JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCES AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

LANDSLIDE HAZARD ZONATION USING GEOSPATIAL AND MULTI CRITERIA DECISION ANALYSIS TECHNIQUES IN GECHI DISTRICT, WESTERN ETHIOPIA

BY: FAYERA GIZAWU GARBABA

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

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CO-ADVISOR: DR. AJAY BABU

NOVEMBER, 2020

JIMMA, ETHIOPIA

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This is to certify that the Thesis prepared by Fayera Gizawu entitled as " Landslide Hazard Zonation (LHZ) using geospatial and Multi Criteria Decision Analysis (MCDA) techniques In Gechi District, Western Ethiopia" Submitted to Graduate Studies of Jimma University, for the award of Master of Science degree in GIS and Remote Sensing.

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Declaration

This is to certify that this thesis entitled "Landslide Hazard Zonation using geospatial and Multi Criteria Decision Analysis techniques in Gechi District, Western Ethiopia**"**, submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Geography and Environmental Studies with specialization in GIS and Remote Sensing at Jimma University, department of Geography and Environmental Studies done by Fayera Gizawu is an reliable work carried out under supervision of Dr. Kefelegn Getahun and Dr. Ajah Babu. The matter embodied in this project work has not been submitted earlier for an award of any degree or diploma to the best of our knowledge and belief.

Name of the Student: Fayera Gizawu

Signature: ____________________ Date: ______________________

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ACRONYMS

AHP:	Analytical Hierarchy process
ANN:	Artificial Neural Networks
ASTER:	Advanced Space-borne Thermal Emission and Reflection Radiometer
CSA:	Central Statistical Agency
EGS:	Ethiopian Geological Survey
NMA:	National Meteorological Agency
ERDAS:	Earth Resource Data Analysis System
EOS:	Earth observatory Satellite
GIS:	Geographic Information System
GPS:	Global Positioning System
GSE:	Geological Survey of Ethiopia
IVM:	Information Value Model
LHEF:	Landslide Hazard Evaluation Factors
LHM:	Landslide Hazard Map
LHZ:	Landslide Hazard Zonation
LSM:	Landslide Susceptible Map
LULC:	Land use Land cover
MCDA:	Multi-Criteria Decision Analysis
NDVI:	Normalized Different Vegetation Index
OLI:	Operational Land Imager
OSM:	Open Street Map
OWWDSE:	Oromia Water Works Design and Supervision Enterprise
RS:	Remote Sensing
TIR:	Thermal Infrared
USGS:	United State of Geodetic Survey
WLC:	Weighted Linear Combination

Abstract

Landslides are considered as the main cause for mass deterioration and distraction of topographic features. It is an ongoing problem in every rainy season where the mass of soil is detached from its original location and moves down the hills thereby causing loss of life and public properties. Therefore, this study aimed to produce landslide hazard susceptibility map based on certain environmental parameters like Elevation, slope, aspect, curvature, lithology, soil texture, land use Land cover, distance to lineament, distance to drainage, distance to road and rainfall by using Geospatial and Multicriteria Decision Analysis at Gechi district, Oromia regional state, western Ethiopia. The weights of selected susceptibility factors were performed using pair wise comparison matrix of analytical hierarchical process (AHP) method. The sum total of all parameters was weighted using Weighted Linear Combination (WLC) to prepare the Landslide Hazard Zonation (LHZ) map. In this study probability and non-probability sampling techniques were employed to collect ground truth data which identifies about the existing landslide and overlaid with the prepared landslide hazard zonation map for validation. The study clearly reveals that about 18.4 km^2 *(1.3%) remains very high hazard zones; whereas about 299.6km*^{2} *(20.5%) was falls in very low hazard zone. Consequently, from the total number of 29 landslide inventory points 82.7% of past landslide events were falls in maximum landslide hazard zone and only 17.3% of landslide events were falls in low hazard zone. So, this shows satisfactory agreement the rationality of considered parameters, the adopted MCDA technique, tools and procedures with the prepared landslide hazard zonation map. Therefore, it is recommended that local governments must develop appropriate plans to reduce landslide effects through land use and land cover policies and regulations.*

Key words: *Landslide Hazard Zonation (LHZ), Analytical Hierarchy process (AHP), Weighted Linear Combination (WLC), Gechi district, Ethiopia.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background

The term landslide can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or a combination of these (Mulatu *et al*., 2011). It is a sign of slope instability which is defined as the tendency for a slope to undergo morphologically and structurally disruptive landslide processes. It could be manifested in different and combinations of various forms, including rock falls, rockslides, debris flow, soil slips, rock avalanches and mud-flows (Chau *et al*., 2004). Landslides are considered as the major factor for mass wasting and landscape building in the mountainous terrains (Mengistu *et al.*, 2019b). The Number of landslide hazard phenomena depends upon the cause of the sliding; multiple landslides occur almost simultaneously when slopes are shaken by an earthquake or over a period of hours or days of intense rainfall (Gebremicheal, 2017).

According to (Woldearegay, 2013) whether occurring naturally or triggered by human activity landslides and landslide-generated ground failures are among the common geo-environmental hazards in many of the hilly and mountainous terrains of both the developed and developing world. It is one of the major problems that cause significant damages to building infrastructures and the natural environments as well as human life all over the world (Dai *et al*., 2002; Raghuvanshi *et al.*, 2014a). And also it is a global hazard in terrestrial environments with slopes, incurring human fatalities in urban settlements, along transport corridors and at sites of rural industry. It is responsible for hundreds of billions in property damage per year, damages transportation networks, buildings and structures, public works projects, causes deaths and injuries for thousands in each year (Dawit, 2016).

Evaluation of landslide hazard entails high-quality landslide databases. Recently, global landslide databases have shown the extent to which landslides impact society and identified areas are most at risk. Earlier global analysis has focused on rainfall-triggered landslides over short five year observation periods (Froude and Petley, 2018). The major types of landslides reported to have been triggered by heavy rainfalls include debris/earth slides, debris/earth flows, and medium to large-scale rockslides (Woldearegay, 2013).

In Ethiopia, landslide-generated hazards are becoming serious concerns to the general public and to the planners and decision-makers at various levels of the government. The highlands of Ethiopia are prone to landslides. The hilly and mountainous terrains of the highlands of Ethiopia are frequently affected by rainfall-induced landslides of different types and sizes. As a result, the general public and infrastructure are being seriously affected during the rainy season (Girma *et al.*, 2015). Thus, it needs more and more attention due to its increasing effect on economic and human losses. Without any doubt one of the crucial environmental problems for the development of Ethiopia, representing a limiting factor for urbanization and infrastructural projects and, generally, for all the activities performed on and at the foot of slopes (Woldearegay, 2013).

With the on-going infrastructural development, urbanization, rural development, and with the land management system, it is foreseeable that the frequency and magnitude of landslides and losses due to such hazards would continue to increase unless appropriate actions are taken in Ethiopia. As a result, Landslide investigations and design of mitigation measures require clear understanding of the processes and factors leading to slope failures based on Multi-disciplinary approach (Woldearegay, 2013).

The MCDA framework is primarily concerned with how to combine the information from several criteria to form a single index of evaluation (Yu *et al*., 2011; Feizizadeh and Blaschke, 2013). Landslide susceptibility mapping (LSM) is making increasing implications for GIS-based spatial analysis in combination with multi-criteria decision Analysis (MCDA) methods. It is considered to be an effective tool to understand natural disasters related to mass movements and carry out an appropriate risk assessment (Mallick *et al*., 2018). Thus, this study is focused on Landslide hazard zonation using geospatial and multi criteria decision analysis techniques in Gechi district, west Ethiopia.

1.2. Statement of the Problem

Landslide hazard is one of the main environmental problems that cause significant damages to infrastructures and the natural environment. It exposes the wellbeing of the society, particularly the local peoples living near steep slopes of active landslide. Thus, landslide is a common geo-environmental hazard in northern, southern and western highlands of Ethiopia. The main causative factors of slope failures are heavy rainfall, high relative relief and complex fragile geology with increased manmade activities (Abebe *et al.*, 2010). These problems are becoming serious concerns to local people and administration as well as federal government bodies in Ethiopia. Many parts of Ethiopia experience problems of landslide with different intensities. For instance, Ayele, (2019) indicated that landslide occurrence in Simada Area Northwest, Ethiopia caused in the death of domestic animals, destructions of homes, farmland with crops, and the displacement of 486 people from their homes. Moreover, from 2005 to 2016, landslide have induced death of 51 people and damaged agricultural lands, houses and infrastructures in Kindo Didaye area, south west Ethiopia (Dawit, 2016). Despite effort have been made in landslide susceptibility mapping in different part of Ethiopia by using different method there is no consensus how to assess landslide susceptibility zonation, data used and kinds of method employed (Ayele,2005).

As Gechi district disaster management office reported in July (2010) in the study area landslide is an ongoing problem in every rainy season where the mass of soil is detached from its original location and moves down the hills thereby causing loss of public properties especially on people's resident, road construction and agricultural land. As a result, about 150m of the asphalt road was damaged and 15ha of land was distracted and out of use. The frequent damage of the road is significantly increased maintenance costs and resulted loss of natural resources. Besides, it is a big problem to dwellers those are leaving near to landslide prone areas and the worries of administrative bodies.

Despite these problems, no attention has been made by the previous researches to identify the causes and effects of the problem by using geospatial technology and future susceptibility map. Therefore, the study area needs a detailed study to assess the causes of landslide and to produce a landslide susceptibility map. Several studies were conducted on landslide hazard susceptibility mapping in the western Ethiopia. For instance, Chimidi et al., (2017) studied on landslide hazard evaluation and zonation in and around Gimbi town, western Ethiopia using statistical approach. According to their study, nine causative factors namely slope material, elevation, slope, aspect, curvature, land-use/land-cover, groundwater, distance to road and stream were considered to landslide hazard map preparation. Also, another study was conducted by Firomsa and Abay, (2019) on landslide susceptibility mapping in the Ebantu district of the Oromia regional state of western Ethiopia using statistical method. They used landslide causative factor such as Lithology, Slope, Land use/Land cover, Distances from drainage and Elevation to asses a landslide susceptibility map. However, they did not considered rainfall and distance to lineament which play significant role in modeling landslide hazard mapping as factors in their analysis (Chen *et al.*, 2016). Moreover, statistical method they used is recognized by complex solutions for analyzing multiple parameter and data sets for the purpose of landslide modeling (Van et al., 2008; Tesfahunegn, 2008). However, GIS-MCE technique has capability to solve complex decision making problem with flexible approach such as AHP which, can act as a powerful method of identifying landslide susceptibility zones (Ahmad, 2014). Hence, this study focuses on modeling landslide susceptibility areas by considering geo-environmental factors using geospatial and MCDA techniques.

1.3. Objectives of the Study

1.3.1. General Objective

The main objective of this study is to prepare landslide hazard zonation map through geospatial techniques in Gechi district, western Ethiopia.

1.3.2. Specific Objectives

The specific objectives of this study were:

- To determine landslide hazard triggering factors of the study area
- To prepare the event based landslide inventory map of the study area
- To map landslide hazard susceptibility zonation in the study area

1.4. Research questions

This study tries to answer the following question:

1. What are the influencing factors that determine landslide hazard in the study area?
2. How to prepare landslide inventory map of the study area?
3. How to produce landslide hazard zonation map of the study area?

1.5. Scope of the Study

Geographically, this study confined to Gechi district, west Ethiopia with total area coverage of 1464 km^2. Methodologically, the study was conducted on landslide hazard zonation through geospatial and multi criteria decision analysis by considering factors like (Elevation, slope, aspect, curvature, lithology, soil texture, land use Land cover, distance to lineament, distance to drainage, distance to road and rainfall) that cause landslide. The time horizon of the study stays from November 2019 to October 2020 academic year.

1.6. Significance of the Study

Ethiopia is currently involved in massive infrastructural development (including roads and railways), urban development and extensive natural resources management. In this whole socio-economic development, landslides and landslide triggered ground failures need to be given due attention in order to reduce losses from such hazards. Thus, the result of the study might useful:

For decision makers: to identify the spatial likelihoods of landslide for safer strategic planning of future developmental activities. Also, it may help to select appropriate sites for agriculture, construction and other development activities in the study area.

For local peoples: The result of the study helps rural peoples who lives near to hill slopes for stimulate the information and better awareness on landslide susceptibility areas. Similarly it acquire tangible information that determine how human activities can enable and increases landslide hazard to do possible remedial on how to minimize the socio-economic loss and natural environment damage due to landslide.

For researchers/scholars: this study may serve as baseline information for who want to further analysis on landslide hazard zonation in the study area.

1.7. Limitation of the Study

This study lack socio-economic data such as group discussion and interviews because of Corona virus disease19. Instead, different international and national literatures were used.

1.8. Organization of the Paper

The thesis organized into five chapters. The first chapter includes an introduction part which includes: background, statement of the problem, objectives, research question, scope, significance, limitation and organization of the study. The second chapter contains the work of previous researchers about the theoretical background of landslide, types of landslide, landslide influencing factors, landslide hazard zonation techniques, and the multicriteria decision analysis method. Chapter three includes an overview of the study area, the methodology of the research work and data analysis. Chapter four describes results and discussion of Landslide Hazard Zonation (LHZ) and the last chapter contains the conclusion and recommendations made by the study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Definition and Concept of Landslide

A landslide is a down movement of rock or soil or both, occurring on the surface of rupture either curved (rotational slide) or planar (translational slide) rupture in which much of the material often moves as a coherent or semi-coherent mass with little internal deformation. It should be noted that, in some cases, landslides may also involve other types of movement, either at the inception of the failure or later, if properties change as the displaced material moves down slope(Highland, 2008). And also it is a sign of slope instability which is defined as the tendency for a slope to undergo morphologically and structurally disruptive landslide processes. It could be manifested in different and combinations of various forms, including rock falls, rockslides, debris flow, soil slips, rock avalanches and mud-flows (Chau *et al.,* 2004). The term "landslide" is used to describe a wide variety of processes that result in the detectable downward and outward movement of a slope material (soil, rock, and vegetation) under the gravitational influence. The materials may move by falling, toppling, sliding, spreading, or flowing (Taylor *et al.,* 2015).

Landslides hazard and its associated slope deformation in different regions of the Ethiopian rift margins and its associated highlands have been studied by many researchers (Abebe *et al.,* 2010; Ayalew and Yamagishi, 2004; Abay *et al.,* 2019). So like the other natural events, a landslide event is also a natural phenomenon that may be triggered by natural causes or human-induced developmental activities. Either of them changes the natural form of the environment (Raghuvanshi *et al.,* 2014).

2.2. Types of Landslide

Landslides can be classified into different types on the basis of the type of movement and the type of material involved (Highland and Bobrowsky, 2008). According to those persons the type of movement describes the actual internal mechanics of how the landslide mass is displaced: fall, topple, slide, spread, or flow. Thus, landslides are described using two terms that refer respectively to material and movement (that is, rock fall, debris flow, and so forth). Landslides may also form a complex failure encompassing more than one type of movement (that is, rock slide-debris flow) (Highland, 2008). According to (Cruden and Varnes, 1996) those movements which have a velocity > 5m/s are considered extremely rapid, and those < 16mm/yrs., are considered extremely slow.

The most accepted classification of the landslide is proposed by (Varnes, 1978). He distinguishes five types of movements namely falls, topples, slides, flows and spreads and also subdivides the type of material into bedrock, debris, and earth. These materials may move by falling, toppling, slumping, sliding, spreading or flowing. Varnes, (1978) defined the major types of slope failures into a creep, slide, fall/topple, flow and spread.

Table 1: Classification of slope movement (Varnes, 1978)

Type of movement			Types of materials		
				Engineering soils	
			Bedrock	Predominantly Coarse (debris)	Predominantly fine (earth)
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topples	Debris topples	Earth topples
Slides	Rotational	Few unit	Rock slump	Debris slump	Earth slump
	Translation	Many units	Rock block slide Rockslides	Debris block slides Debris slides	Earth block slides Earth slides
Lateral spread			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
Complex	Combination of two or more types of movement				

I. Falls

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders that become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water (Varnes, 1978).

II. Topple

Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks (Novotny, 2013).

III. Slide

A slide is a down slope movement of a soil or rock mass occurring on surfaces of rupture or on relatively thin zones of intense shear strain. In a rotational landslide, the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope. The mass in a translational landslide moves out or down, outwards along a relatively planar surface with little rotational movement or backward tilting. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil (USGS, 2004).

IV. Flow

According to (USGS, 2004) there are four basic categories of flows that differ from one another in fundamental ways.

Debris flows: A debris flow is a form of a rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as the slurry that flow downslope. Debris flows include<50% fines. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows. Debris avalanche**:** this is a variety of very rapid to extremely rapid debris flow.

Earth flow: Earth flows have a characteristic "hourglass" shape. The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

Mudflow: A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."

Creep: Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges.

V. Lateral spreads

Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesion fewer sediments (usually sands and silts) are transformed from a solid into a liquefied state. Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and May then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials, movement occurs for no apparent reason. A combination of two or more of the above types is known as a complex landslide (USGS, 2004).

2.2.1. The complex type of movement:

The complex type of movement sometimes a combination of two or more types of failure happens in a single slope. This type of combination of failure may happen at the same time or during the lifetime of slope failure (Cruden and Varnes, 1996).

2.3. Landslide Triggering Factors

There are two considering factors that occurring landslide, internal factors and external triggering factors. The intrinsic causative parameters affect landslide are; slope geometry, slope material, structural discontinuities, land use, and land cover, and groundwater; while, seismicity, rainfall, and manmade activities are considered as extrusive triggering factor (Ermias *et al*., 2017). The environmental factors are a collection of data layers that are expected to have an effect on the occurrence of landslides and can be utilized as causal factors in the prediction of future landslides (Corominas and Mavrouli, 2011).

Causative factors that are used as an input for the landslide hazard evaluation include lithology, proximity to the fault, land use, slope steepness, aspect, elevation and proximity to drainage (Abay *et* *al.,* 2019). According to Chimidi *et al.,* (2017) factors were considered for LHM including slope material, elevation, slope, aspect, curvature, land-use/land-cover, groundwater, distance to road and stream.

Intrinsic parameters are the causative parameters that define the favorable or unfavorable stability conditions within the slope. These intrinsic parameters are slope geometry, slope material, Structural discontinuities, land use and land cover and groundwater (Raghuvanshi *et al*., 2014). The considered causative factors mainly determine landslide includes; slope material, slope, aspect, elevation, land use, and land cover and groundwater-surface traces (Kumar *et al*., 2015).

Elevation: Elevation is another factor that plays an important role in landslide susceptibility assessments considered in several researchers (Dai *et al*., 2002; Yalcin *et al*., 2011). The influence of elevation may be attributed in terms of degree of weathering, variation in humidity, rate of hydrate reaction, erosion process and depth of weathering (Girma *et al.*, 2015). The main assumption is that the intensity of exogenous processes increases with rising altitudes. Exogenous processes disrupt the slope surface which leads to lower stability (Kova *et al*., 2017).

Slope: Slope is an important factor with regard to landslide initiation. In most studies of landslides, the slope steepness is taken into account as the major causative factor of the landslide (Asmelash and Barbieri, 2012). Slope morphometry maps define slope categories on the basis of the frequency of occurrence of particular angles of slope. The geomorphological history of the area determines the distribution of the slope categories as the angle of slope of each unit reveals a series of localized processes and controls which have been imposed on the facet (Raghuvanshi *et al*., 2014).

Aspect: Aspect is defined as the direction of the maximum slope of the terrain surface with reference to the north (Xu and Shen, 2012). The aspect of a slope can influence landslide initiation because it affects moisture retention and vegetation cover, and in turn soil strength and susceptibility to landslides (Kumar *et al.*, 2015).

Curvature: the term curvature is theoretically defined as the rate of change of slope gradient or aspect, usually in a particular direction (Gallant and Wilson, 2000). The morphology of the topography can be defined by curvature values. If the surface is upward concave at that raster cell the curvature is negative whereas if the surface is upward convex at that cell the curvature is positive. If the surface is flat the curvature value will be zero. The chances of landslide activity increase with an increasing negative value of curvature. According to the topographic type, the value is higher in the hilly and mountainous areas and low in flat areas (Lee and Min, 2002).

Proximity to Lineament: Lineaments are map-able linear features present on the surfaces of the earth, which indicates the zone of weakness and structural discontinuities in a rock. Lineaments affect surface material structures and have a significant influence on topography permeability and thus slope stability. The proximity of a slope to these features influences its stability, increasing the susceptibility of landslides occurrence (Samanta, 2016). Geological fault and joint areas are in general, highly susceptible to landslides because the surrounding rock strength decreases due to tectonic breaks (Chen *et al.,* 2017). So the lineaments can cause landslide formation and the hazard is decreased with increasing distance from lineament structures

Proximity to drainage: The closeness of the slope to drainage structures is another important factor in terms of slope stability. Streams may adversely affect stability by eroding the slopes or by saturating the lower part of material until resulting in water level increases (Dai *et al*., 2001; Yalcin, 2005). Distance to stream is one of the controlling factors for the stability of a slope (Reis *et al*., 2012). They can lead the failure of banks because of the sub-quotation of slopes, and the modification of the ground caused by gully erosion may also influence landslide initiation (Dai *et al*., 2002).

Lithology: Lithology is one of the most important parameters in landslide studies because different lithological units have different susceptibility (Dai *et al*., 2002). Hence, it needs to be considered. Lithology significantly influences the occurrence of landslides, because lithological variations often lead to a difference in the strength and permeability of rocks and soils (Abay *et al*., 2019).

Soil properties: Soil properties influence landslide occurrences. It could happen when the soil moisture content exceeds the liquid limit in the field. This event generates dangerous and prospectively devastating results as the soil becomes visible to be stable and then when distressed can unexpectedly break away. Increase in soil moisture content decreases soil strength by diminishing capillary cohesion (Handy and Spangler, 2007)

Proximity to roads: Road-cuts are usually sites of anthropologically induced instability. A given road segment may act as a barrier, a net source, a net sink or a corridor for water flow, and depending on its location in the mountains, it usually serves as a source of landslides. Some slope failures start above roads but are often intercepted by them (Ayalew and Yamagishi, 2004).

Land Use/Land Cover: Land cover is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. whereas land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods (Gebremicheal, 2017).

The land cover may also describe the potential for instability of slopes. Sparsely vegetated areas and barren areas demonstrate more erosion, thus greater instability as compared to reserve or protected forests, which are thickly vegetated and are less prone to mass wasting processes. The agricultural lands represent areas of repeated water charging for cultivation purposes and as such may be considered stable since agricultural practices are made on relatively gentler slopes (Mulatu *et al*., 2011). Land-use and land-cover is a key factor for landslide occurrence. Regions with dense vegetation are found to be prone to landslide than sparse vegetation, agriculture, and urbanization (Girma, 2013; Raghuvanshi *et al*., 2014).

Rainfall: The frequency and magnitude of rainfall events, together with other factors such as lithology, Topography, and land cover, influence the landslide occurrence. Heavy rainfall is indicated as the main triggering factor for almost all landslides (Broothaerts *et al*., 2012). The intensity of rainfall has a direct relation with the slope instability problems. For this reason, only most of the landslides occur during the rainy season (Dai *et al*., 2001; Ayalew and Yamagishi, 2004). Rainfall can result in surface erosion and also it can recharge groundwater which ultimately saturates the slope material (Raghuvanshi *et al.* 2014).

2.4. Landslide Inventory mapping

Landslide inventory mapping is one of the simplest qualitative approaches of landslide susceptibility mapping. It is also known as 'distribution analyses'. Landslide details are obtained through historical records, field survey mapping, aerial photo interpretation, and satellite images. Landslide inventory map also shows a slope failure by a single event or they may show cumulative effects of many events (Guzzetti *et al*., 2005; Raghuvanshi *et al*., 2014).

The Landslide hazard estimation must begin with a clear understanding of what has happened in the past in the area. This is to know what type of landslides have occurred and with what mechanism these were triggered. There needs to be a clear understanding of the possible causative and triggering factors that might have possibly resulted in landslides (Kumar *et al*., 2015). In Gechi district there are so many event and past landslide inventories area. So, in this study landslide inventory data were collected and inventory map was prepared.

2.5. Landslide hazard zonation mapping Techniques

There are various methods to study and evaluate the landslide phenomena and its causative and triggering factors. Landslide hazard zonation is an important step in landslide investigation, landslide risk management, and catastrophic loss reduction and assists in the development of guidelines for sustainable land use planning (Mengistu *et al*., 2019b).

In the last few years, LHZ has been carried out in different parts of the world. Several approaches have been developed for LHZ such as Expert Evaluation Techniques (Inventory Based Approach and heuristic approach), deterministic approach, statistical approach (Bivariate and Multivariate Statistical Approaches), and multi-criteria decision-making approach (Raghuvanshi *et al.*, 2014; Chimidi *et al.*, 2017; Hamza and Raghuvanshi, 2017).

2.5.1. Statistical approach

In statistical methods, logistic regression models have been frequently used in geological hazard research and employed to explore the factors that influence landslides and determine landslide probability (Ayalew and Yamagishi, 2005; Van *et al*., 2006). Compared with other statistical approaches, Brenning (2005) found that logistic regression models have a relatively low rate of error. Logistic regression can include dichotomous dependent variables (e.g., whether a landslide occurred) and independent variables, as well as categorical or continuous variables (Chang *et al.*, 2007; Atkinson and Massari, 1998)

In the last few years, the approach towards LHZ has been changed from a heuristic (knowledge-based) approach to a data-driven approach (statistical approach) to minimize subjectivity in weight assignment procedure and produce more objective and reproducible results (Kanungo *et al.*, 2009). Methods based on a statistical analysis of geo-environmental factors related to landslide occurrence are preferred. The statistical methods for LHZ can be grouped into two bivariate statistical analyses and multivariate statistical analysis. The statistical methods are used to evaluate spatial landslide instability based on the relationship between landslide activities and their causative factors (Tilahun and Raghuvanshi, 2017).

Bivariate statistical approach

Several statistical methods can be applied to calculate weight values, such as the information value method, weights of evidence modeling, Bayesian combination rules, certainty factors, the Dumpsters-Shafer method, and fuzzy logic. According to Gebremicheal, (2017) in this statistical approach, every individual causative factor weight to landslide is evaluated. The weight or contribution of a causative factor to the landslide hazard is determined on the basis of landslide density. In this approach, GIS plays a great role starting from the division of each parameter maps into a number of the relevant class;

determination of landslide density and weighing the value of each parameter map; geoprocessing of thematic maps; and weighting of values to the various parameter maps.

In the bivariate method causative factors for a landslide to occur are compared to the existing landslides. Based on landslide severity and distribution the weights are assigned to the landslide causing factors. Bayesian Model, Frequency Analysis approach, Information Value Model (IVM) are a few bivariate methods applicable for hazard zonation mapping. The main disadvantage of the bivariate statistical method is independence between different parameter maps with respect to probability to landslide occurrence, (Van *et al*., 2008).

Multivariate Statistical Analysis

Multivariate statistical analysis for landslide hazard zonation considers the relative contribution of each thematic data layer to the total landslide susceptibility (Kanungo *et al*., 2009). These methods calculate the percentage of landslide areas for each pixel and landslide absence, the presence data layer is produced followed by the application of the multivariate statistical method for reclassification of hazard for the given area. Logistic regression model, Determinant analysis, multiple regression models, conditional analysis, Artificial Neural Networks (ANN) are commonly used methods for landslide hazard zonation mapping.

2.5.2. Deterministic approach

The deterministic approach provides landslide hazards in absolute values in the form of safety factors, or probability (Raghuvanshi *et al*., 2014; Kumar *et al*., 2015). The deterministic analyses are quantitative and are applied to small to medium size areas at large to medium scale mapping. They also require a large amount of detailed input data and they may lead to oversimplification if such data are only partially available (Raghuvanshi *et al*., 2014). Deterministic numerical methods cannot be economically applied effectively for large areas (Beyene, 2016).

2.5.3. Expert Evaluation Techniques

This approach provides landslide hazard zonation based on the observational past experience gained over causative factors and their contribution to the instability of slopes in the area. The causative factors responsible for landslide activity, which were considered during using such technique, were relative relief, slope morphometric, geology, groundwater and land use/ land cover. The information pertaining to these causative factors was collected from the field and analyzed as per the LHEF scheme (Woldegiorgis *et al*., 2014).

The expert evaluation technique includes landslide inventory mapping and heuristic approaches. Landslide inventory maps highlight the location and extents of recorded landslides thus helps in demarcating landslide susceptible areas whereas heuristic technique includes opinion in classifying the landslide hazard which is based on quasi-static variables (Dai *et al*., 2001). The decision rules are therefore difficult to formulate because they vary from place to place.

2.5.4. Multi-Criteria Decision Analyses

The MCDA framework is primarily concerned with how to combine the information from several criteria to form a single index of evaluation (Yu *et al.*, 2011; Feizizadeh and Blaschke, 2013). GIS-MCDA can be thought of as a process that transforms and combines geographical data and value judgments (the preferences of the decision-maker) to obtain information for decision making. GIS-MCDA based landslide analysis allows combining information derived from heterogeneous sources to support landslide monitoring. One of the multi-attribute techniques which have been incorporated into the GIS-based landslide analysis procedures is the Analytical Hierarchy Process (AHP) originally introduced by (Saaty, 1977). Weighted Linear Combination (WLC) and Analytic Hierarchy Processes (AHP) are the two most known Multi-Criteria Decision Analysis methods.

Analytical Hierarchy Process

The AHP model as developed by Saaty (1980) is a decision-aiding tool for dealing with complex and multi-criteria decisions. AHP builds a hierarchy of decision elements (factors) and renders comparisons possible between pairs of factors in the form of a matrix. The development of the AHP pair wise comparison is based on the rating of relative preferences for two criteria at a time. Each comparison is a two-part question determining which criterion is more important and to what extent, using a scale with values from the set: {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9}. The values range from 1/9 representing the least important (than) to 1 for equal importance and to 9 for the most important (than), covering all the values in the set (Bakhtiar and Blaschke, 2013). AHP has been successfully employed in GIS-based MCDA since the early 1990s. One of its wide applicability in recent years is in the field of landslide study. Several landslide studies have been published using the AHP approach (Yu *et al.*, 2011; Feizizadeh *et al.*, 2012; Feizizadeh and Blaschke, 2013).

Analytical Hierarchal GIS Multicriteria decision analyses (MCDA) provide a rich collection of techniques for landslide susceptibility mapping (Feizizadeh *et al.*, 2012). AHP has the advantage of permitting a hierarchical structure of the criteria which provides users with a better focus on the specific criteria (factor) and sub-criteria (classes) when allocating the weight (Ishizaka and Labib, 2009). It to be structured into a hierarchy descending from an overall objective to various 'criteria', 'sub-criteria', and so on until the lowest level. The overall goal of the decision is represented at the top level of the hierarchy while the criteria and sub-criteria contributing to the decision are represented at the intermediate levels. Finally, the decision alternatives are positioned at the last level of the hierarchy (Abay *et al.*, 2019).

AHP's ability to incorporate different types of input data, and the pair wise comparison method for comparing two parameters at the same time. However, both the comparison of the parameters relative to each other and the determination of the decision alternatives, namely the effect values of the sub-criteria of the parameters (weight), were based on the comparison of landslide susceptibility map (Feizizadeh *et al.*, 2013).

Weighted Linear Combination

The WLC method is one of the most commonly used GIS-MCDA to aggregate the overall factors to produce a single map (Malczewski, 2000). The WLC technique is a popular method that is customized in many GIS and is applicable for the flexible combination of maps. The tables of scores and the map weights can be adjusted to reflect the judgment of an expert in the domain of the application being considered (Ayele, 2009).

The WLC method starts with a comparison of the data-layers corresponding to the landslide controlling parameters and the landslide inventory map and involves the computation of the landslide density so as to assign primary-level weights for each class of a particular parameter. The final steps of this method are a combination of all the weighted layers into a single map, and the classification of the scores of this map into landslide susceptibility (Ayalew and Yamagishi, 2004). MCDA technique is useful for overlaying large data/maps and easy to understand/ implement (Ahmed, 2015). Thus, in this study, Multi-Criteria Decision Analysis method was applied to delineate and map landslide hazard zonation.

2.6. Previous Studies on Landslide in Ethiopia

As stated by different researchers, landslide hazard is one of the crucial environmental problems for the development of Ethiopia, particularly in the northern, western and southern highlands.

Abebe *et al*., (2010) studied landslides in the Ethiopian highlands and the rift margins and their findings show that the high relief and rugged topography, the occurrence of clayey horizons within the sedimentary sequences, the dense network of tectonic fractures and faults, the thick alluvial mantles on volcanic out-crops, and the thick colluvial–alluvial deposits at the foot of steep slopes are the predisposing factors for a large variety of mass movements.

Mulatu *et al*., (2011) conducted landslide hazard zonation mapping around Gilgel-Gibe II, Southwestern Ethiopia. In their study, they have classified the landslide potential areas into a high hazard, Moderate Hazard, and low hazard areas.

Ayele *et al.,* (2014) although used Weighted Linear Combination method for mapping landslide susceptibility of Abay Gorge. The factors he was used to identify landslide hazard zonation are land cover, slope angle, lithology, geological structures, drainage pattern and hydrogeology/ groundwater conditions, degree of weathering and soil types.

Girma, (2015) made a study on landslide hazard zonation in Ada Berga District, central Ethiopia using a GIS-based statistical approach. In this study, the considered landslide causative factors are lithology, soil deposit, slope, aspect, elevation, curvature and land use/land cover and groundwater.

As Kumar *et al*., (2015) conduct the research in Meta Robe district, Oromia Ethiopia by using grid overlay and GIS modeling approaches to prepare landslide hazard zonation map. The research showed that GIS modeling produced a better landslide hazard zonation map. Also, the grid overlay method is a more tedious and time-consuming approach.

Dawit, (2016) made the study on landslide hazard evaluation and zonation in the area of Kindo Didaye woreda, southwest Ethiopia. In this study landslide hazard zonation of the study area was carried out by using two methods: Integrated slope stability susceptibility evaluation parameter and a raster-based information value model approach. The findings show that the deformation, cultivation and modifying the slopes by manmade activities in addition to high rainfall and groundwater are the most influential causative parameter for the occurrence of a landslide in the study area.

Chimidi *et al.,* (2017) studies on landslide hazard evaluation and zonation in and around Gimbi town, western Ethiopia – a GIS-based statistical approach. According to this study, nine factors were considered for the LHM preparation including slope material, elevation, slope, aspect, curvature, land-use/land-cover, groundwater, distance to road and stream. From this study, five hazard zones and fifty past landslide sites were identified. They concluded that 75% of the past landslides fall within very high and high hazard zones; as a result future planning and development of the town should consider this.

Hamza and Raghuvanshi, (2017) made a study on landslide hazard evaluation and zonation (LHZ) in Jeldu District in Central Ethiopia. The considered governing factors in this study are aspect, slope and elevation, lithology, soil and land use/land cover. The results revealed that 12% of the study area falls under no hazard, 27% as low hazard, 32% as a moderate hazard, 21% as high hazard and the rest 8% as very high hazard.

And, also Mengistu *et al*., (2019) made an output on Landslide Hazard Zonation and Slope Instability Assessment by using Optical and InSAR Remote Sensing: the case of Arbaminch-Gidole Road, Southern Ethiopia. In order to allocate landslide hazard zones in this study area triggering factors were considered are; aspect, slope, elevation, NDVI, lithology, and land use/ land cover.

Table 2: Examples of landslide susceptibility model studies in Ethiopia

Study area	Topic	Techniques	Parameters Determining LSM	Author (year)
Gilgel-Gibe II, South western Ethiopia	landslide hazard zonation mapping	Landslide Hazard evaluation Factor (LHEF)	geology, slope morphometry, relative relief, LULC and ground water	Mulatu *et al*., 2011
Abay Gorge	landslide susceptibility mapping	Weighted Linear Combination method	LULC, slope angle, lithology, geological structures, drainage and groundwater	Ayele *et al*., 2014
Ada Berga District, Ethiopia	landslide hazard zonation	GIS-based statistical approach	Lithology, soil, slope, aspect, elevation, curvature, LULC and groundwater.	Fikire, 2015
Meta Robi district, Ethiopia	landslide hazard zonation	grid overlay and GIS modeling approaches	slope material, slope, aspect, elevation, land use	Kumar *et al*., 2015

			and land cover and groundwater	
Kindo Didaye woreda, southwest Ethiopia	landslide hazard evaluation and zonation	Slope stability Susceptibility Evaluation Parameter (SSEP)	Relative relief, slope, slope material, structural discontinuity, land use/ land cover, groundwater, rain, seismicity and manmade activities	Dawit, 2016
In Jeldu District in Central Ethiopia	landslide hazard evaluation and zonation	GIS-based bivariate statistical approach	aspect, slope, elevation, lithology, soil and land use/land cover	Hamza and Raghuvanshi, 2017
Arbaminch-Gidole Road, Southern Ethiopia.	Landslide Hazard Zonation and Slope Instability Assessment	Information value method	aspect, slope, elevation, NDVI, lithology, and land use/ land cover	Mengistu *et al.*, 2019

2.7. Role of Geospatial technologies in Landslide Hazard Zonation

Remote sensing and GIS-based mapping integrated with field surveys of landslide affected sites are used in preparing the landslide causative factors and inventory maps. Integrated work of Remote Sensing and GIS plays a vital role in many aspects of disaster management, ranging from risk modeling and vulnerability analysis to early warning. Earth Observation System (EOS) otherwise known as Remote Sensing (RS) and GIS assist professionals in disaster management in a very effective manner and provides more precise data. With this technology, it is easy to obtain homogeneous data covering the entire world over a short period of time (Krishnamoorthi, 2016).

Remote sensing methods, using aerial photographs and satellite images are employed to obtain significant and cost-effective information on landslides (Lee and Pradhan, 2006). Remote sensing (RS) techniques are widely used in landslide susceptibility assessment in both the generation of landslide parameters thematic layers and the production of landslide inventory maps (Kouli *et al.*, 2009).

According to Rai *et al*., (2014), remotely sensed data are used in solving various environmental tasks. This technology can be used as an effective aid in natural hazard investigation, as well as for the purpose of environmental planning. A geographic information system (GIS) is a framework for gathering, managing, and analyzing data. Rooted in the science of geography, GIS integrates many types of data. It analyzes spatial location and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals deeper insights into data, such as patterns, relationships, and situations helping users make smarter decisions.

The application of GIS was found vastly useful for thematic data layer generation and for their spatial data analysis, which involved complex operations (Sarkar and Kanungo, 2004). A GIS allows for the storage and manipulation of information concerning the different terrain factors as distinct data layers and thus provides excellent tools for slope instability zonation. Further, it contains effective tools for examining spatial variability. The main advantages of using a GIS in assessing landslide hazards include: Improving the hazard occurrence model in slope stability analysis by varying the input parameters and evaluating the results in an iterative process of trial and error (Baban and Sant, 2005). A handheld global positioning system (GPS) device was used to identify the locations of the landslide (Ahmed and Forte, 2014).

CHAPTER THREE

3. METHODS AND MATERIALS

3.1. Description of the study area

3.1.1. Location of the study area

The study area is located in Buno Bedele zone, Oromia Regional State, Western Ethiopia, which is about 420 Km far to the west of the capital city from Addis Ababa. It lies between 8º10'30'' - 8º35'30'' N latitude and 36º17'00'' - 36º53'00'' E Longitude, and it covers a total area of 1464 Km^2 (Fig 3.1).

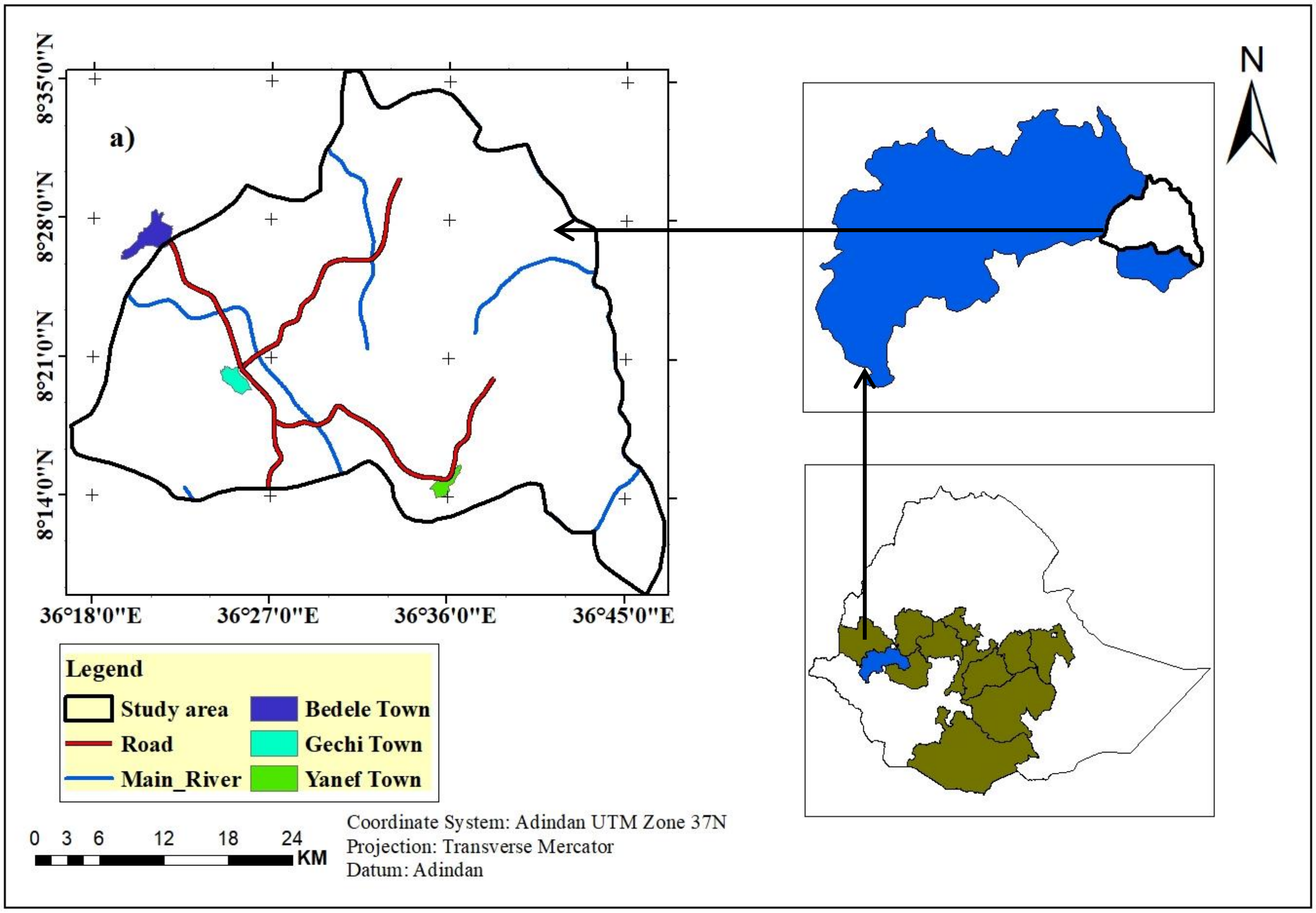

Figure 1: Location map of the study area. (Source: CSA data)

3.1.2. Topography and Drainage

The study area has diverse altitude, which includes lowland and plateau with , some undulating to steep land forms, including depressions and valley floors ranging from low land (1288m) to the highest elevation reaches up to (2481m) above mean sea level and also there are many rivers and streams which cross the study area. These streams and rivers start from the South and Southwest part of the study area and they drain to-wards North, Northeast and Northwest (Fig 2).

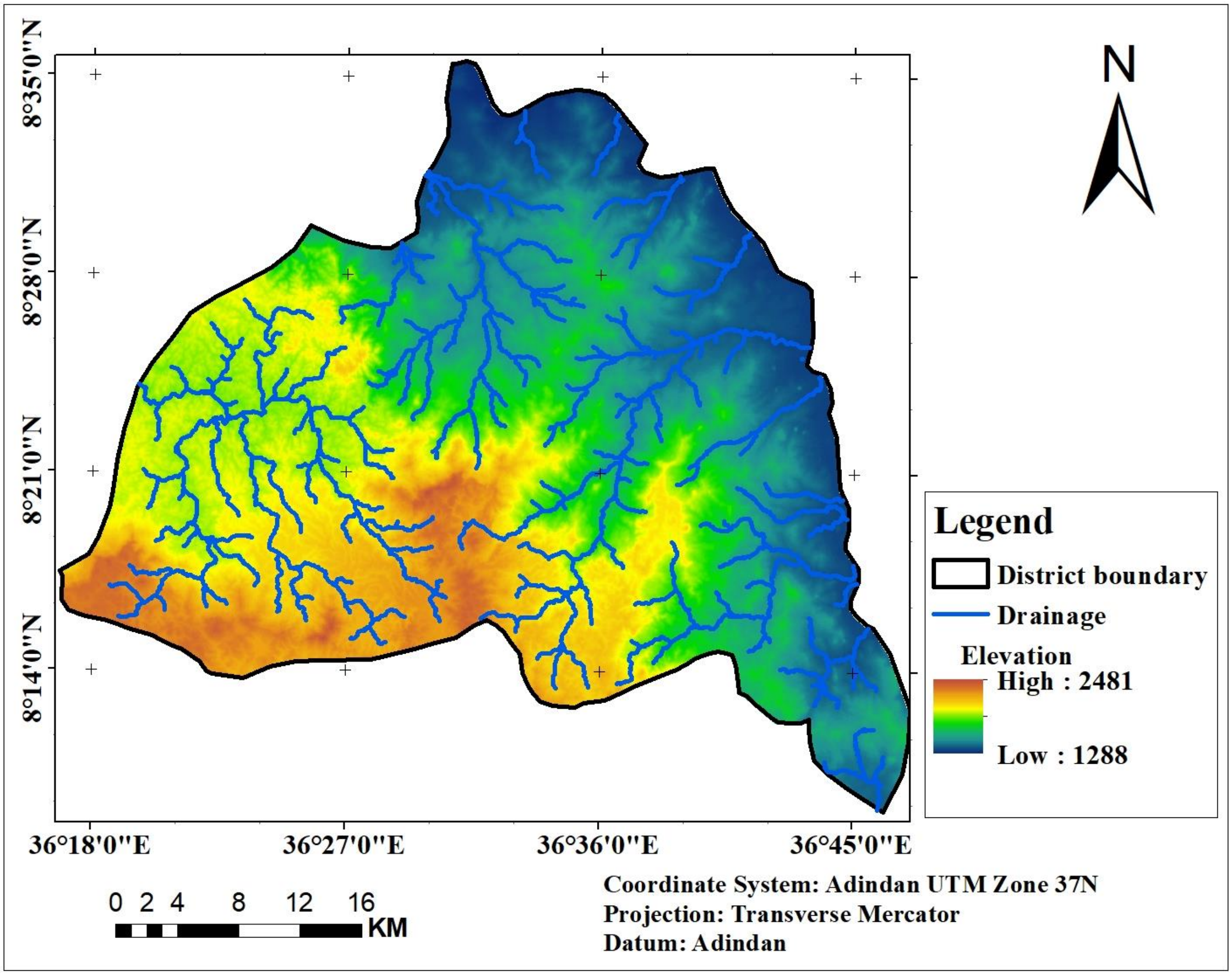

Figure 2: Topography and drainage map of the study area. (Source: ASTER DEM 30m)

3.1.3. Rainfall and Temperature

Gechi District is grouped under semi-humid climatic zones. The average monthly rainfall of the study area is varying from each other. The study area receives high monthly rainfall in May, June, July, and August (Fig 3). So, in the half of autumn and summer seasons of the study area has a high rainfall, as well the average annual rainfall of the study area for consecutive eight years are 1973mm/yr. The annual mean average temperature for ten years (2008-2018) is from the minimum temperature 14^0C to the maximum temperature reaches up to 25^0C (computed from NMA 2008-2018).

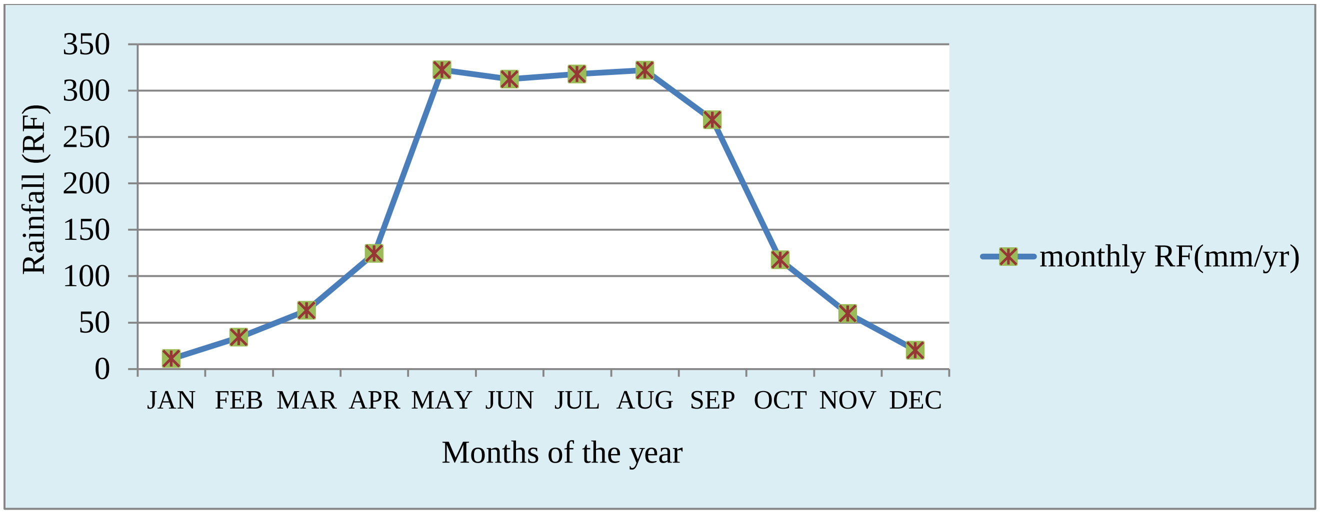

Figure 3: Monthly rainfall of the study area. (Source: NMA 2008-2018)

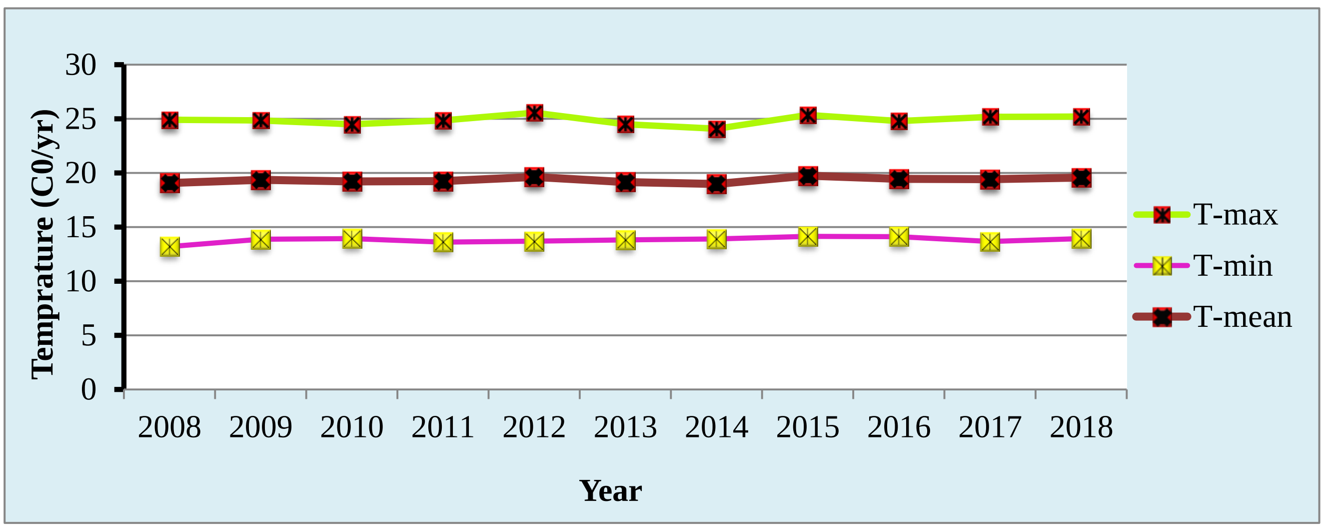

Figure 4: Maximum, minimum and mean average temperature of the study area. (NMA 2008-2018)

3.1.4. Demography

According to the Central Statistical Agency (CSA) reported in 2007 a total population of Gechi district is 70,478, out of this population 35,307 were men and 35,171 were women. Among this population around 5,442 or 7.72% were urban dwellers. The majority of the inhabitants were Muslim, which account 87.7%, while 10.58% were Orthodox, and 1.66% was Protestant. Coffee is an important cash crop of this district.

3.2. Data collection

3.2.1. Data Types and Sources

In order to achieve the objective of the study primary data (data collection from field) and secondary data (from different organizations, freely available remote sensing data and different literatures) were collected.

Field data for landslide inventory

Field data collection was performed to obtain information about the inventory of landslide. GPS instrument were used for landslide inventory data collection along the margin of active landslides.

Remote sensing data

Landsat 8 OLI/TIR image of Jan 14/2019 was downloaded from USGS website which is cost freely available data with no cloud cover with spatial resolution of 30m for multispectral and 15m for panchromatic band. This data was used to extract information about LU/LC and lineament factors of the study area.

As well, ASTER DEM of 30m resolution was downloaded from USGS website to extract elevation, slope, aspect, curvature and also hydrologic parameter (distance from drainage) and also road data was downloaded from open street map (OSM) to analysis distance from road factor.

Soil data

Soil data was obtained from Oromia Water Work Design and Supervision Enterprise (OWWDSE) with the scale of 1:50,000 soil survey to drive soil texture of the study area.

Geological data

The lithological unit of the study area was derived from geologic map of Arjo with the scale of 1:250,000 which were obtained from Geologic Survey Ethiopian (GSE).

Rainfall data

Annual rainfall data of the study area was obtained from National Metrological Agency (NMA). The data was taken from six stations those are Bedele, Arjo, Agaro, Yayu, Nekemte and Jimma. In general, data types and source which are used for the study were listed as (Table3).

Table 3: Data type and source

No.	Data type	Data Source	Data format	Scale	Purpose
1.	Boundary	CSA data	Shapefile		Delineate study area map
2.	Inventory data	Field work	Row data		Landslide inventory map
3.	DEM(ASTER)	USGS	Raster	30m	Extract elevation, slope, aspect, curvature and drainage
4.	Geological map	EGS	Raster	1:250,000	Lithological factor of the study
5.	Climate	NMA	Tabular		Rainfall map
6.	Soil	OWWDSE	shapefile	1:50,000	Soil map
7.	Landsat8 OLI/TIRS 2019	USGS	Raster	30m	Extract lineament and Land use/Land cover factor
8.	Road	OSM/htpp://www.openstreetmap.org/	shapefile		Road proximity map

3.2.2. Software and tools

To achieve the objective of the study, software like Arc GIS 10.3, ERDAS IMAGINE 2015, Geomatica 2018, Google Earth 2019, TerrSet (AHP Plugin), and materials like handheld GPS, and Digital Camera were used.

3.3. Data Analysis

There are various methods to study and evaluate the landslide-prone area with its causative factors. In this study, Multi-Criteria Decision Analysis (MCDA) method was adopted to delineate and map landslide hazard zonation (Ahmed, 2015). Weighted Linear Combination (WLC) and Analytic Hierarchy Processes (AHP) are the two most known Multi-criteria analysis methods which were applied in the study. With MCDA method, eleven causative factors were used as input for the landslide hazard zonation which includes: elevation, slope, aspect, curvature, soil texture, lithology, proximity to lineament, land use/land cover, proximity to road, proximity to drainage, and rainfall.

All the factors were reclassified and new values were assigned for each factor. Reclassification and rating of classes for each criterion to be considered were performed based on the international and national standards taken from different literatures (Table 4). Accordingly, the classes of each factor that have the maximum impact of landslide was assigned the maximum value, whereas classes in which less impact of landslides were assigned with a minimum value (Ayele, 2014).

Table 4: Factors to be considered for landslide hazard zonation with their rating values

Factors	Categories/value ranges	Value	Sources
Elevation	1497–1696 m	1	Hamza and Raghuvanshi, 2017
	1696–1821 m	5	
	1821–1954 m	4	
	1954–2126 m	3	
	2126–2426 m	2	
Slope	(0−5°)very gentle slope	1	Mengistu *et al.*, 2019
	(5−12°)gentle slope	3	
	(12−30°)moderately steep slope	4	
	(30−45°)steep slope	5	
	>45° escarpment	0	
Aspect	Flat (-1)	0	
	North (0–22.5°)	4	Mengistu *et al.*,2019
	Northeast (22.5–67.5°)	3	
	East (67.5–112.5°)	2	
	Southeast (112.5–157.5°)	1	
	South (157.5–202.5°)	4	
	South west(202.5°–247.5°)	5	
	West (247.5–292.5°)	1	
	Northwest (292.5–337.5°)	2	
Curvature	-3.5 – 0	5	Ayele, 2019; Girma, 2015
	0	2	
	0 – 3.9	5	
Lithology	Pyroclastic deposit	5	Mengistu *et al.*,2019
	Basal sandstone	4	
	Basalt	2	

	Colluvial deposit	3	
	Basaltic Gneiss rock	1	
	Alluvium, sand and clay	5	
Soil Texture	Clay	1	Melkamu, 2019
	Clay loam	2	
	Sandy clay loam	3	
	Sandy loam	4	
	Sandy	5	
Distance from	0–200	5	
lineament(m)	200–400	4	Chen *et al.*, 2016
	400–600	3	
	600–800	2	
	800–1000	1	
	>1000	0	
Distance from	0-25	5	
road(m)	26-50	4	Feizizadeh *et al.*, 2013
	51-75	3	
	76-100	2	
	100 <	1	
Distance from	0–150 m	5	
drainage	150–300 m	4	
	300–450 m	3	Firomsa and Abay, 2019;
	450– 600 m	2	Abay *et al.*, 2019
	and >600 m	1	
Land use/ Land	Bush land	6	
cover	Forest land	2	Chimidi *et al.*, 2017
	Densely vegetated land	1	
	Sparsely vegetated	5	
	Water body/springs	6	
	Irrigated wetland	4	
	Cultivated land	7	

	Bare land	3	
	Urban/build-up area	4	
Rainfall(mm)	<300	1	Raghuvanshi *et al.*, 2014
	300–700	2	
	701–1100	3	
	1101–1500	4	
	>1500	5	

3.3.1. Landslide Inventory Mapping

The beginning of any landslide hazard evaluation is the identification and mapping of all landslide phenomena or preparation of landslide inventory (Ermias *et al.*, 2017).

Landslide events in the study area were collected through field survey using hand-held GPS. In this study, both probability and non-probability sampling techniques were employed.

From probability sampling technique, the study used clustered sampling approach to determine the spatial distribution of inventory points in the study area. Accordingly, the study area was divided in to two zones; i.e. eastern and western. Of the total sample points of landslide prone areas, about nineteen (19) and ten (10) points were purposively collected from the western and eastern zone respectively. Lastly, landslide inventory map was prepared using ArcGIS 10.3 software (Figure 5).

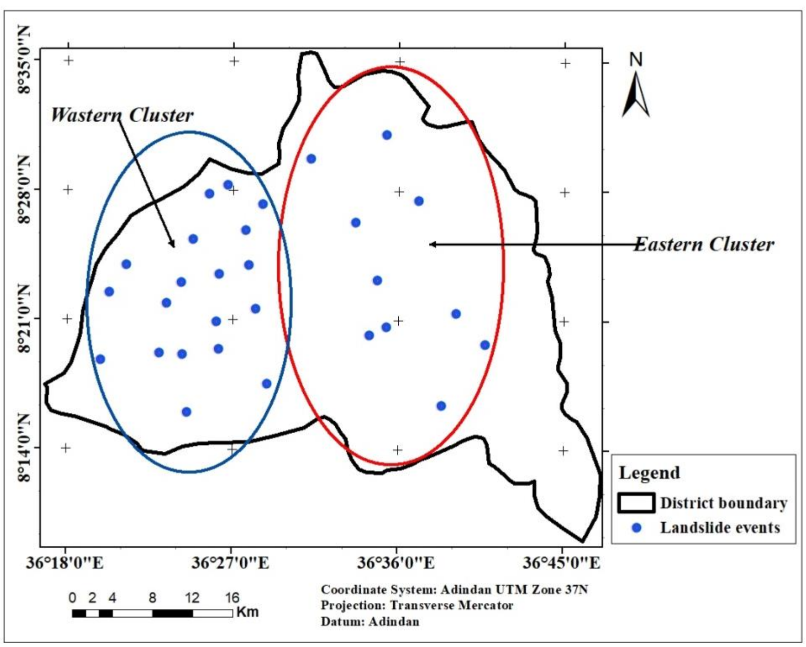

Figure 5: Sample points of landslide inventory points

3.3.2. Landslide Triggering Factors Evaluation

I. Environmental Factor

The environmental factors are the collection of data that are expected to have an impact on the event of landslide; and can be utilized as causal factors in the prediction of future landslides (Raghuvanshi *et al.,* 2014; Van Westen *et al.*, 2008).

Land use /Land cover

LU/LC factor map of the study area was extracted from Landsat8 OLI/TIR image 2019 which contains 30 m spatial resolution for multispectral and 15 m for panchromatic bands. To do this the important image processing were carried out.

Image pre-processing: Image interpretation and processing were carried out by using ERDAS IMAGINE 2015. Before extracting the information from the image some preprocessing were conducted: Layer Stack and, combining multiple bands of a satellite image into one file was carried out. The image of the study area was masked by using the study area boundary. In this study image enhancement such as, haze reduction and atmospheric noise reduction were performed to enhance visual interpretability of the image. Lastly, post-image processing (image classification and accuracy assessment) were performed to generate LU/LC factor map of the study area.

Image classification: In this study supervised classification techniques with maximum likelihood algorism was used to categorize the land use/land cover types. Furthermore, representative points were recorded to represent the various land use/land cover classes during field observation in accessible places. Accordingly, 10 samples for each land use class were selected from field survey using random stratified method to represent different land use/land cover classes of the study area. Consequently, Google Earth image was used as a guideline to identify representative land cover classes. This was used for solving the problems of identifying features of similar reflectance. The land use pattern is often has a great influence in the landslide occurrences because they relate to the anthropogenic interference on hill slopes (Pradhan *et al.,* 2010). LU/LC types of the study area was classified in to seven namely (Forest, agriculture, Settlement, shrub land, grassland, water body and bare land) land use land cover classes.

Accuracy assessment: land use/land maps derived from remote sensing imagery always contain some sort of errors due to many factors which range from classification technique to method of satellite data capture. Therefore, accuracy assessment was performed for image classification to tell how accurately the land use/land cover maps were classified using ERDAS Imagine 15 accuracy assessment tool. Accordingly, points for each land use/land cover were selected from field survey and Google earth image of the study area using random stratified method. As a result, 140 random points were selected. The overall classification accuracy was computed by the total number of correct class predictions (the sum of the diagonal cells) divided by the total number of cells based on the formula below.

$$\textbf{Total (overall)Accuracy} = \frac{\textbf{Number of correctely plot (value)}}{\textbf{total number of plot (value)}} \times \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

$$\mathbf{UAC} = \frac{\mathbf{Xij}}{\mathbf{X+i}} * \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

$$\mathbf{PAC} = \frac{\mathbf{Xij}}{\mathbf{Xi+}} * \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3}$$

Where:

- UAC = User accuracy, - PAC = producer accuracy,
- Xij= the diagonal values, - Xi+ = the column total, and

X+i = row total, r is the number of categories,

The image classification accuracy is further assessed by calculating Kappa coefficient 'k'. Kappa analysis generates a kappa coefficient or K_{hat} statistics, the values of which range between 0 and 1. Kappa coefficient (K_{hat}) is a measure of the agreement between two maps staking into account all elements of error matrix (Anand, 2018). It is defined in terms of error matrix as given below:

$$\boldsymbol{K_{hat}} = \frac{\mathbf{Obs - Exp}}{\mathbf{1 - Exp}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4}$$

Where: Obs = Observed correct, it represents accuracy reported in error matrix (Overall accuracy) and

Exp = Expected correct, it represents correct classification.

II. Topological factor

Topographic factors (elevation, slope, aspect, curvature and drainage) of the study area were generated from ASTER DEM 30m resolution.

Elevation

The variation in elevation may be related to different environmental settings such as vegetation types and rainfall (Catani *et al*.., 2013). Elevation factor of the study area was prepared from the downloaded ASTER DEM data by clipping using Gechi district boundary. The prepared elevation factor ranges from 1288 to 2481m above msl. Accordingly, the area was classified into five elevation classes using Arc GIS 10.3 software and the values were assigned based on the contribution of each class on landslide susceptibility mapping.

Slope

Slope is an important factor with regard to landslide initiation. In most landslides studies, the steepness of the slope is taken into account as the major causative factor of the landslide (Asmelash and Barbieri, 2012). The slope map of the study area was generated from ASTER DEM using ArcGIS spatial analysis. The generated slope ranges from 0^0 to 49.9^0. Thus, it was reclassified into five ranges of classes in Arc GIS software as ($0\text{-}5^0$, $5\text{-}12^0$, $12\text{-}30^0$, $30\text{-}45^0$ and $>45^0$). The values were assigned based on their contribution of each class on landslide hazard rating.

Aspect

The aspect of a slope can influence landslide initiation, because it affects moisture retention and vegetation cover, and in turn soil strength and susceptibility to landslides. The amount of rainfall on a slope may also vary depending on its aspect (Kumar *et al*., 2015). The aspect factor was generated using ASTER DEM the study area as in put data. As a result, it was ranged from negative 1^0 to 359.67^0. Then, Aspect layer of the study area was generated as Flat (-1), North (0-22.5) – Northeast (22.5-67.5), East (67.5-112.5), Southeast (112.5-157.5), South (157.5-202.5), Southwest (202.5-247.5), West (247.5-292.5), Northwest (292.5-337.5) and North (337.5-360). Therefore, it was classified into five classes as (Flat, North–Northeast, Northeast–East–Southeast, Southeast–South–Southwest and Southwest–West Northwest) using Arc GIS software. The values were ranked for each of Aspect classes based on expert knowledge and literature review.

Curvature

The curvature values represent the topography of the area that indicates where the surface is concave, convex or flat resulting in acceleration of flow. Where acceleration of flow happens, the stream gains energy and its ability to transport particles will be increased (Ayele, 2019). Curvature map of the study area was derived from ASTER DEM of the study area and ranges (-7.9^0 to 6.7^0). Thus, it was classified into 3 curvature classes as (Concave (0 to -7.9), Flat (0) and Convex (6.7 to 0) using ArcGIS spatial analysis tool.

III. Geologic factor

Lithology significantly influences the occurrence of landslides, because lithological variations often lead to a difference in the strength and permeability of rocks and soils (Abay *et al.*, 2019). Lithological units of the study area were digitized from Geologic Survey of Ethiopia (GSE) at 1:250,000 scales. The soft copy of lithological map was geo-referenced, and it was digitalized in ArcGIS environment to utilize the raw data as information. As a result, lithological unit such as pyroclastic deposit, Eluvium deposit, (upper, medium and lower) basalt, Alluvium deposit and granite were digitized. The lithological unit which was digitized in the form of vector data format was converted into raster format using Arc-GIS 10.3. Therefore, it was reclassified and ranked according to their susceptibility to landslide hazard assessment. Finally, a thematic lithological map of the study area was prepared.

IV. Soil texture

Soil texture is important factor which cause landslide hazard, because the sizes of soil particles determine the tendency of soil particles to resist sliding across each other (Musinguzi *et al.*, 2014). Thus, for the study soil texture data of the study area was obtained from OWWDSE, (2014) which is present in a vector format with the scale of 1:50,000. This vector format was converted into raster using ArcGIS conversion tool. In the study area five soil texture classes namely (clay loam, sandy clay loam, sandy loam, loam and loamy sand) were exists. For each of texture classes the values were given based on the observed literature.

V. Distance from lineament

Lineaments affect surface material structures and have a significant influence on topography permeability and thus slope stability. The proximity of a slope to these features influences its stability, increasing the susceptibility of landslides occurrence (Samanta, 2016). Lineament data were extracted from landsat8 OLI/TIR image of 2019 by using Geomatica 2018 software. The lineament factor was characterized as proximity analysis by the use of Euclidian distance tool and distance to lineament factor was reclassified into five ranges (0-200m, 200-400m, 400-600m, 600-800m and >800m) and each class was ranked according to their importance for landslide susceptibility evaluation in GIS environment.

VI. Distance from drainage

The proximity of the slope to the drainage course is an important factor that dictates the slope evolution of the area. Rivers with a number of drainage networks have a high probability of landslide occurrence as they saturate the underwater section of the slope forming material (Akgun and Turk, 2011). Drainage data was derived from ASTER DEM using hydrology in ArcGIS spatial analysis. Distance to drainage factor of the study area was classified into five ranges with an interval of 150m distance as (0-150m, 150-300m, 300-450m, 450-600m and >600m). Also, the new values were assigned for each class of distance.

VII. Distance from road

Road-cuts are usually sites of anthropologically induced instability. A given road segment may act as a barrier, a net source, a net sink or a corridor for water flow, and depending on its location in the mountains, it usually serves as a source of landslides(Ayalew and Yamagishi, 2004). The road proximity layer was divided into five categories (0-25m, 25-50m, 50-75m, 75-100m and >100) in ArcGIS 10.3 using standard classification scheme known as manual method

VIII. Rainfall

The high annual rainfall and the concentration of the rain in one rainy season causes saturation of the soil, and positive pore pressure in the soil during the rainy season which can then serve as a catalyst in causing a landslide (Broothaerts *et al.,* 2012). The annual rainfall data with its spatial location were obtained from National Metrological Agency (NMA 2008_2018). The rainfall data of (Bedele, Arjo, Agaro, Yayu, Genet and Atnago) station were interpolated by using IDW in ArcGIS geostatistical analysis. The general assumption of the IDW method of interpolation is that the value of an unknown point is the weighted average of known values within the neighborhood. The main advantages of IDW are that it is instinctive and efficient (Azpurua and dos Ramos, 2010). The Rainfall factor of the study was clipped from the six rain gauge stations interpolated by using extract by mask tool in ArcGIS. As result, the study area gains the highest amount of rainfall from Bedele station. Finally, rainfall factor of the study area was classified into five ranges as (1821-1850mm, 1850-1880mm, 1880-1910mm, 1910-1940 and >1940).

3.3.3. Assigning Factor Weights

GIS-Based MCDA methods were applied to calculate weights for each criteria factor maps using TerrSet geospatial modeling and monitoring. In this study AHP method was applied for driving factor weights as a percentage of influence for landslide hazard zonation and prepare matrix table. The weights developed to each factor are given based on the analytical hierarchy process proposed by (Saaty, 1980) by means of providing a series of pair-wise comparisons of the relative importance of factors. It was performed based on expert judgment and review of the literatures. Once the weight has been derived the next is calculating the consistency ratio to measure how the judgment is rational or not. If CR > 0.1 our judgment is not accepted and if it is less than 0.1 it is accepted. The consistency ratio was calculated using the formula below.

$CR=CI/RI$ *………………………………………………………………………Equation 5*

Where, CR- consistency ratio, CI- consistency index and

RI is random consistency index and to calculate CI

CI= (µmax-1)/n-1……………………………………………………………………………Equation 6

Where **µmax** is the principal Eigen vector and **n** is the number of factor considered.

Table 5: Weight of each landslide conditioning factors by AHP model; Source: (Chen *et al.*, 2016).

Criteria	1	2	3	4	5	6	7	8	9	Weights (Wi)
Slope degree(°)	1	7	5	9	3	2	5	6	3	0.279
Slope aspect	1/7	1	1/3	3	1/4	1/6	1/3	1/2	1/5	0.038
Plan curvature	1/5	3	1	4	1/3	1/5	1/2	1/2	¼	0.057
Altitude (m)	1/9	1/3	1/4	1	1/5	1/7	1/3	1/2	1/6	0.027
Distance from lineament (m)	1/3	4	3	5	1	1/2	2	3	½	0.118
Lithology	1/2	6	5	7	2	1	3	4	2	0.200
Distance from drainage (m)	1/5	3	2	3	1/2	1/3	1	1/2	1/2	0.071
LULC	1/6	2	2	2	1/3	1/4	2	1	1/3	0.061
Precipitation (mm/yr.)	1/3	5	4	6	2	1/2	2	3	1	0.149
Consistency ratio: 0.049										

The larger the weight means the more influencing factor. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination in ArcGIS environment.

3.3.4. Weighted Linear Combination

The distinguishing feature of GIS is its capacity for integration and spatial analysis of multisource datasets. So, among MCDA procedures WLC is flexible, easy to use and frequently for factors aggregation (Malczewski, 2006). This study was used MCDA method to combine all the factor maps to be considered for LHZ by using weighted Linear Combination techniques by the formula.

$\boldsymbol{LSI = \sum_j n = Wjwij}$ ………………………………………………………….*Equation 7*

Where, Wj: weight value of parameter j; Wij: weight value of class i in parameter j and n: number of parameters.

3.3.5. Validation of landslide hazard zonation map

The landslide susceptibility analysis result is verified using known landslide locations (Woldearegay, 2005). Landslide inventory map is essential and key starting point for studying the relationship among landslide and conditioning factors (Raghuvanshi *et al.*., 2015). Field observations for the validation of final result were carried out by collecting inventory data using handheld GPS. As a result, 29 points of existing landslide were recorded. These were used for validation of standardized landslide hazard prone areas. Verification of the result was performed by comparing known landslide location data (the landslide inventory) with the landslide susceptibility map.

Accordingly, the inventory data was overlaid with LSM and it was used as landslide susceptibility validation. The general workflow of the study is shown as Figure6 bellow.

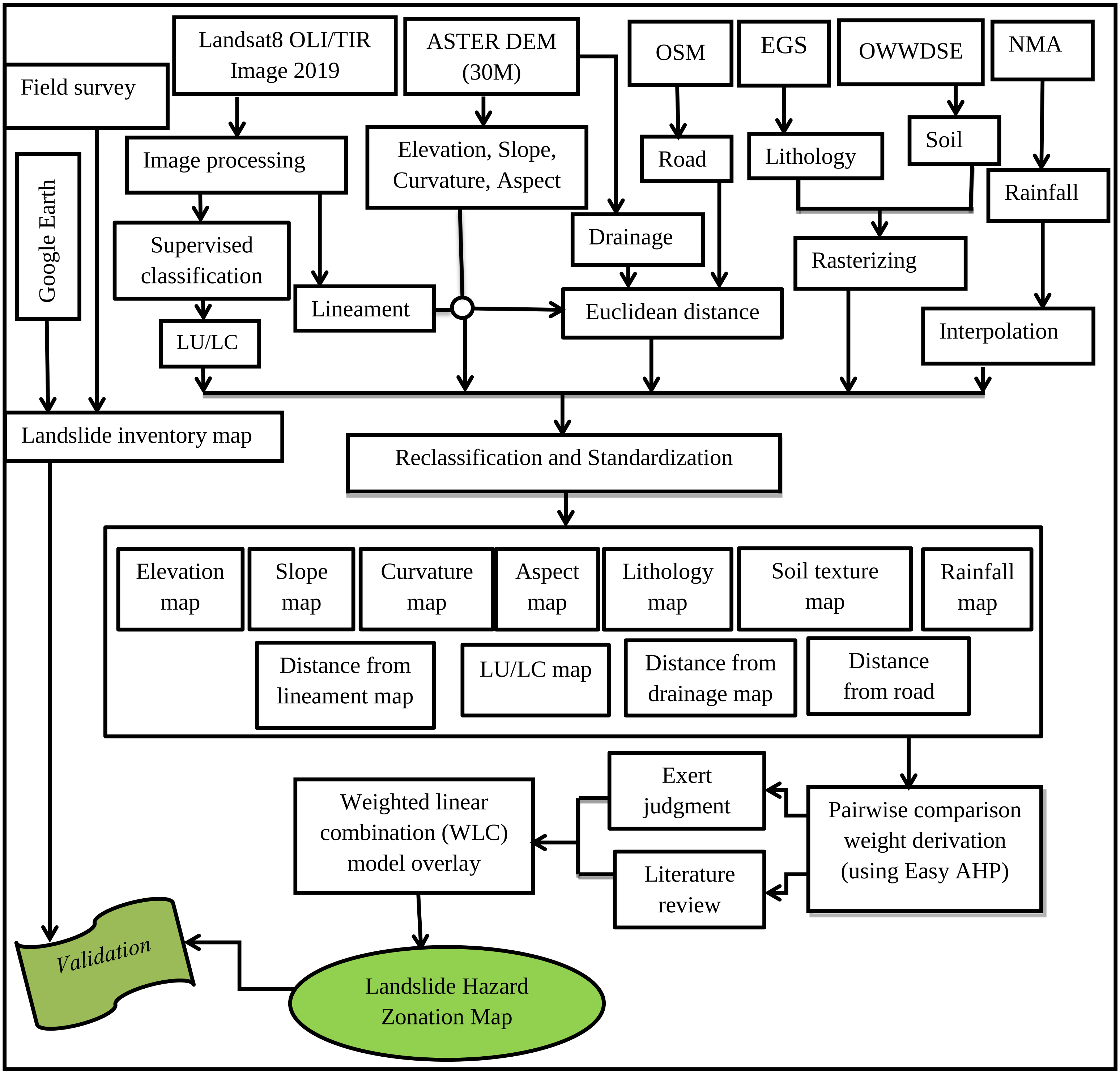

Figure 6: Methodological follow diagram of the study

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Landslide Inventory Map

Findings from ground truth of 29 landslide inventory points collected, most landslides were occurred around western part and some of them are in eastern and southeastern parts of the study area. From the total inventory points, fifteen (15) landslides were falls under slope those exceeds 30^0 with cultivated land near to the stream. Further some of landslides were occurred in the slope ranges of $12\text{-}30^0$ with in irregular topographic setup. This result is in agreement with (Dai *et al.*, 2001; Lee, 2005; Woldearegay, 2005; Yalcin, 2007; Long et al., 2011) that slope gradient is very regularly used in landslide susceptibility since land sliding is directly related to the slope angle. The inventory map is also used an input map for verification of the susceptibility of landslide hazard zonation for the study area (Figure 7).

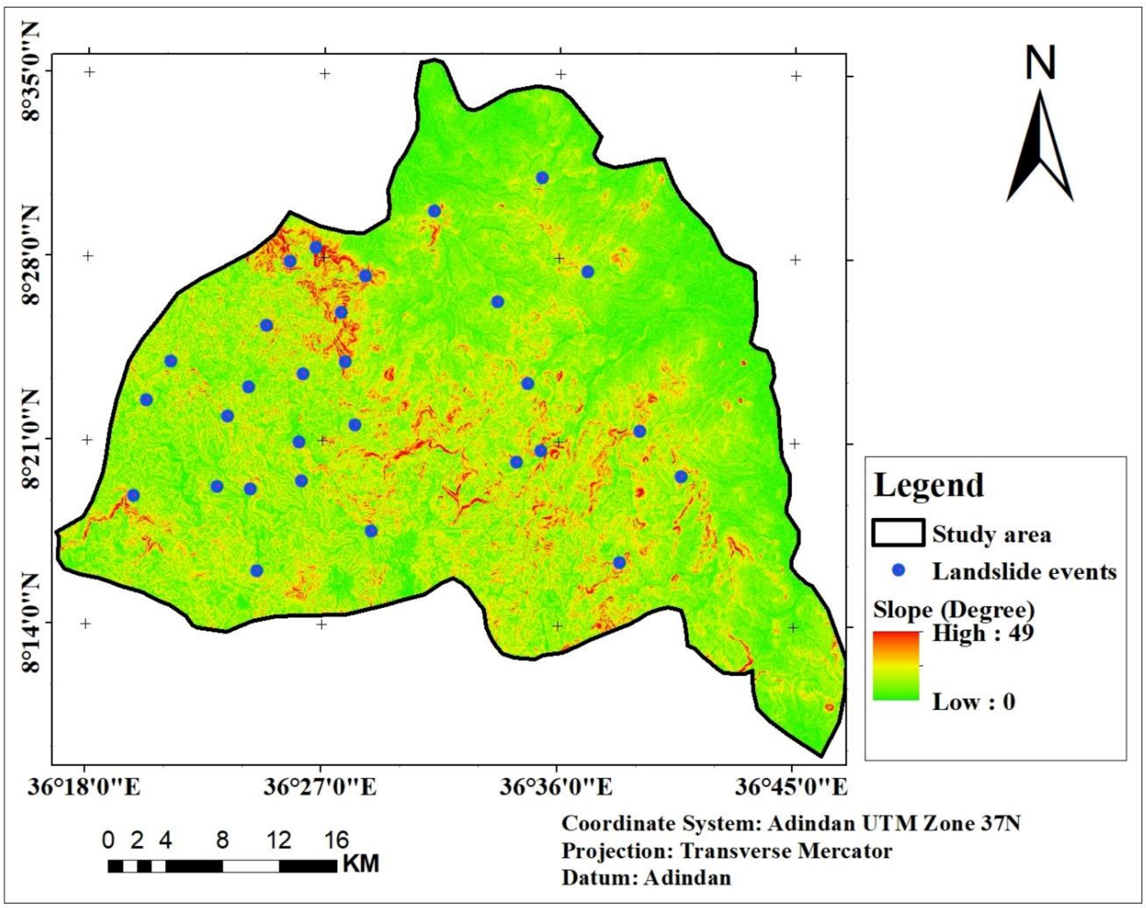

Figure 7: Landslide Inventory map of the study area

4.2. Landslide Hazard Triggering Factors

4.2.1. Elevation `

Elevation of the study area was classified into five classes with respective of area coverage (Table 6). Of the total landslide inventory points, five (5) of them were grouped under an elevation range of 1288-1696. The value assigned for this elevation range was 1 with corresponding to very low susceptibility level. This range covers about an area of 661.4 Km^2 of the study area. Therefore, since few points recorded in this large area most portion of the study area is not susceptible for landslide. Additionally, from 29 landslide inventory points, 8 landslides were occurred in elevation ranges of 1696-1821m which cover 6.9% of the total area. For this elevation range, five values were assigned which in turn the susceptibility of this area is categorized as very high. This implies that landslide was frequently occurred in this ranges. However, its area coverage is lower with compered to very low susceptibility area. Accordingly, elevation range of 1821–1954m, 1954–2126m and 2126–2481m of the study area determine magnitude and extend of landslide of the region. This is in line with some studies that elevation ranges in 1696-1954m are high susceptible to landslide whereas elevation less than 1696 and greater than 1954 are less susceptible to landslide (Hamza and Raghuvanshi, 2017; Chimidi *et al.,* 2017). Landslide density decreases both upward and downward from the elevation range (Ayalew and Yamagishi, 2005). As shown in Figure 8, Northwest and central portion of the study area are high susceptible to landslide whereas, the northern and eastern areas are less prone to landslide hazard. For instance; (Raghuvanshi *et al*., 2015; Ahmed, 2009) shows that elevation is considered to be an important triggering factor which may possibly affect the slope material by weathering process.

Table 6: Elevation class and area coverage

S/No	Ranges(m)	Value	Landslide occurred	Susceptibility	Area (km^2)	Area (%)
1	1288-1696	1	5	Very low	661.4	45.2
2	1696-1821	5	8	Very high	100.9	6.9
3	1821-1954	4	7	High	231.2	15.8
4	1954-2126	3	7	Moderate	253.2	17.3
5	2126-2481	2	2	Low	217.3	14.8
Total			**29**		**1464.0**	**100.0**

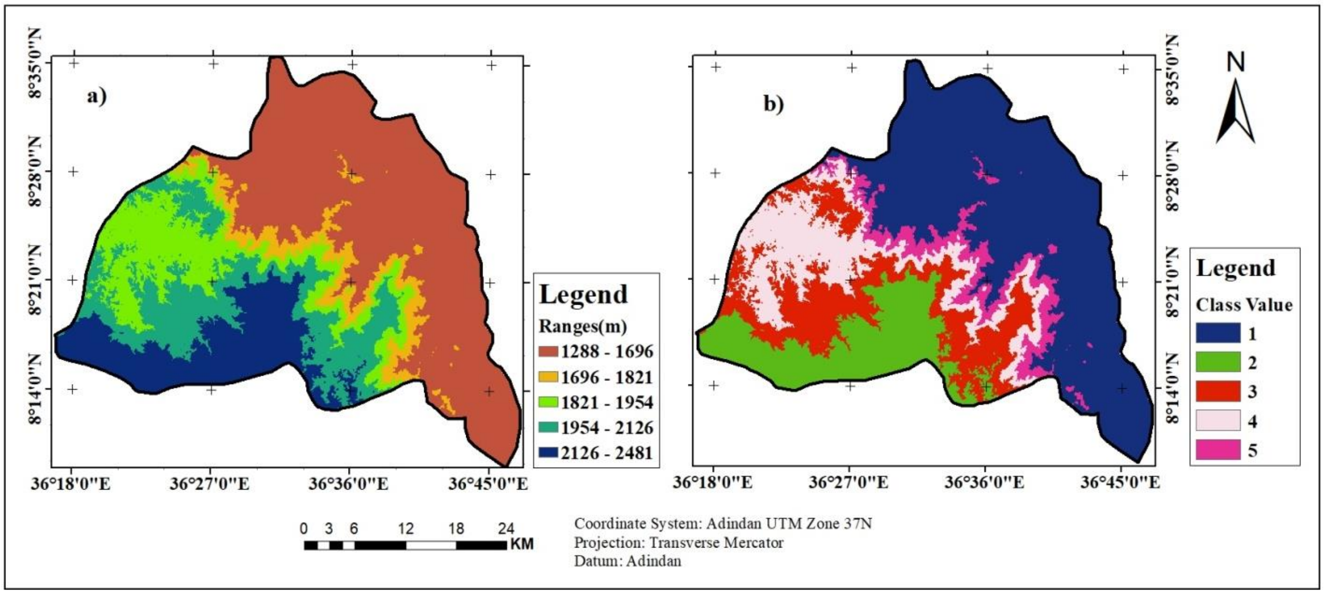

Figure 8: a) Elevation map and b) Elevation susceptibility map

4.2.2. Slope

For this study, the slope factor was divided in to five categories (Table 7) and the values were assigned for each class. As well, the area coverage of the slope classes was calculated. Regarding to landslide occurrences, from the total landslide inventory recorded, about thirteen (13) landslides have occurred in the slope greater than 30^0 which covers 23.9% of the total area. For these slope classes the values were assigned as 4 and 5 respectively based on the observed literature reviews. This shows that the slope ranges in these slope classes have high probability of landslide susceptibility. Accordingly, from the total landslide inventory, two (2) landslides were occurred in slope less than 5^0 that was assigned with lowest susceptibility level as one (1) value. Moreover, 5 and 9 landslides were observed in the slope ranges of $5\text{-}12^0$ and $12\text{-}30^0$ and their values were assigned as 2 and 3 respectively.

The result shows that the highest landslide susceptible level was clearly identified in the slope ranges of $>30^0$ and lowest landslides susceptibility were observed in the slope ranges of $0\text{-}12^0$ with related to their area coverage. In most studies of landslides, the slope steepness is taken into account as the major causative factor of the landslide (Teferi, 2005; Asmelash and Barbieri, 2012). If the slope is steeper it is more susceptible to instability as compared to gentle slope (Ayele, 2014). Gentle slopes are expected to have a low frequency of landslides because they possess lower shear stresses associated with low gradients (Ahmed, 2009; Raghuvanshi *et al.*, 2015). Erden and Karaman, (2012) suggested that this parameter has been considered as one of the most important factors in landslide susceptibility assessment. Even today it is the important factor when landslide hazard analysis is considered. The spatial distribution of slope susceptibility map is shown in (Figure9).

Table 7: Slope class and area coverage

S/No	Range(degree)	Value	Landslide occurred	Susceptibility	Area (km^2)	Area (%)
1	0-5	1	2	Very low	5.3	0.4
2	5-12	2	5	Low	392.3	26.8
3	12-30	3	9	Moderate	717.2	49.0
4	30-45	4	8	High	339.2	23.2
5	>45	5	5	Very high	10.0	0.7
Total			**29**		**1464.0**	**100.0**

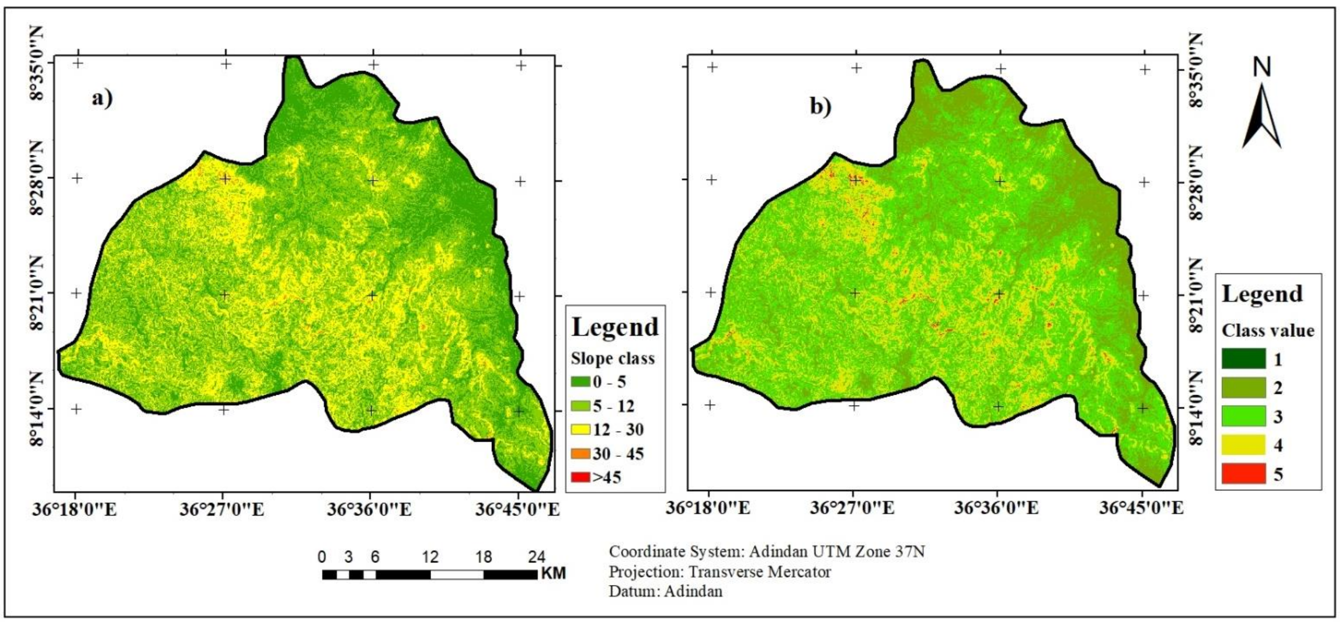

Figure 9: a) Slope map and b) Slope susceptibility map

4.2.3. Aspect

The aspect factor of the study area was classified into five classes as flat, north-northeast, east-southeast, south-southwest and west-northwest (Figure10 and Table8). From the total landslide occurrence 17 landslides were observed within slope inclined towards west-northwest and south-southwest. This implies that in this aspect class the magnitude of landslide susceptibility higher than the other. Accordingly, the slopes inclined towards west-northwest and south-southwest which covers about 40.4% of the study area was assigned with high value as 5 and 4 respectively (Table8).

Moreover, aspect classes of flat, north-northeast and east-southeast were assigned as less susceptible to landslide which covers 7.2%, 30.9% and 21.5% and assigned as 1, 2, and 3 respectively. This result is in agreement with study conducted by (Chimidi *et al.,* 2017). They reported that slopes oriented towards southwest, west and northwest showed high probability for landslide occurrence. It also justify that aspect of a slope can influence landslide initiation, because it affects moisture retention and vegetation cover, and in turn soil strength and susceptibility to landslides which is in line with (Kumar *et al.,* 2015).

Table 8: Aspect class and area coverage

S/No	Aspect(degree)	Value	Landslide occurred	Susceptibility	Area(km^2)	Area (%)
1	Flat	1	1	Very low	106.0	7.2
2	N-NE	2	5	Low	451.9	30.9
3	E-SE	3	6	Moderate	315.0	21.5
4	S-SW	4	10	High	302.5	20.7
5	W-NW	5	7	Very high	288.7	19.7
Total			**29**		**1464.0**	**100**

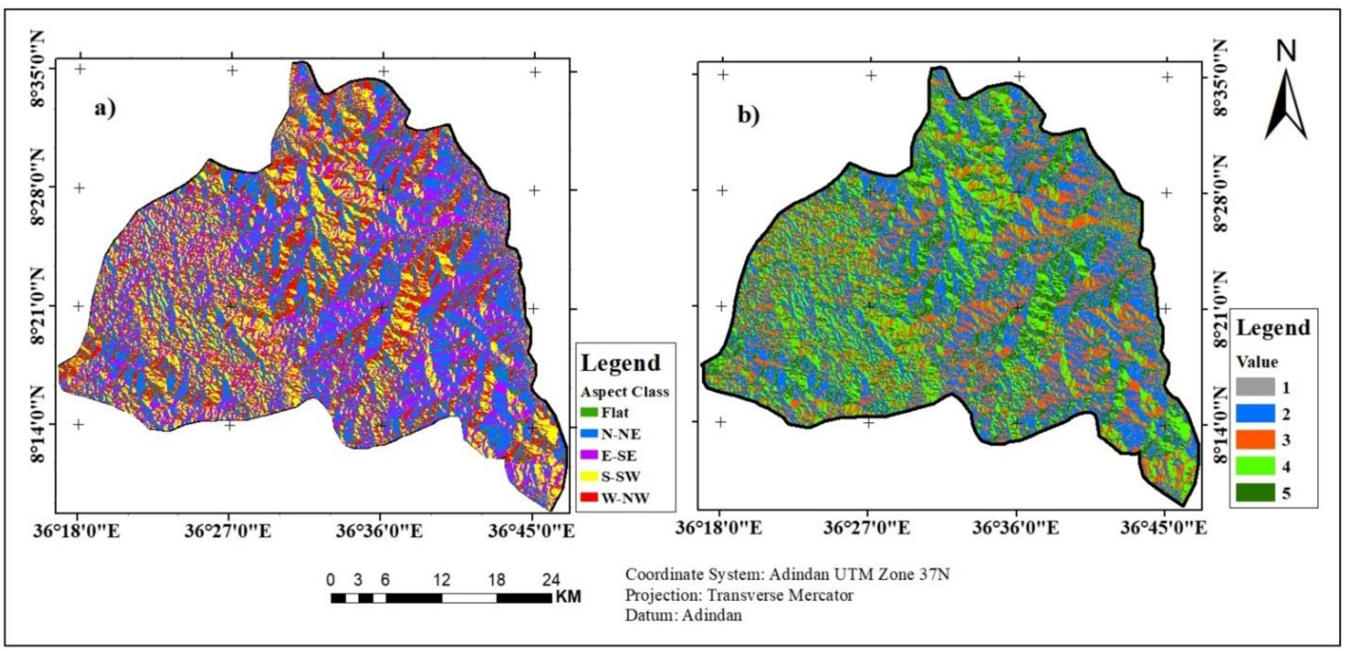

Figure 10: a) Aspect map and b) Aspect susceptibility map

4.2.4. Curvature

The curvature factor of the study area was classified into three ranges of classes as Concave (0 to -7.9), Flat (0) and Convex (6.7 to 0) and the values were assigned based on the rate of each class on landslide hazard zonation. Among the total area flat is the most dominated and which covers about 58.3% while, 20.9% and 20.8% of the total study area were covered by concave and convex respectively (Table9). With related to landslide occurrence 10 landslide was occurred within concave slope, which is 34.5% of landslide occurrence in 20.9% of the total study area. Moreover, 8 landslides were falls in curvature classes of convex. Similarly 11 landslides were observed within flat (0) area. As a result, concave and convex aspect classes are more influencing landslide occurrence with compared to their area coverage. Accordingly, the maximum values were assigned for the curvature classes within negative and positive. These curvature classes are groundwater accumulation areas and percolated into the soil mass. Further, flat area was assigned with lowest susceptibility of landslide. This result is in agreement with (Girma, 2015; Chen *et al.*, 2016; Ayele, 2019). That the chances of landslide activity increase with an increasing negative and positive values of curvature. According to the topographic type, the value is higher in the hilly and mountainous areas and low in flat areas (Lee and Min, 2002). The spatial distribution of curvature susceptibility is shown in (Figure11).

Table 9: Curvature class and area coverage

S/No	Curvature	Value	Landslide occurred	Susceptibility	Area(km^2)	Area (%)
1	Flat	2	11	Low	854.2	58.3
2	Convex	4	8	High	304.5	20.8
3	Concave	5	10	Very High	305.3	20.9
Total			**29**		**1464.0**	**100.0**

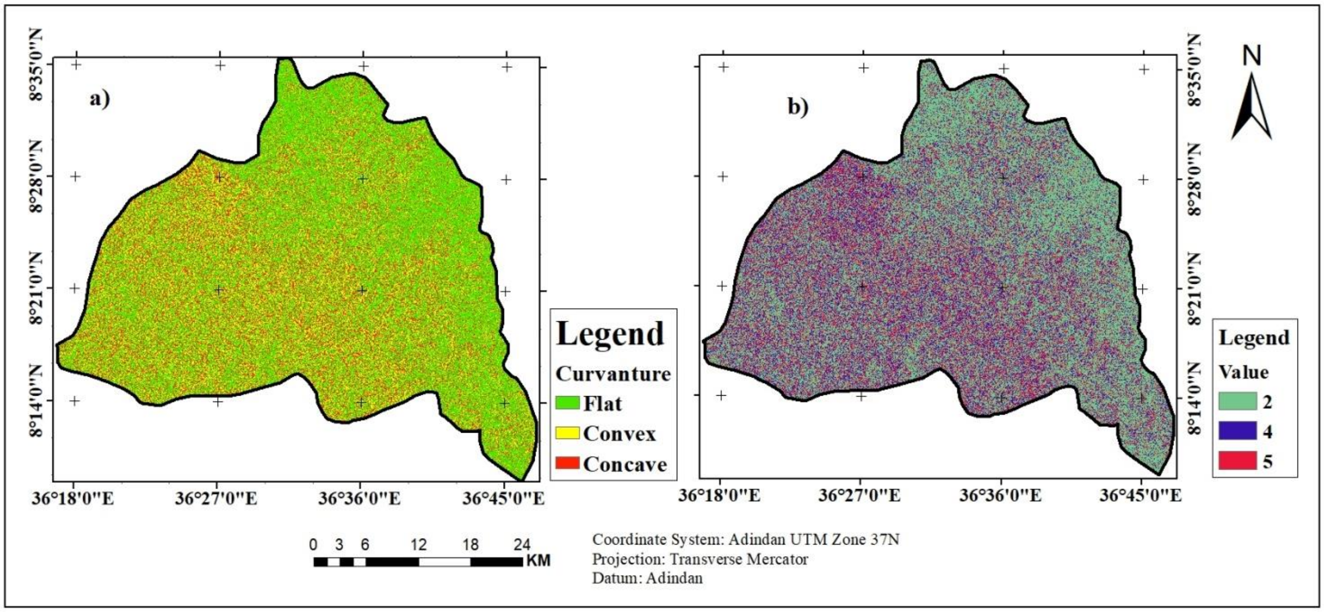

Figure 11: a) Curvature map and b) Curvature susceptibility map

4.2.5. Lithology

In the present study area seven lithological units was identified. These lithological units are pyroclastic deposit, Eluvium deposit, Alluvium deposit, (upper, medium and lower) basalt and granite (Figure12). As Table 10 shows basalt is the most dominant which covers about 1133.8Km2 (77.4%) of the total study area. The second dominant is pyroclastic deposit and its area coverage is 185.7Km^2 (12.7%); while, 6%, 3% and 0.9% of the total area were covered with alluvium, eluvium and granite respectively. Regarding to landslide occurrence, from the total inventory points 72.4% of landslides were revealed within basalt which was assigned with 2 values. Accordingly, from the total landslide incidents, 17.2% was observed within pyroclastic deposit. This implies that, by comparing with its area coverage pyroclastic is the most susceptible to landslide than the other lithological units. The maximum value (5) was assigned for pyroclastic deposit while, the lowest value (1) was assigned to granite. This is in agreement with (Shiferaw, 2014; Ayele, 2019) that pyroclastic are less resistance lithology because of they are weathered easily and susceptible to landslide. The study justify that lithology can significantly influences the occurrence of landslides, because lithological variations often lead to a difference in the strength and permeability of rocks and soils which is in line with (Abay *et al.*, 2019).

Table 10: Lithology unit and area coverage

S/No	Lithological Unit	Value	Landslide occurred	Susceptibility	Area(Km^2)	Area (%)
1	Granite	1	0	Very Low	12.5	0.9
2	Lower basalt/ middle basalt/ upper basalt	2	21	Low	1133.8	77.4
3	Eluvium deposit	3	1	Moderate	43.7	3.0
4	Alluvium deposit	4	2	High	88.3	6.0
5	Pyroclastic deposit	5	5	Very High	185.7	12.7
Total			**29**		**1464.0**	**100.0**

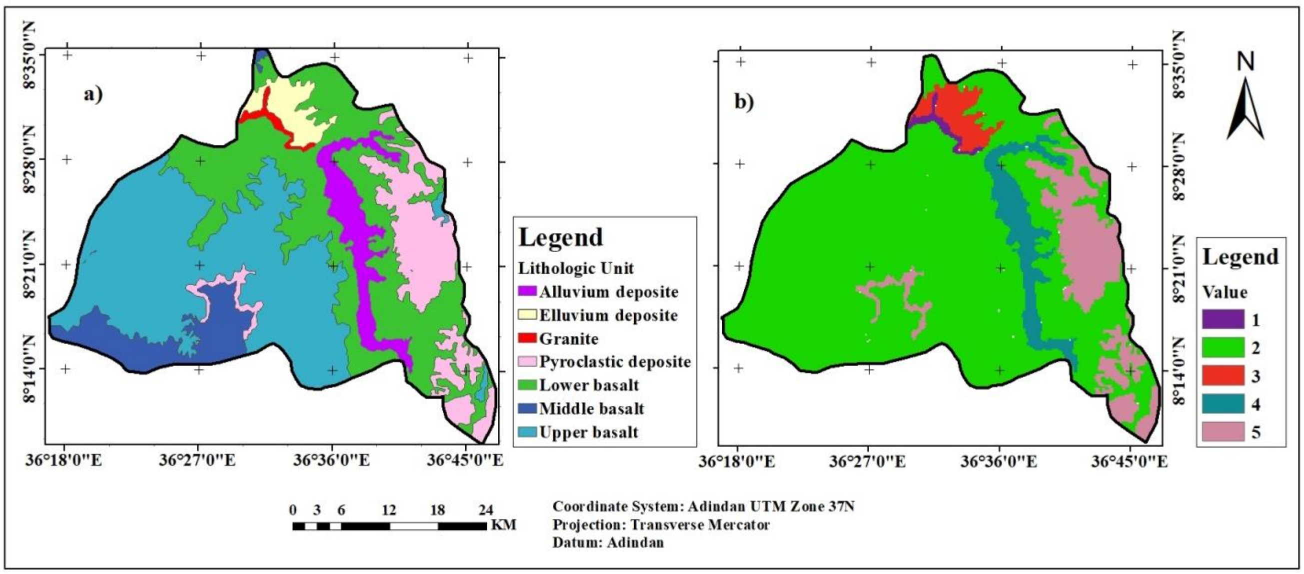

Figure 12: a) Lithology map and b) Lithology susceptibility map

4.2.6. Soil Texture

In this study, five soil texture types namely clay loam, sandy clay loam, sandy loam, loam and loamy sand were identified (Figure13). As (Table11) shows sandy loam is the most dominant in the study area which covers about 931.7Km^2 (63.6%) of the total area was assigned as five (5) value. Whereas, 0.2% of the total area was covered with both loam and clay loam. The lowest value was assigned for clay loam soil texture which means very low susceptible. Furthermore, from the total area 24.1% and 12.1% were covered with sandy clay loam and loamy sand was assigned with 4 and 3 values respectively. From the total landslide inventory points, about 76% of the total landslides were falls in sandy loam soil characters. This means it is the highest priorities on the occurrence of landslide and the next influencing is sandy clay loam which 17% of landslide events were observed. This result is in agreement with (Melkamu, 2019) which suggests that sandy loam has maximum value in terms of friction and porosity with relation of slope instability. Other studies also show that soil texture is an important factor for landslide because the size of soil particles determines the tendency of soil particles to resist sliding across each other (Musinguzi et al., 2014).

Table 11: Soil texture types and area coverage

S/No	Texture	Value	Landslide occurred	Susceptibility	Area(Km^2)	Area (%)
1	Clay Loam	1	0	Very Low	0.8	0.1
2	Sandy Clay Loam	4	5	High	352.8	24.1
3	Loam	2	0	Low	1.0	0.1
4	Sandy Loam	5	22	Very High	931.7	63.6
5	Loamy Sand	3	2	Moderate	177.8	12.1
Total			**29**		**1464.0**	**100.0**

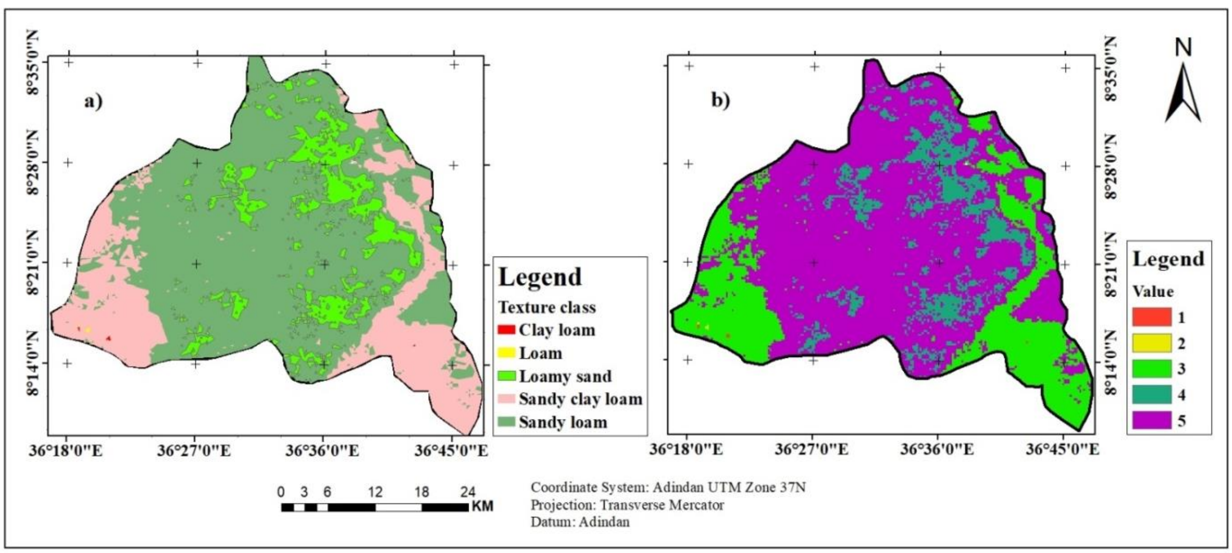

Figure 13: a) Soil texture map and b) Soil texture susceptibility map

4.2.7. Land use/land cover

LU/LC types of the study area were classified in to seven classes namely agricultural land, settlement, bare land, shrub land, grassland, forest land and water body. From the result both agricultural land and water body covers about 41.9% of the total study area. The value given for these land use land cover class was 5 while, forest area covers about 15.5% which is assigned with minimum value in influencing of landslide susceptibility map. Moreover, settlement/bare land, shrub land and grassland were covers 14%, 23.2% and 5.4% and assigned as 4, 3 and 2 respectively (Table12 and Figure14). From the total 29 landslide inventory points, 13 landslides were falls in cultivated land and water body. Cultivated land occupies the largest portion which is about 39% of the total study area. This made the area to be susceptible for landslide hazard because of unmanageable use of natural resources and expansion of farm lands to steep slope. As well, only 7% of the total inventory points were falls under forestland which covers 15.5% of the total area. This is clearly shows that cultivated land influences landslide which is in line with a number of studies like (Pradhan *et al.*, 2010; Broothaerts *et al.*, 2012; Mengistu *et al.*, 2019; Firomsa and Abay, 2019) that impacts of deforestation and improper cultivation practices on hill slopes increases landslide frequency. Also it satisfies that the land use pattern is often has a great influence in the landslide occurrences because they relate to the anthropogenic interference on hill slopes (Firomsa and Abay, 2019).

Table 12: Land use land cover class and their area coverage

S/No	LULC Class	Value	Landslide occurred	Susceptibility	Area(km^2)	Area (%)
1	Agriculture/water body	5	13	Very high	613	41.9
2	Settlement/Bare land	4	6	High	205.4	14
3	Shrub land	3	7	moderate	339.5	23.2
4	Grassland	2	1	Low	79.6	5.4
5	Forest	1	2	very low	226.5	15.5
Total			29		1464.0	100.0

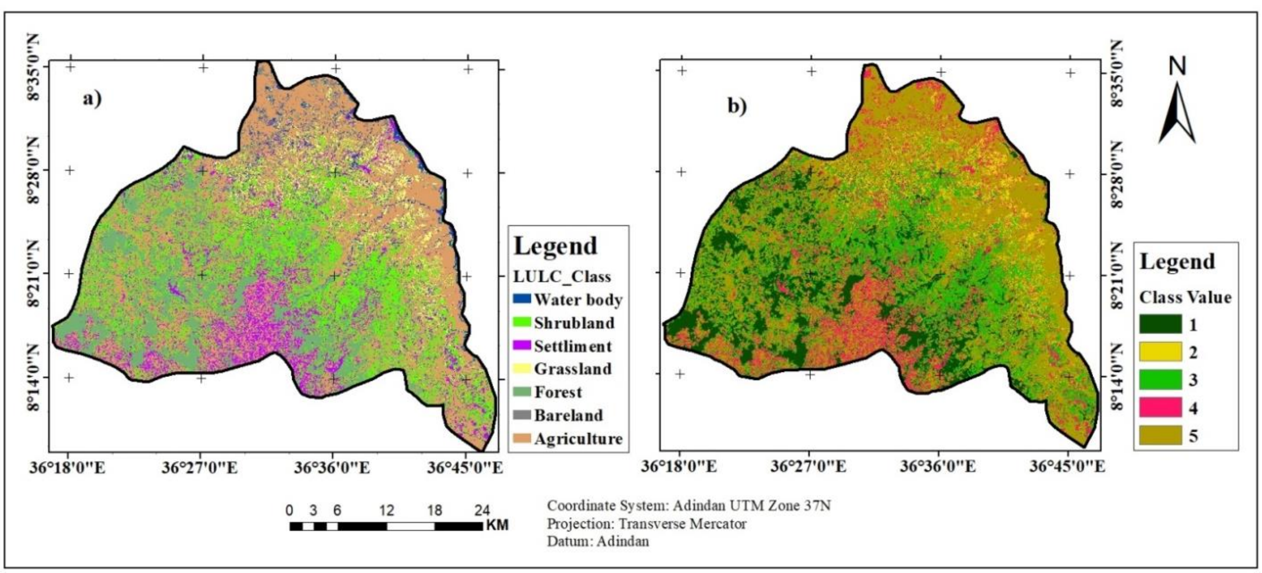

Figure 14: a) Land Use Land Cover map and b) land use land cover susceptibility map

LULC Classification Accuracy Assessment

In this study 140 total random points were used for land use/land cover accuracy assessment. It was also checked with reference data from Google Earth to assess the accuracy of the classification. From the result the study revealed that overall accuracy of 86.4% and a kappa statistics of 0.836 (Table13). The kappa coefficient implies that the classification process is avoiding 83.6% of the errors that a completely random classification produces.

Table 13 land use land cover accuracy assessment

CD	FL	AG	WB	BL	ShL	Smt	GL	RoT	RT	CLT	NC	PA	UA
FL	18	0	0	0	2	0	1	21	21	21	18	85.7%	85.7%
AG	0	23	1	2	0	0	1	27	27	27	23	85.2%	88.5%
WB	0	0	13	0	1	0	0	14	15	14	13	92.6%	86.7%
BL	1	0	0	22	0	1	0	24	25	24	22	91.7%	88%
ShL	2	1	1	0	17	0	1	22	21	22	17	77.3%	80.9%
Smt	0	0	0	1	1	11	0	13	12	13	11	84.6%	91.7%
GL	0	2	0	0	0	0	17	19	20	19	17	89.5%	85%
CT	**21**	**27**	**15**	**25**	**21**	**12**	**20**	**140**	**140**	**140**	**121**		

Overall Classification Accuracy= 86.4%,

Overall Kappa Statistics = 0.84

(Note; FL= Forest Land, AG= Agriculture, WB= Water Body, BL= Bare Land, ShL= Shrub Land, Smt= Settlement, GL= grassland, CT= Column Total, RoT= Row Total, RT= Reference Total, CLT= Classified Total, NC= Number Correct, PA= Producers Accuracy, UA= Users Accuracy).

4.2.8. Distance from drainage

Rivers with a number of drainage networks have a high probability of landslide occurrence as they eradicate the slope base and saturate the subsurface water section of the slope forming material (Akgun and Turk, 2011). In this study distance from drainage was classified into five different ranges at 150m of intervals (0 – 150, 150 – 300, 300 – 450, 450 – 600 and >600) (Table13). Distance from drainage in the ranges of 0–300m covers 30.5% of the total study area. Moreover, drainage distance in the ranges of 300-450, 450-600 and >600 were covers 12.7%, 7.8% and 49.1 of the total area respectively (Figure15). Accordingly, maximum value was assigned to an area within 150m from drainage in both side, which is five (5) and area out of 150m has assigned in a descending order up to one (1) which is a lowest value. Most of the recorded landslides have occurred close to drainages which is about 55.2% of the total landslides. As a result, in the study area distance from drainage ranges between 0-300m is the most susceptible to landslide whereas, distance from drainage >600m has the minimum contribution to slope failure in the study area. This result justifies that the relationship between landslide occurrence and the distance from the stream are inversely proportional (Ayele, 2019). Also, it approve that the closeness of the slope to drainage structures is an important factor in terms of slope stability. Streams may adversely affect stability by eroding the slopes or by saturating the lower part of material until resulting in water level increases (Dai *et al*., 2001; Yalcin, 2005).

Table 14: Distance from drainage and area coverage

S/No	Distance band (m)	Value	Landslide occurred	Susceptibility	Area(km^2)	Area (%)
1	0-150	5	7	Very high	155.9	10.7
2	150-300	4	9	High	290.0	19.8
3	300-450	3	4	Moderate	185.3	12.7
4	450-600	2	2	Low	113.6	7.8
5	>600	1	7	Very low	719.1	49.1
Total			**29**		**1464.0**	**100.0**

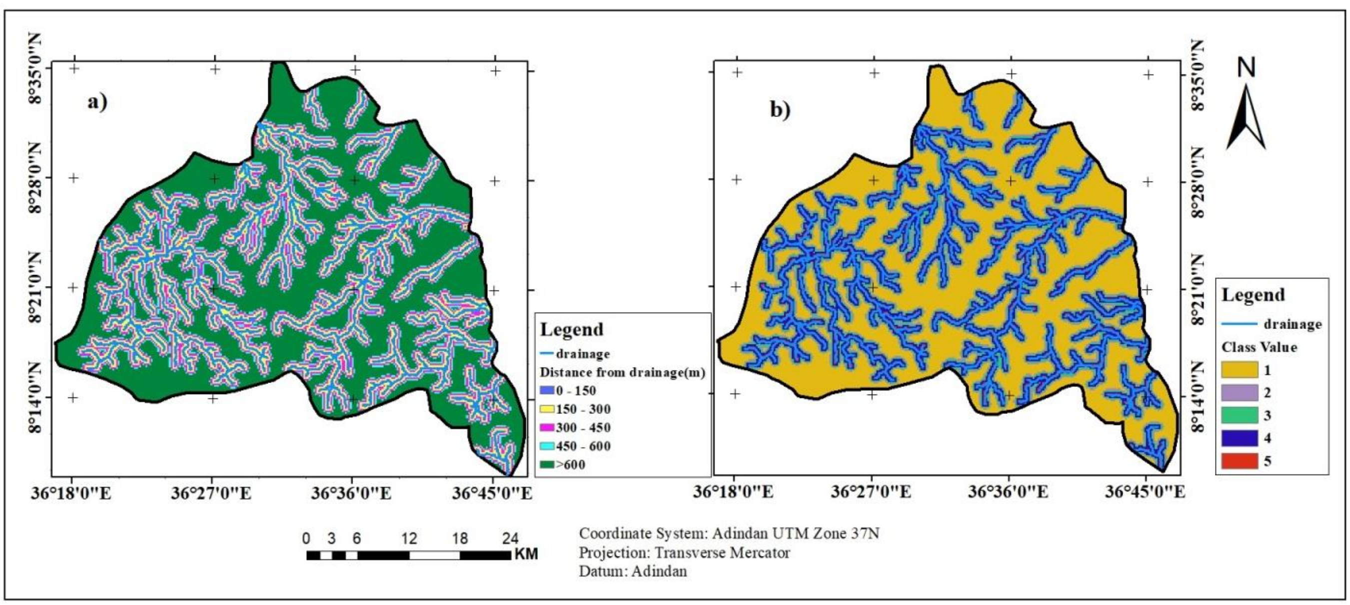

Figure 15: a) Distance from drainage networks and b) Susceptibility map based on distance from drainage networks

4.2.9. Distance from lineament

The lineament factor of the study area was classified into five class using 200m intervals. Accordingly, the distance from lineament ranges between 0-200m and 200-400m covers about 22.9% and 21.6% while, 400-600m, 600-800m and >800m covers 17.3%, 11.8% and 26.4% of the total area respectively (Table14). The maximum value was assigned to an area within 200m from lineament in both side, which is five (5) and the minimum value was assigned to an area greater than 800m from lineament which is one (1). From the total landslide recorded about 72.4% of landslide was occurred within an area close to lineament less than 400m. This shows that an area within the ranges of 0-400m lineament distance are the highest slope instability while, distance from lineament greater than 800m identifies that lowest landslide hazard occurrence. This indicates that the lineaments affect surface material structures and has a significant influence on topography permeability and slope stability. The proximity of a slope to these features influences its stability, increasing the susceptibility of landslides occurrence (Samanta, 2016).

Table 15: Distance from lineament and area coverage

S/No	Distance band (m)	Value	Landslide occurred	Susceptibility	Area (km^2)	Area (%)
1	0 – 200	5	11	Very high	335	22.9
2	200 – 400	4	10	High	316	21.6
3	400 – 600	3	5	Moderate	253	17.3
4	600 – 800	2	--	Low	173	11.8
5	>800	1	3	very low	387	26.4
Total			**29**		**1464**	**100.0**

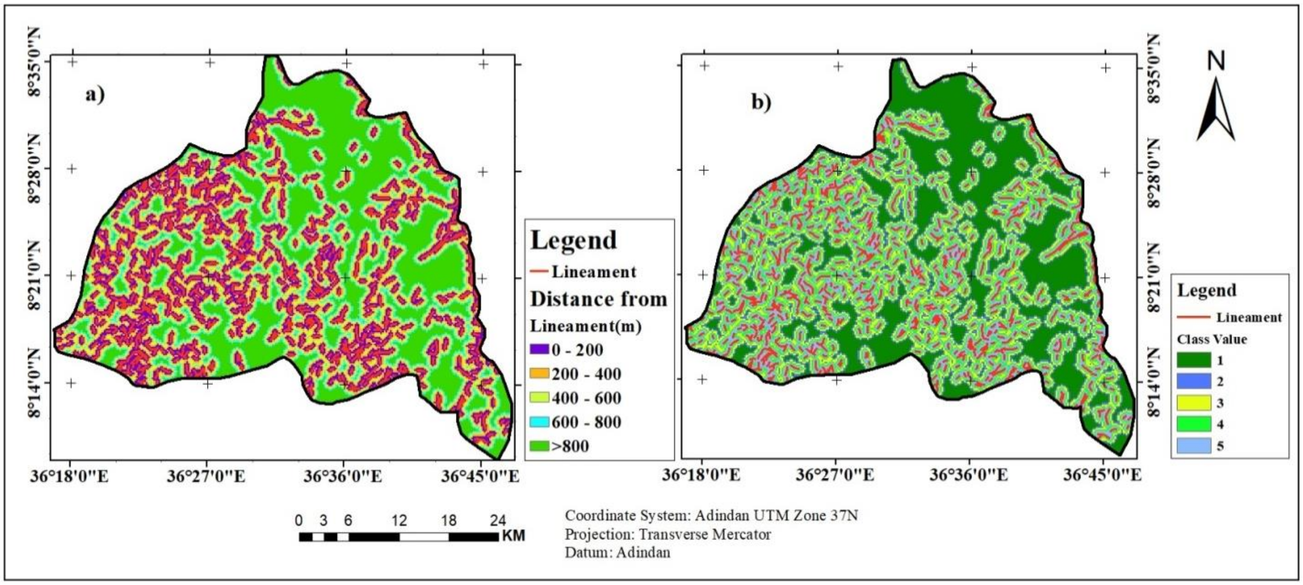

Figure 16: a) Distance from lineament map and b) Distance from lineament susceptibility map

4.2.10. Distance from road

Road-cuts are usually sites of anthropologically induced instability. A given road segment may act as a barrier, a net source, a net sink or a corridor for water flow, and depending on its location in the steep slope, it usually serves as a source of landslides (Ayalew and Yamagishi, 2004). Road proximity layer was divided into five categories with an interval of 25m (Figure17 and Table15) using standard classification scheme known as manual method. From these ranges about 98.7% of the study area was covers with in an area which is greater than 100m away from road. Thus, maximum value was assigned to an area within 25m from road in both side, which is (five) 5 and the minimum value was assigned for an area which is far from road >100m. Furthermore, an area ranges within 25-50m, 50-75m and 75- 100m were assigned as 4, 3 and 2 value respectively. From the total landslide recorded about 3.4% was occurred within the distances to road ranges of 0-25m while, the remains are manifested within an area away from road greater than 100m which is about 96.6% of the total landslides.

Table 16: Distance from road class and area coverage

S/No	Distance band (m)	Value	Landslide occurred	Magnitude of susceptibility	Area(km^2)	Area (%)
1	0-25	5	1	Very high	3.4	0.2
2	25-50	4	--	High	6.4	0.4
3	50-75	3	--	Moderate	4.5	0.3
4	75-100	2	--	Low	4.5	0.3
5	>100	1	28	Very low	1445.3	98.7
Total			**29**		**1464.0**	**100.0**

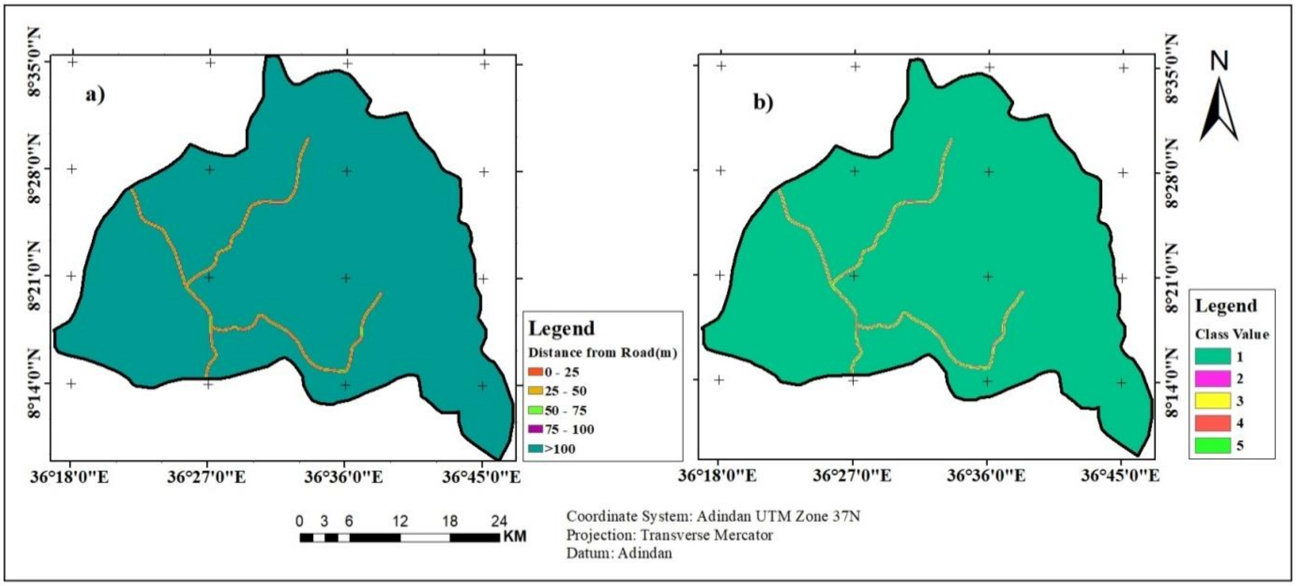

Figure 17: a) Distance from road map and b) Distance from road susceptibility map

4.2.11. Rainfall

The annual rainfall data with its spatial location were obtained from National Metrological Agency (NMA). The rainfall data of station (Bedele, Arjo, Agaro, Yayu, Atnago and Genet) was interpolated by using IDW. As a result, the study area gains the highest amount of rainfall from Bedele station. Finally, rainfall factor of the study area was classified into five ranges (Table16) and the priority values were given for each class based on the order of landslide susceptibility ratings (Figure18). Thus, the highest rainfall >1910mm/yr is the most dominant which covers 63.8% of the total area. The area that gains annual rainfall greater than 1940mm/yr was assigned with maximum value which is five (5). Accordingly, the remaining 1821-1850mm/yr, 1850-1880mm/yr and 1880-1910mm/yr those covers

6.1%, 8.4% and 21.6% of the total area were assigned as 1, 2 and 3 respectively. Regarding to landslide occurrence, about 19 landslide events means 65.5% of the total landslide was occurred in the area of annual rainfall >1940mm/yr. This result is in line with (Raghuvanshi *et al.*, 2014; Chen *et al.*, 2016) that the heavy rainfall is the main triggering mechanism for many landslide occurrences. Also, it confirms that the high annual rainfall and the concentration of the rain in one rainy season causes saturation of the soil, and positive pore pressure in the soil during the rainy season which can then serve as a catalyst to allow other causal factors to act more effectively in causing a landslide (Broothaerts *et al.*, 2012).

Table 17: Rainfall class and area coverage

S/No	Interval(mm/yr)	Value	Landslide occurred	Susceptibility	Area(km^2)	Area (%)
1	1821-1850	1	1	Very low	89.3	6.1
2	1850-1880	2	--	Low	123.4	8.4
3	1880-1910	3	4	Moderate	316.7	21.6
4	1910-1940	4	5	High	483.5	33.0
5	>1940	5	19	Very high	451.2	30.8
Total			**29**		**1464.0**	**100.0**

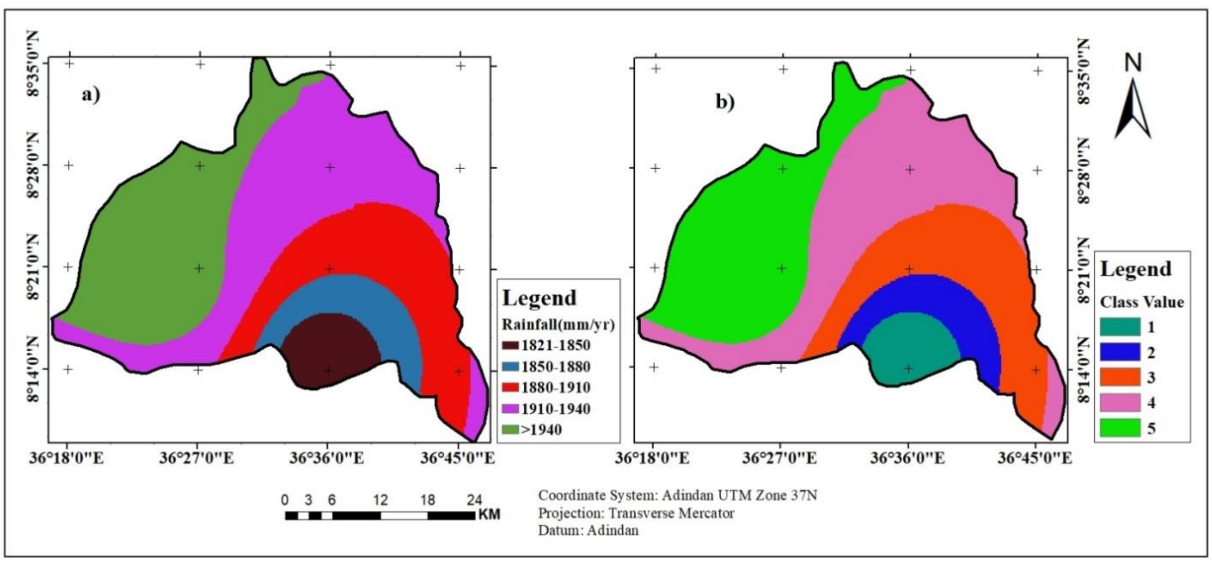

Figure 18: a) Rainfall map b) Rainfall susceptibility map

After all thematic data were classified in to different ranges and categories; resampling techniques were carried out to make them similar resolution and scale.

4.3. Assigning Factor Weights

After the classification and standardization of each triggering factor, weight was given for each layer based on pairwise comparison of two data layers at the same time, using pairwise comparison rating scale in TerrSet Geospatial monitoring and modeling software. Moreover, AHP weight derivation was, 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 landslide suitability which is proposed by Saaty (1980). As a result, the larger the weight means the more influencing factor. Although, the factors and the resulting weights of each factor was, used as input for weighted linear combination. Thus, all possible combinations of two factors were compared based on standard literatures to prepare a pair-wise comparison matrix from which the module calculates a set of weights and consistency ratio. Figure18 tells the AHP weight derivation interface to derive the weights, with its consistency ratio, for landslide hazard zonation is produced. Consistency ratio is very import to ensure the credibility of the relative influence during the pair-wise comparison process.

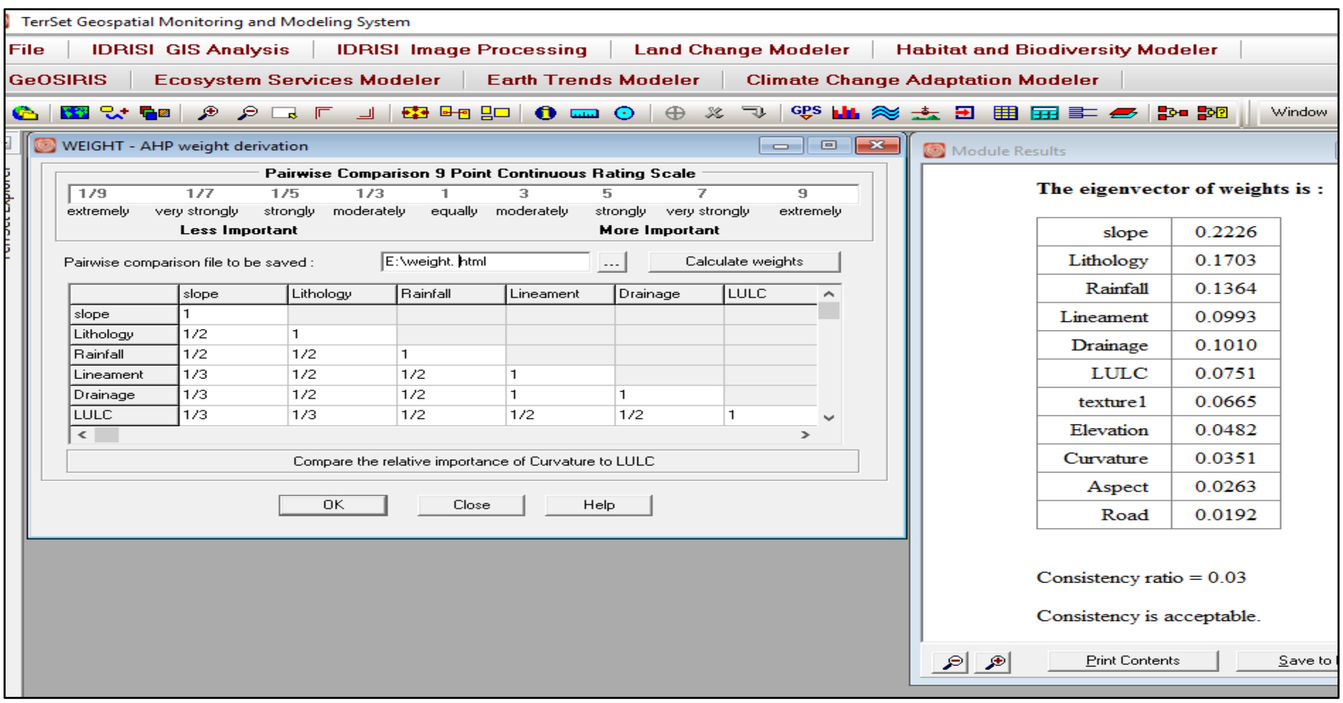

Figure 19: AHP weight derivation methods all causative factors for landslide hazard zonation.

Table 18: Analytical Hierarchy Process weight derivation modules

	S	L	RF	DL	DD	LUC	ST	E	C	A	DR	Weight	Weight (%)
S	1											0.223	22.3
L	1/2	1										0.170	17.0
RF	1/2	1/2	1									0.136	13.6
DL	1/3	1/2	½	1								0.099	9.9
DD	1/3	1/2	½	½	1							0.101	10.1
LUC	1/3	1/3	½	½	1/2	1						0.075	7.5
ST	1/4	1/3	1/3	½	1/2	1/2	1					0.067	6.7
E	1/4	1/4	1/3	1/3	1/3	1/2	1/2	1				0.048	4.8
C	1/5	1/4	¼	1/3	1/3	1/3	1/3	1/2	1			0.035	3.5
A	1/5	1/5	¼	¼	1/4	1/3	1/4	1/3	1/2	1		0.026	2.6
DR	1/7	1/6	1/5	¼	1/5	1/4	1/5	1/4	1/3	1/2	1	0.019	1.9
Total												1.000	100.0

Consistency ratio = 0.03 ⟹ Consistency is acceptable.

(Note: S= Slope, L= Lithology, RF= Rainfall, DL= Distance from Lineament, DD= Distance from Drainage, LUC= Land Use Land Cover, ST= soil texture, E= elevation, C= curvature, A= Aspect and DR= Distance from Road).

The weight calculated (Table 20) indicates the relative importance of the factors in contributing landslide susceptibility evaluated. From the result, the highest weights were given to slope, lithology and rainfall factor. But, distance from road, aspect and curvature were taken as the lowest influencing factors in this work. However, they play their own contribution on the formation of existing landslide in the study area.

4.4. Weighted Linear Combination Using Weighted Overlay

The final steps of this method are a combination of all the weighted layers into a single map, and the classification of the scores of this map into landslide susceptibility (Ayalew and Yamagishi, 2004). In this study, WLC method was used to combine all the factor maps considered for landslide susceptibility analysis. Through a weighted linear combination, the considered factors were combined by using Arc GIS weighted overlay analysis and the final landslide susceptibility map was prepared.

4.5. Landslide Hazard Zonation Map

The landslide hazard zonation map prepared for this study was classified into five classes and its area coverage was calculated. Accordingly, very high hazard 1.3% (18.4 km^2), high hazard 18.9% (276.4 km^2), moderately hazard 38.7% (567.2km^2), low hazard 20.7% (302.4km^2) and very low hazard zone covers 20.5% (299.6km^2) of the total study area respectively (Table18). Based on the result obtained, the final map was prepared (Figure20). The result of the study shows that the spatial distributions of landslide hazard are distributed throughout the study area. However, landslide susceptibility areas were mostly inhabited towards the northwest and western part of the study area. More than half of high and very high landslide susceptibility areas were found around this location. As a result, maximum landslide hazard was occupied in cultivated land with the slope exceeds 30^0 which is characterized with sandy loam soil texture. These highest susceptibility areas are also determined with distance from drainage less than 150m and high annual rainfall greater than 1910mm/yr. Very low hazard zone is found on very gentle slope which are far away from lineaments with granite and eluvium lithological units in the study area. This result is in agreement with (Teferi, 2005; Chen *et al.*, 2016; Ermias *et al.*, 2017; Mengistu *et al.*, 2019) that landslide hazard is a product of many factors particularly slope which has a great influence in the case of this study.

Table 19: Landslide hazard zonation and area coverage

S/No	Landslide Hazard Zonation	Area(km^2)	Area(ha)	Area (%)
1	Very high	18.4	1,838.3	1.3
2	High	276.4	27,644.5	18.9
3	Moderate	567.2	56,718.5	38.7
4	Low	302.4	30,243.3	20.7
5	Very low	299.6	29,955.5	20.5
	Total	**1,464.0**	**146,400**	**100.0**

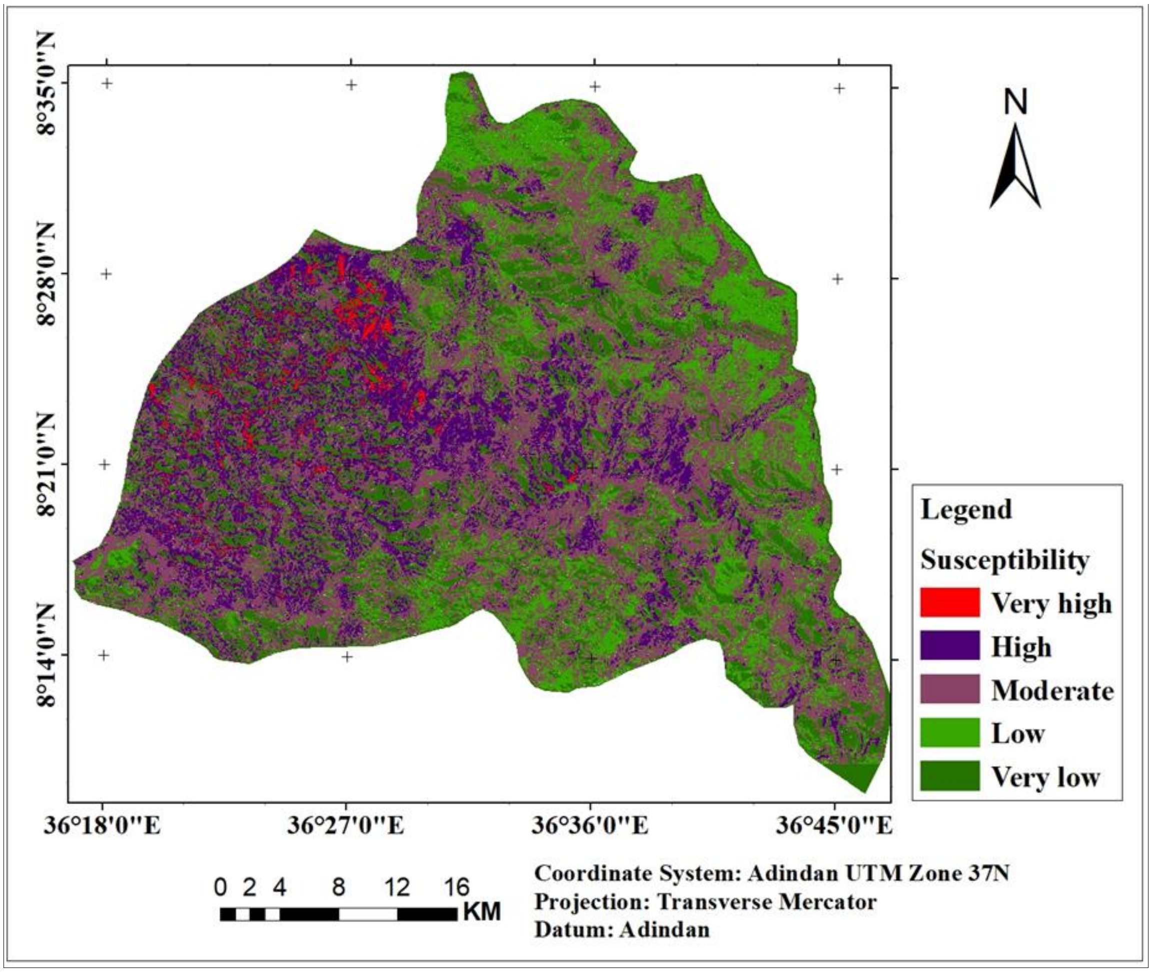

Figure 20: Landslide hazard zonation map of the study area

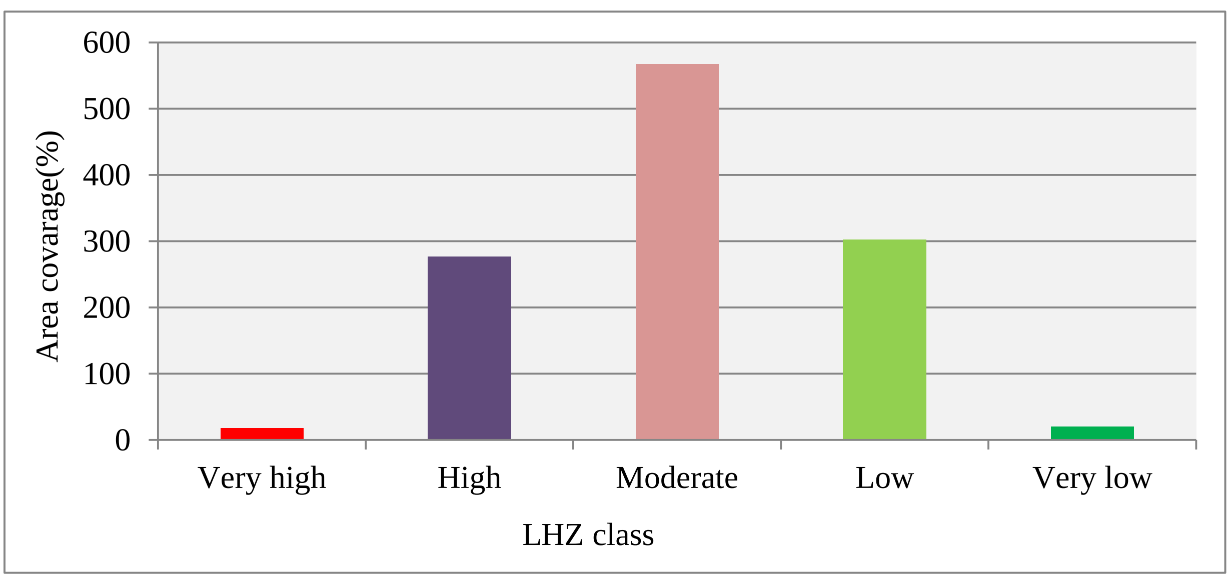

Figure 21: The magnitude of landslide hazard in the study area and their area coverage's

4.5.1. Validation of Landslide Hazard Map

The landslide susceptibility analysis result is verified using known landslide locations (Woldearegay, 2005). In this present study about 29 ground truth data showing the existing landslide were collected. Accordingly, the inventory data was overlaid with landslide hazard map and it was used as landslide susceptibility validation (Figure22). Thus, it was carried out by comparing existing landslide inventory data with the landslide hazard map. As a result, from the total number of landslide inventory data, seventeen (58.6%) landslide events fall in very high landslide hazard zone, seven (24.1%) landslide events falls in high hazard zone and only three (10.4%) landslide events were falls in moderate hazard zone while, in low and very low hazard zones two (6.9%) past landslides were observed. The comparison of the modeled landslide susceptibility map with the real landslide activity distribution map has shown 82.7 % of the landslides fall within the extreme hazard zone, and the remaining with the moderate, low and very low hazard zones. Thus, 82.7% of existing landslide shows satisfactory agreement with the prepared landslide hazard zonation map (Figure20).

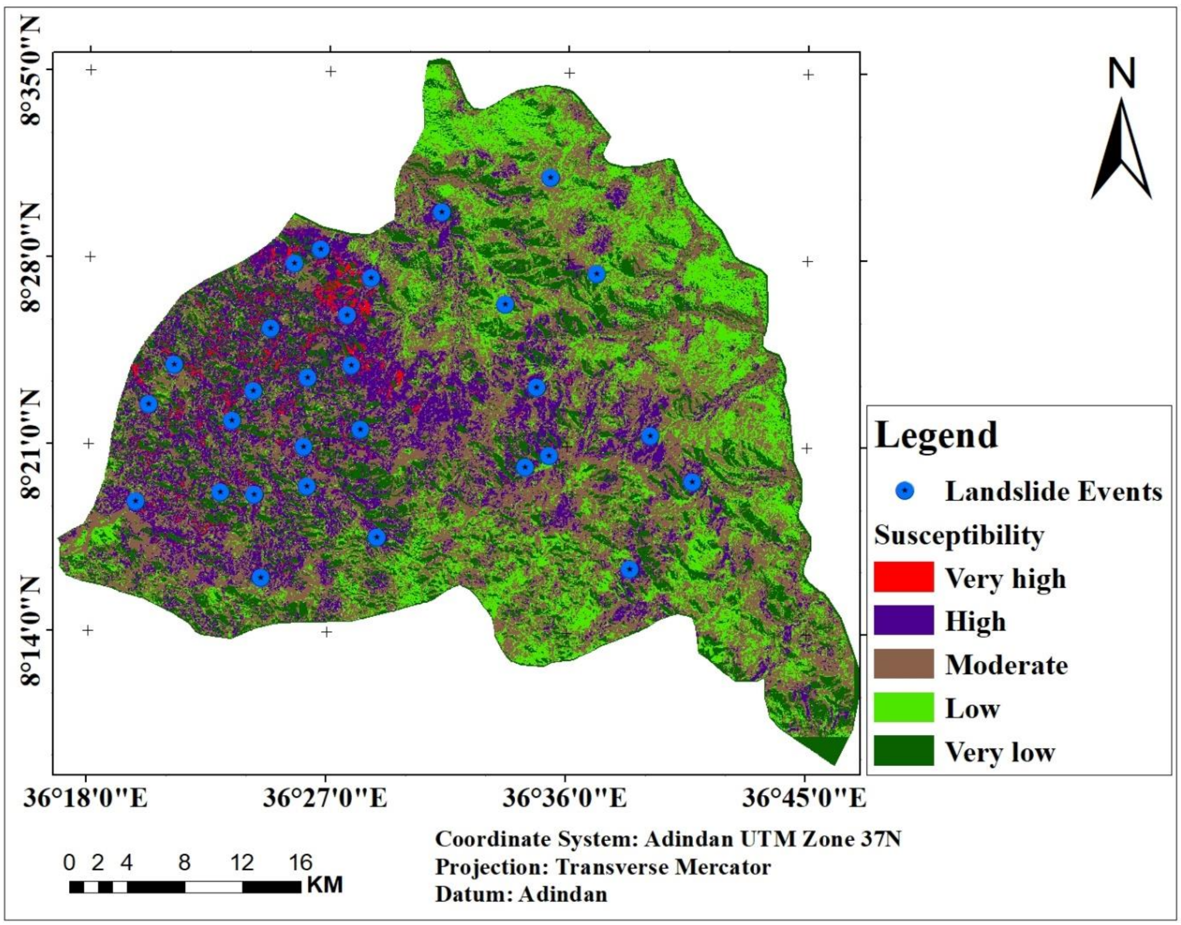

Figure 22: landslide inventory overlaid with landslide hazard map for validation

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The Multicriteria decision analysis method and the available spatial datasets were, used to prepare a landslide hazard zonation map in the Gechi district of the Oromia regional state of western Ethiopia. Twenty nine Ground truth data about past landslides were collected and landslide inventory mapping was carried out in the study area. Accordingly, the inventory data was overlaid with landslide hazard map and it was used as landslide susceptibility validation. Eleven landslide causative factors namely; Slope, lithology, elevation, aspect, curvature, land use land cover, soil texture, distance from lineament, distance from drainage, rainfall and distance from road were considered. These factors were reclassified and the values were assigned for each classes of the factors based on their susceptibility of landslide hazard. Resampling technique was carried out to be come all thematic maps into the same resolution and scale. Their weights which was derived by analytical hierarchy process indicate that the influence of each factor for landslide occurrence in the study area. This has been done by pairwise comparison matrix which is assigned based on expert response and by determining the literature reviews. The derived weight clearly identify that slope, lithology, rainfall and distance to drainage are the greater degree of influence whereas distance to road showed a little role in timing landslide occurrences.

Lastly, the sum totals of all weighting parameters were developed to prepare the LHZ map using Arc-GIS software. Accordingly, the area were classified as very high hazard zones 18.4 km^2(1.3%), high hazard zones 276.4 km^2(18.9%), moderately hazard zone 567.2km^2(38.7%), low hazard zone 302.4km^2(20.7%) and about 299.6km^2(20.5%) of the study area was falls in very low hazard zones.

Regarding to landslide inventory, from the total number of inventory points 82.7% of past landslide events were falls in high landslide hazard zone and only 17.2% of landslide events were falls in moderate, low and very low hazard zone. So, the factors which were taken to model landslide susceptibility and the method that was used in the study is satisfactory agreement with the prepared landslide hazard zonation map.

5.2. RECOMMENDATION

Based on the findings of the study the following foremost recommendations were forwarded.

- Local administrative must develop appropriate plans to reduce landslide effects through land use and land cover policies and regulations.
- Farming activity which carried out near to drainage area and on the steep slope greater than 30^0 should be restricted and forest conservation activity has to be take place so as to minimize landslide event.
- The area delineated as very high and high hazard zones has a probability for future landslide and related slope instability problems. So, before taking any activity like; infrastructure development, on this area, detail study should be conducted.
- The future landslide interventions in Gechi district suggested for land management and concerned body should be, based on the findings of the current study to take more effective management of landslide.

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ANNEX

Annex 1 Average Annual rainfall (2008-2018) of the neighboring stations of the study area (mm)

Stations	Jan	Feb	Mar	May	Jun	July	Aug	Sept	Oct	Nov	Dec	A_RF
Arjo	10.9	35.7	89.3	309.1	317.1	343.9	383.3	284.1	106.9	50.9	10.8	2066.1
Bedele	19.5	39.2	97.9	303.3	319.4	341.9	386.2	297	115.5	49.5	18.3	1987.8
Yayu	30.3	28	79.6	189.7	231	257.7	289.1	241	96.9	33.7	34.2	1597
Atnago	16.8	56.9	96.7	242.6	272.2	449.8	358.2	278.1	128.5	27.4	9.7	2044.6
Genet	31.2	54.2	95.8	247.4	332.2	451	453.1	269.2	159	41.2	17.4	2282
Agaro	28.1	42.7	106.6	169.4	241.6	229.9	253	189.9	124.1	48	33.1	1573.1

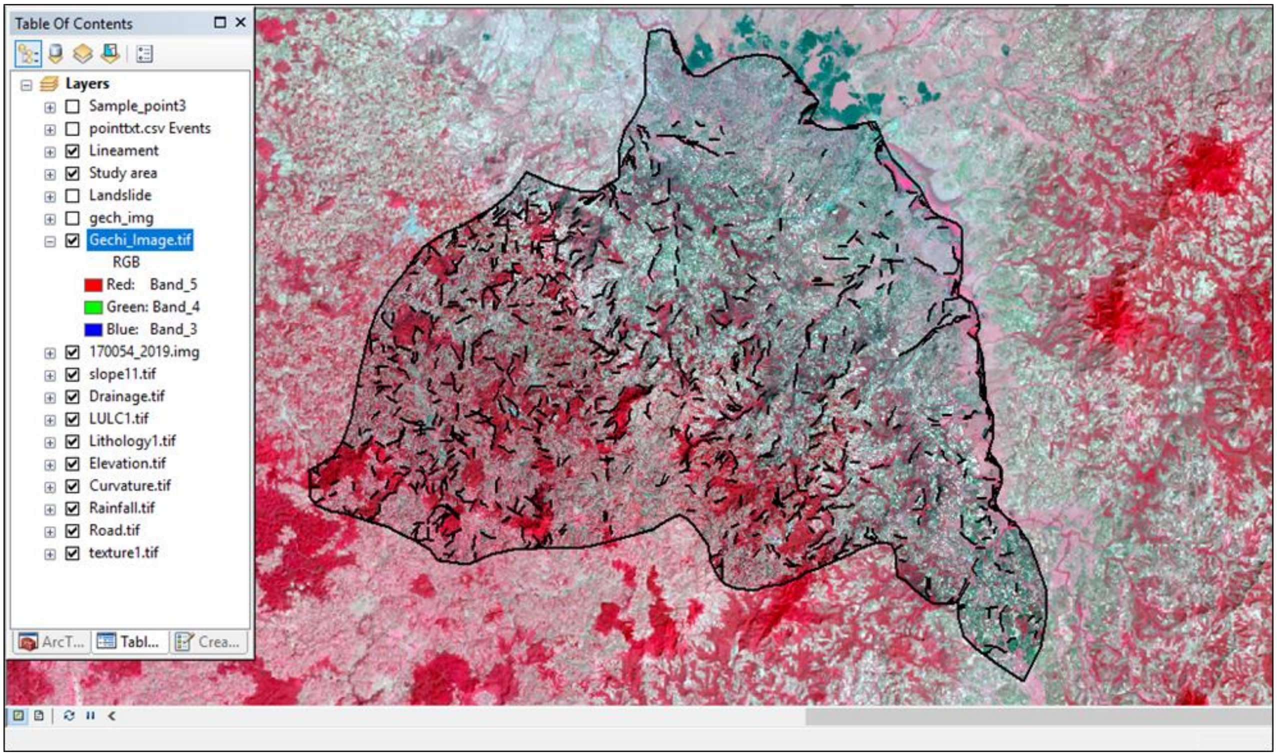
Annex 2 location points of landslide inventory data collected from field.

S/No	Existing Landslide	X	Y	Z
1	point1	234525.9971	942304.2021	1469
2	point2	226976.2786	939967.7945	1452
3	point3	218651.0733	937365.4278	1779
4	point4	216817.6741	936434.8756	1791
5	point5	237704.1365	935693.2899	1585
6	point6	222123.3267	935401.1496	1589
7	point7	231406.4719	933555.5022	1584
8	point8	220432.6382	932833.1322	1766
9	point9	215186.0324	931923.8604	2030
10	point10	208492.7705	929412.6223	1893
11	point11	220720.9549	929378.6126	1836
12	point12	217750.9533	928487.1622	1922

13	point13	233516.7921	927805.5015	1757
14	point14	213953.1293	927610.7413	1879
15	point15	206745.6486	926702.9028	1932
16	point16	212484.7826	925546.5647	1904
17	point17	221373.9194	924942.6689	1956
18	point18	241397.8281	924471.3079	1772
19	point19	217444.2175	923709.0587	1914
20	point20	234413.8942	923110.6056	1730
21	point21	232739.3283	922279.1237	1788
22	point22	244271.0389	921303.0757	1750
23	point23	217653.5732	920988.8943	2047
24	point24	211706.2656	920577.6258	1999
25	point25	214050.5094	920404.6137	2039
26	point26	205845.9957	919954.2021	2110
27	point27	222522.5784	917483.2106	2239
28	point28	239943.8789	915243.4682	1867
29	point29	214478.9819	914659.1876	2134

Annex 3: Plate that identifies landslide on grassland and shrub land in the study area (source: author, 2020)

Annex4: Landsat8 OLI/TIR image which Lineament and LULC were extracted from.



Annex 5: Arjo Geologic map which was used to derive lithology factor of the study area