1996). Fuzzy set theory and its applications. *kluwer Academic publisher*, pp.435.

Appendix A

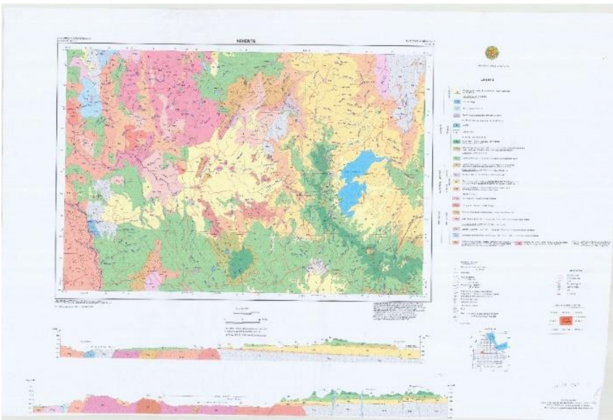


Figure A. 1 Geological map of Nekemte area

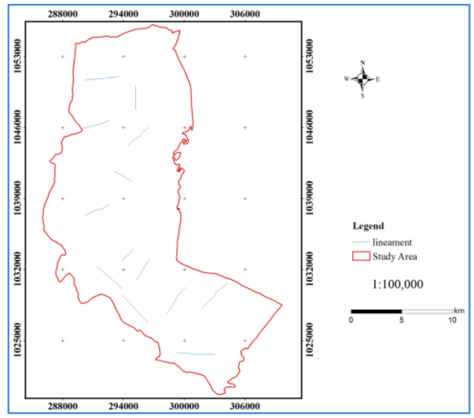


Figure A. 2 Lineament map of study area

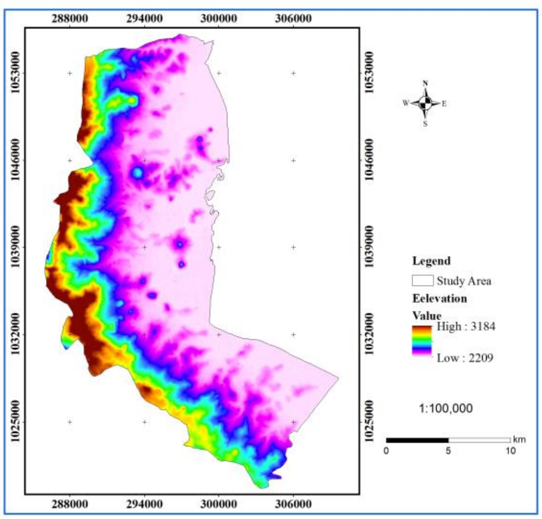


Figure A. 3 Digital elevation model of study area

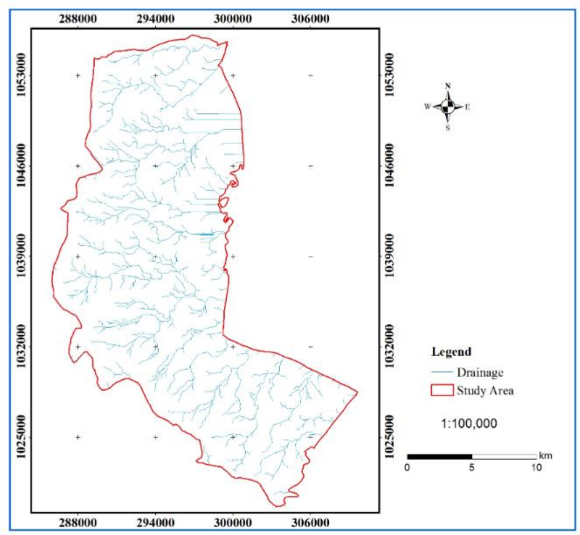


Figure A. 4 Stream network of study area

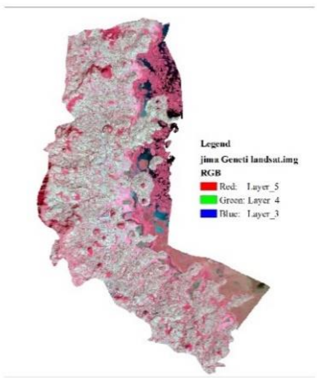


Figure A. 5 Landsat image of study area Figure A. 6 Landslide on grassland

Figure A. 7 Landslide on steep slope Figure A. 8 Landslide on agricultural land

Table A. 1 Landslide inventory database

s/no	Landslide location coordinate x	y	Elevation	Landslide location	Landslide type	Land use land cover present in slide
1	292135	1050086	2474	Town	Rotational slide	Grassland
2	291678	1047468	2362	Village	Earthflow	Agriculture
3	292414	1043541	2305	Village	Transitional slide	Agriculture
4	290306	1040527	2570	Town	Debris flow	Grassland
5	292193	1039805	2290	Village	Earthflow	Agriculture
6	293283	1039524	2273	Village	Rock fall	Forest
7	292746	1038258	2270	Town	Rotational slide	Grassland
8	293474	1037529	2274	Village	Transitional slide	Agriculture
9	292336	1037097	2322	Village	Earthflow	Grassland
10	293135	1036826	2330	Village	Rotational slide	wetland
11	294214	1036800	2353	Village	Earthflow	Forest
12	293798	1036421	2401	Village	Earthflow	Grassland
13	292441	1036327	2321	Village	Debris flow	Agriculture
14	293110	1035720	2349	Village	Rotational slide	Agriculture
15	293187	1035255	2273	Village	Debris flow	Agriculture
16	292446	1035614	2333	Village	Rock fall	Agriculture
17	292048	1035412	2386	Village	Rotational slide	Agriculture
18	291877	1035156	2406	Village	Transitional slide	Forest
19	291504	1034733	2446	Town	Earthflow	Grassland
20	291205	1035014	2490	Village	Debris flow	Agriculture
21	290842	1034637	2572	Village	Rotational slide	Forest

22	290961	1034289	2524	Village	Earthflow	Wetland
23	291254	1033694	2513	Village	Debris flow	Agriculture
24	290731	1032742	2682	Village	Earthflow	Agriculture
25	290165	1035180	2833	Village	Rotational slide	Agriculture
26	288577	1036463	2536	Village	Transitional slide	Agriculture
27	287573	1038712	2656	Village	Debris flow	Forest
28	293341	1034401	2311	Village	Earthflow	Wetland
29	295705	1034916	2232	Village	Rotational slide	Grassland
30	294161	1033646	2249	Village	Debris flow	Grassland
31	293504	1033004	2289	Village	Earthflow	Grassland
32	294583	1032306	2370	Village	Transitional slide	Forest
33	295776	1031883	2275	Village	Transitional slide	Agriculture
34	292236	103120	2635	Village	Debris flow	Wetland
35	297824	1031620	2246	Village	Rotational slide	Agriculture
36	294638	1051158	2256	Village	Debris flow	Agriculture
37	297157	1027068	2454	Village	Transitional slide	Agriculture
38	300606	1028437	2331	Village	Earthflow	Forest
39	302138	1024188	2462	Village	Rotational slide	Agriculture
40	291852	1054782	2412	Village	Earthflow	Wetland

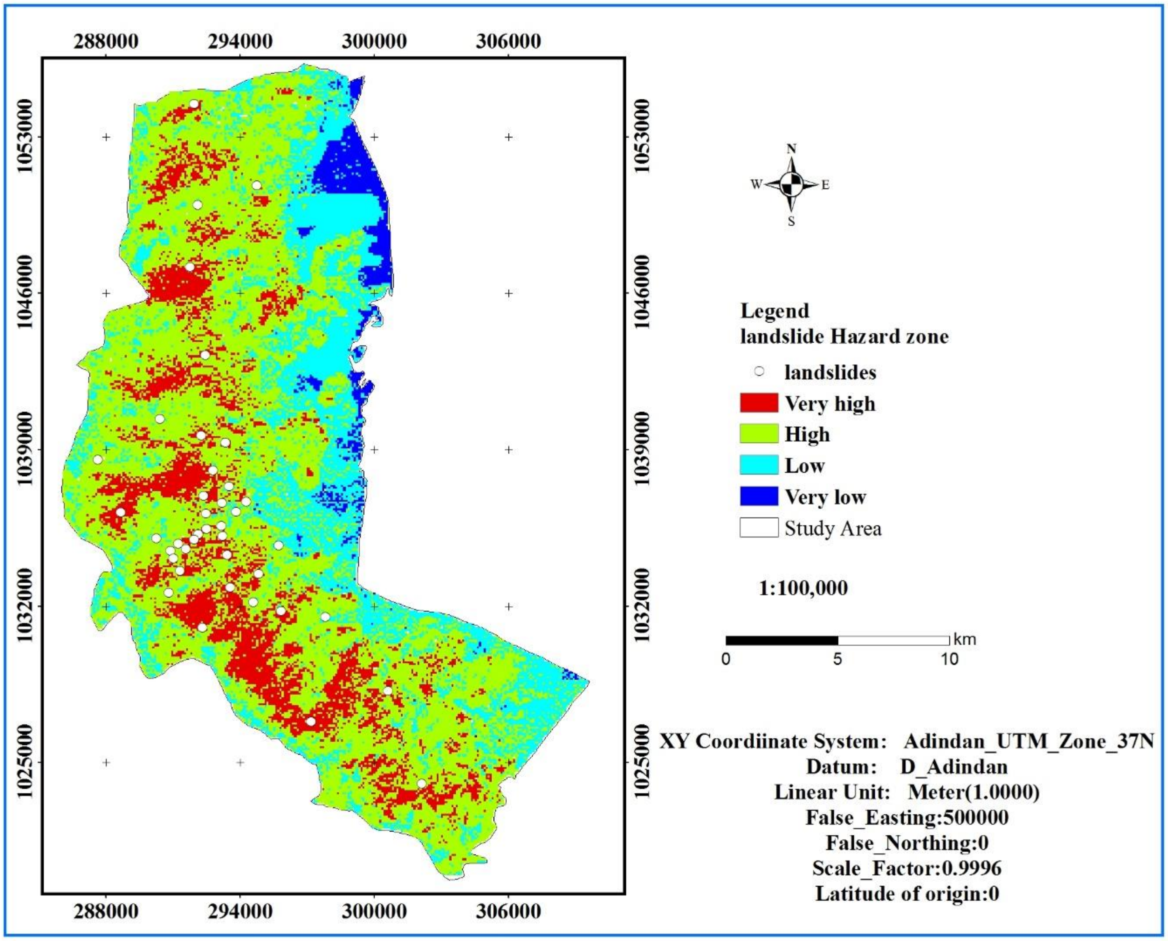


Figure A. 9 Landslide inventory overlaid with landslide hazard map