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LANDSLIDE HAZARD ZONATION MAPPING OF BONGA TOWN USING STATISTICAL INFORMATION VALUE MODEL TECHNIQUES, SOUTHWESTERN ETHIOPIA

TATEK TADESSE ROBI

A Thesis Submitted to the School of Earth Sciences, Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geological Engineering

March, 2024

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PREPARED

BY

TATEK TADESSE ROBI

ADVISOR: DR. TRUFAT HAILE MARIAM

March, 2024

ADDIS ABABA

SIGNITURE PAGE

This is to certify that the thesis prepared by TATEK TADESSE, entitled: *Landslide Hazard Zonation Mapping of Bonga Town Using Statistical information value model Techniques, Southwestern Ethiopia:* submitted in partial fulfillment of the requirements for the Degree of Master of Science (Engineering Geology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

APPROVED BY BOARD OF EXAMINERS:

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Main Advisor ___________________ **Signature** ______________ **Date** _______________

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Chair of School or Graduate Program Coordinator

ABSTRACT

A landslide is the downward and outward movement of slope-forming material consisting of rock, soil, and artificial fill. In the present study, landslide hazard zonation was carried out in Bonga town in southwest Ethiopia, 449 km from Addis Ababa, the capital city of Ethiopia. The main objective of this study was to prepare landslide hazard zonation based on an information value statistical approach.

In the case of landslide hazard zonation map carried out by taking into account the nature and distribution of landslides occurring in the Bonga town. Furthermore, the possible relationship between the landslides and the associated causal factors such as slope, aspect, lithology, land use and land cover, drainage density, and relative relief will be considered in this method. The data for above mentioned have been collected and rating value by using information value statistical approaches for each causative parameters to define the elements of the landslide hazard zonation map. The sum combination of all parameters of the weighted layers into a single map and the classification of the scores of this map into landslide hazard zonation and also verifications were based on the field mapped data identifying the existing landslide and overlaid with the prepared landslide hazard zonation map. The result landslide susceptibility index map has been classified into three landslide hazard zonation classes

The results of the landslide hazard zonation map of the present study area through information value methods show classified into three hazard classes 3.64 km2 (27%) of the area belongs to the low hazard class, 5.9 km2 (43%) of the area belongs to the moderate hazard class and 4.2 km2 (30%) of the area belongs to the high hazard class. Whereas, the landslide hazard zonation map of the study area verified based on information value methods, out of seven(7) existing landslides inventory and the result indicated that (71%) of the five past landslides were within the moderate zone of the prepared landslide hazard zonation map. (21%) of the two past landslides occur in high-hazard areas, which have a high hazard class. The remaining (8%) past landslides are of low hazard and have a practical possibility of landslide occurrence. Thus, in general, it can be said that about 96% of the past landslides have been validated by the landslide hazard zonation map, which shows a satisfactory agreement on the rationality of the considered parameters and the adopted bivariate statistical value model technique.

DEDICATION

This is to certify that the thesis prepared by Tatek Tadesse, entitled: *Hazard Zonation Mapping of Bonga Town Using Statistical information value model Techniques, Southwestern Ethiopia:* submitted in partial fulfillment of the requirements for the Degree of Master of Science (Engineering Geology) complies with the regulations of the University and meets the accepted standards concerning originality and quality.

Tatek Tadesse Robi	**Date**	**Signature**
Name of the Candidate	____________	___________

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LIST OF ACRONYMS

CP	Conditional probability
EBCS	Ethiopian building code standardization
DEM	Digital elevation model
GIS	Geographic information system
GPS	Geographic positioning system
HHZ	high-hazard zonation
IV	Information value;
LHEF	landslide hazard evaluation factors
LHZ	landslide hazard zonation
lhZ	Low hazard zonation
LSI	landslide susceptible index
LULC	land uses and land cover
MHZ	Moderate hazard zonation
NMOA	National Metrology agency
NPix{SBi}	The number of landslide pixels within the factor class,
NPix{Bi}	The number of pixels of a factor class
NPix{TS}	The total sum of pixels of a landslide of the whole study area and
NPix{A}	The total pixels of the whole study area
PP	Prior probability
VLHZ	Very low hazard zonation
VHHZ	Very high hazard zonation
WBi	Weight of Factor class

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Landslide is the downward and outward movement of elements that create a slope, such as rocks, soils, manmade fills, or a mix of these Mulatu et al., (2011). It's an indication of slope instability, which is the susceptibility for landslide processes to occur on a slope that disturb both morphologically and structurally. It may take on multiple forms, or combinations of them, such as mudflows, rock avalanches, debris flows, rock falls, and soil slips (Chau et al., 2004). In mountainous areas, landslides are thought to be the primary cause of mass wasting and landscape construction (Mengistu et al., 2019b). The frequency of landslide hazards is contingent upon the reason for the sliding; when slopes are trembled, several landslides transpire nearly concurrently.

Landslides and ground collapses caused by landslides are among the frequent geo-environmental hazard in many of the hilly and mountainous terrains of both the developed and developing worlds, whether they occur naturally or are caused by human activity (Woldearegay, 2013). Landslide is one of the main issues that seriously hazard human lives, natural habitats, and building infrastructure globally (Dai et al., 2002; Raghuvanshi et al., 2014a). Furthermore, it poses a worldwide risk in terrain that slopes, resulting in sufferers among people in metropolitan areas, transportation corridors, and rural industrial sites. Every year, it causes hundreds of millions of dollars' worth of property damage, harms public works projects, buildings and structures, transportation networks, and results in fatalities and injuries (Dawit, 2016).

In the world landslides were increased causing loss of life, destroying infrastructure, industrial development, villages, or even entire towns (Kifle Woldearegay, 2013; Anbalagan and Singh, 1996, Arnous, 2011). Due to growing urbanization and other developmental activities on steep terrain, as well as awareness of their effects, the current state of landside risks has drawn attention from all over the world (Aleotti and Chowdhury, 1999). Mapping and detecting potential danger zones by parameter analysis is the process of landslide hazard analysis (Arnous, 2011).

In Ethiopia, landslide is a common phenomenon, which causes significant damage to people and property. Almost 60% of the total population in Ethiopia lives in the highland areas which are characterized by high relief, complex geology, high rainfall, uneven morphology, very deep valleys and gorges with active river incision (Ayalew 1999). Landslides are mostly caused by natural and man-made factors and are common in the country's northern, southern, and western highlands as well as partially on the rift escarpment Ayalew and Yamagishi (2004), Ayenew (2005), Engedawork Mulatu et al. (2009), Bekele Abebe et al. (2010), Kifle Woldearegay (2013), and Raghuvanshi et al. (2014). In Ethiopia, highland areas of the north, south, west, and rift escarpment have frequently seen landslides (Ayele et al., 2014). The rapid population growth demanded the use of areas that were not previously used for settlement, urban expansion, agricultural and other purposes there by exposing these areas to landslide problems after rainy seasons (Temesgen et al. 2001; Abebe et al. 2010; Woldearegay 2013). Farmlands, property, infrastructure, livelihood, and the natural environment are all significantly impacted by landslides (Lulseged Ayalew, 1999; Lulseged Ayalew and Yamagishi, 2004; Tenalem Ayenew and Barbieri, 2005). Determining, assessing, and characterizing locations that are susceptible to landslides is essential for effective strategic planning and risk reduction address this kind of landslide-related risk (Anbalagan, 1992; Raghuvanshi et al., 2014; Fikre Girma et al., 2015).

Landslides in the study area caused destruction to roads, farm lands, houses, and different infrastructure (Woldearegay et al, 2012). Also described in the report of the geological survey (GSE, 2014), shows landslides commonly occurring in Jimma, Bonga, and Dewuro zones. It varies in type mainly from complex to compounds, rotational, transitional to lateral spread. All those are slides occurring due to natural factors as well as anthropological.

1.2 Statement of problem

One of the primary environmental issues that seriously affect infrastructure and the environment is the landslide hazard. In Ethiopia, landslides frequently occur in the country's western, southern, and northern highlands. Landslide hazards in Bonga town have a long history that dates back to 1964. In 1998, as a result of high-intensity rainfall, the old landslide started again and caused damage to governmental institutions, cultural sites, and private houses (Mekuria, 2000). The main road, which connects Bonga-Tepi-Masha, passing through Alamo and Gatiba, was disrupted in four different directions (Mekuria, 2000; Tsige et al., 2017). Mostly, the Saint

Michael church floor and its compound, the Girazimach Paulos health center, mission residential areas, roads, and a secondary school around Beide Mariam were damaged by landslide hazards (Mekuria, 2000). Private and public buildings were cracked by landslide hazards in Bonga town (Mekuria, 2000; Tsige et al., 2017). More than 120 private houses and more than 10 public buildings were damaged by landslides (Tsige et al., 2017). In particular, the main road from Gebretsadik Shawo Hospital to the Coffee Land Hotel cracked, and there was downsliding, which occurred several times. Landslide hazard zonation mapping is a scientific way of identifying the vulnerability of areas to landslides based on landslide-controlling factors.

This influencing aspect makes a landslide hazard zonation map crucial for identifying the unique probability of a landslide, safer strategic planning of upcoming development projects, and minimizing the negative economic effects. The primary goal of the study was to create a landslide hazard zonation for this region to enhance the current spatial plan and direct the local government to oversee both current and future land use.

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 statistical information value model techniques of Bonga town, southwestern Ethiopia.

1.3.2. Specific Objectives

The specific objectives of this study were:

- To identify landslide prone areas
- To prepare the event based landslide inventory map of the study area
- To map landslide hazard zonation and validate in the study area

1.4 Scope of the Study

Geographically, this study confined to Bonga town, southwest Ethiopia with total area coverage of 13.7km^2. Methodologically, the study was conducted on landslide hazard zonation through GIS and bivariate statistical through information value model decision analysis by considering factors like (slope, lithology, land use/land cover, drainage density, aspect and relative relief) that cause landslide. The landslide hazard zonation map of each landslide-prone area was mapped based on the 1:50,000 scale zone.

1.5 Significant of the study

A map showing the Landslide Hazard Zonation (LHZ) is the primary output of this research. It is used to make suitable mitigation measures to lessen damage and identify potential threats based on the LHZ. It is an important role for contribution planners in selecting promising sites for development, such as buildings, and road construction, helping recognize and delineate hazard-prone zones, so that environmental redevelopment programs can be initiated by approving suitable mitigation strategies. Additionally, this map can serve as a basis for land-use planning and the creation of suitable slope-stabilization plans.

1.6 Limitations of the study

One potential constraint could have been the lack of past data recording of landslides in the region, as well as the fact that the landslides were hidden by low shrubs and grass and were not visible. Information value model of statistical need more landslide unit of sample for analysis but this study area was observed only seven sample of landslide data unit.

1.7 Outcome of the study

The ultimate results of this study are preparation of a landslide hazard zonation map at scale of 1:50,000 and making of relevant suggestion based on the landslide class map. These actions aim to mitigate potential landslide hazard.

1.8 Organization of paper

The thesis organized into six 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 bivariate decision analysis method. Chapter three includes an overview of the study area and geology. Chapter four includes the methodology of the research work and data analysis. Chapter five 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 Type 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). The landslide can occur as a falling, flowing, toppling slide or as a combination of two or more slope failures

Cruden and Varnes (1996). Classification of slope movements is stated in terms of: - fall, topple, slide, spread, and flow (Varnes, 1984); Combining the two terms gives classifications such as Rock fall, Rock topple, slide, Debris flow, Earth slide, Earth spread, etc. show table 1.

Table 2.1 classification of slope movements (Varnes, 1978)

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BED ROCK	ENGINEERING SOILS	
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock Block Glide Rock slide	Debris Block Glide Debris slide	Earth Block Glide Earth slide
FLOWS		Rock Flow	Debris Flow	Earth Flow
		(deep creep)		
COMPLEX	Combination of two or more principal types of movement			

2.2.1 Fall

Falls can be defined as the rapid movement of masses of soil or rocks separated from vertical slopes or cliffs with little or no shear displacement former to the occurrence (Fig.2.1 D). They are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water (Varnes, 1978).

2.2.2 Topples

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).This kind of slope failure is defined as the presence of rocks of a steeply inclined joint set with a strike aligned approximately parallel to the slope face. They are columnar-jointed volcanic terrain and near rivers where the banks are steep (Varnes, 1978) (Fig.2.1 E)

2.2.3 Slides

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. The volume of mass is increased from areas of local failure. Slides can be divided into two types, such as Rotational and translational

2.2.3.1 Rotational

Rotational slide occurs when the failure is "spoon-shaped" and the mass movement down and outer the concave surface (Fig.2.1A). They occur in homogeneous "fill" materials (USGS,2004).

2.2.3.2 Translational

A slide can also have a tendency to return to equilibrium; if the surface is slanted, translational slides move over a significant distance (Fig.2.1 B). Failure of translation slides happens at joints and along faults (USGS,2004).

2.2.4 Lateral spread

Mass movements on high to moderate slopes that result from a slow plastic deformation or liquefaction in a subsurface horizon covered in a more coherent surface layer are known as spreads (Fig.2.1J). The underlying material shifts and slides outward on this higher layer, breaking it up in the process (USGS, 2004).When the failing surface is harder than the layer beneath it, lateral spread failure happens. The failing surface separates gradually and holds together. Because they happen on mild or level slopes, they are distinct from other landslides.

2.2.5 Flow

The failure mass looks like a vicious liquid. This is because of actions from heavy rainfall affecting weak slopes which together form a slurry-like material that flows. Flow failure can be divided into debris flow, debris avalanche, creep, and earthflow (USGS,2004).

2.2.5.1 Debris flow

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. It has large quantities of fine material in the slurry due to the presence of water (Fig2.1 F).

2.2.5.2 Earthflow

Earth flows have a characteristic –hourglass‖ shape. It can happen due to saturation of soil due to intense rainfall excessive loading on the slope or other natural reasons like earthquakes. This mass in earthflow moves as viscous flow with large internal deformations (Fig.2.1H) (USGS, 2004).

2.2.5.3 Mudflow

A mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. 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.

2.2.6 Creeps

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 (Fig 2.1 I).

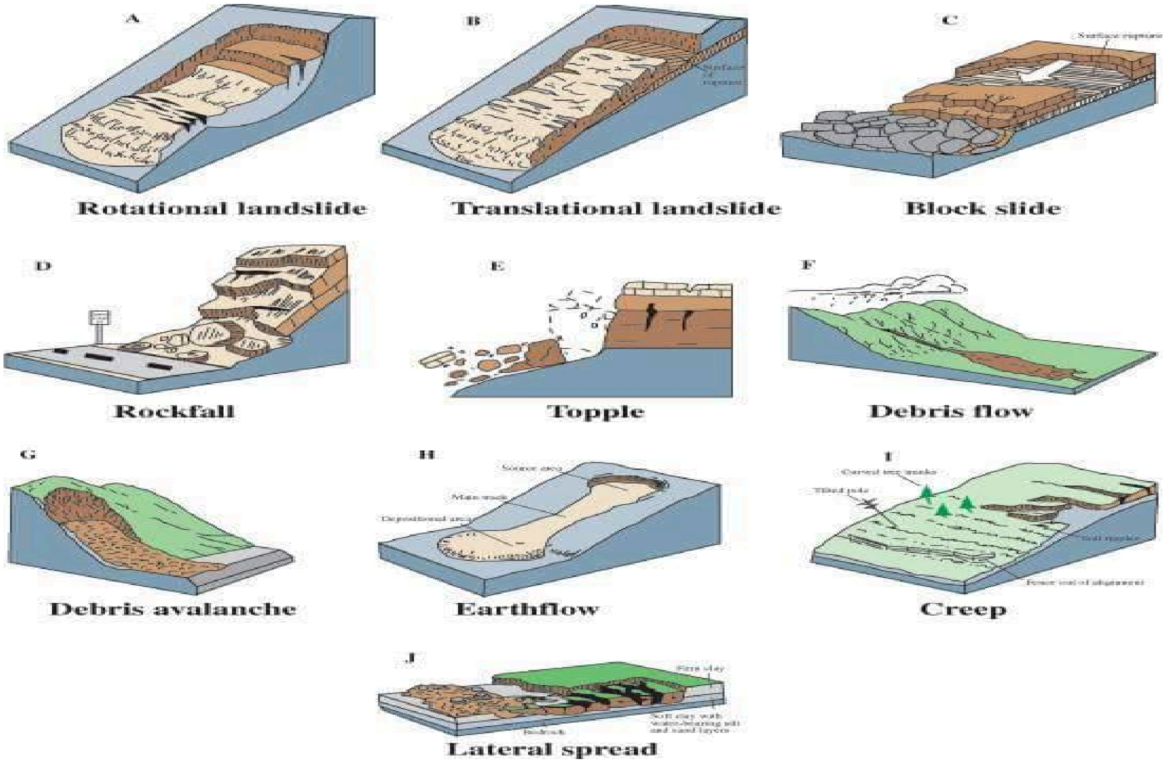


Fig 2.1 Schematic representations type of landslide (source: htt pubs, usgs.gov/fs/2004/3072)

2.3 Couse of landslide occurrences

Various researchers have considered several causative factors that may be responsible for landslide occurrences.

2.3.1 Intrinsic factor

The causal characteristics known as intrinsic parameters specify the slopes favorable or unfavorable stability conditions. According to Raghuvanshi et al. (2014), these intrinsic characteristics include groundwater, land use and cover, slope geometry, slope material, and structural discontinuities. The primary causal elements that determine landslides include slope material, slope, aspect, elevation, land use, land cover, and groundwater-surface traces (Kumar et al. 2015). The inherent properties of the slope determine whether the stability conditions are favorable or unfavorable. These intrinsic characteristics include things like groundwater, land use, land cover, slope geometry, slope material, and structural discontinuities (Anbalagan, 1992; Wang and Niu, 2009; Ayalew et al., 2004). The parameters specified for each of these intrinsic elements may have an effect on the slope's stability condition.

2.3.1.1 Slope material

Lithology is one of the most crucial factors in landslide investigations (Dai et al., 2002). Therefore, it must be taken into account. Lithological units have differed in their susceptibility. Because of lithological variances frequently result in differences in the strength and permeability of rocks and soils have a considerable impact on the occurrence of landslides (Abay et al., 2019).

2.3.1.2 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). Slopes that are steeper indicate more material strength even though they also have more potential energy to cause failure. This trade-off between higher driving power and increased soil strength appears to lessen the impact of slope steepness (Roth, 1983). Slope inclinations are frequently divided into ranges for zoning purposes. It has been observed that the strength of the slope-forming material greatly influences how steep a slope is, and that a high slope made of competent rocks is more stable than a gentle slope made of weaker formation (Neaupane et al. 2006).

According to Anbalagan (2014), the Influence of slope- Provides favorable conditions for landslides; steeper slopes are prone to slippage of land. It is known that most of the materials are stable up to a certain angle- “Critical angle”. Slope angle substantially impact the landslide incidences (Kanungo et al. 2006; Gupta et al. 2008; Dahal et al. 2009). Slope map was prepared covering six classes: very low/flat (0° -5°), low (5°-15°), moderate (15° -25°), moderately high (25°- 35°) and high (35° - 45°) and very high (>45°) Anbalagan et al., (2015).

2.3.1.3 Aspect of Slope

When creating maps of the zonation of landslides, aspect is one of the most important factors. Exposure to sun radiation, rainfall, and discontinuities which are linked parameters of aspect might regulate the occurrence of landslides (Bera et al. 2018). Flat, north, east, south, and west are the aspect classes based on which aspect degree is categorized. 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).

2.3.1.4 Land use/ Land cover change

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). Reserved or protected woods, which are densely planted and typically less vulnerable to mass wasting processes, exhibit slower erosion and more instability than barren and sparsely vegetated places (Dai et al., 2002a).

2.3.1.5 Relative relief

Relative relief is the difference between maximum and minimum elevation point within an area and it is widely used in LHZ model (Gupta et al. 1999; Saha et al. 2005; Kanungo et al. 2009b). According to Pachauri and Pant (1991), described high relief areas have the greatest risk for landslides. Gravity slides and debris flows have been more frequent in higher relief places. Comparing places with higher relative relief to those with lower relative relief reveals more unstable circumstances. Consequently, regions with greater relative relief have been given a higher LHEF grade (Anbalagan, 1992). The relative relief map prepared categories have been chosen for hazard evaluation purposes: very low relief (<50m), low relief (50m – 100m), moderate (101m – 200m), high (201m – 300m) and very high (>300m) were considered for landslide LHZ Anbalagan (2008).

2.3.1.6 Drainage density

Drainage concentrations indicate the composition of the soil and its geotechnical characteristics; drainage plays a significant role in regulating landslides (Pareta, 2004).Depending on the underlying rock structure, the area's climate, and the land's slope, the streams within a drainage basin take on specific patterns. Dendritic and radial patterns are seen in the majority of the drainage M. S. Rawat et al. 2015; High drainage density locations are ideal for causing landslides, which is a lot of landslides happen there M. S. Rawat et al. 2015. Any mountainous mountain area's river or stream alignment is important for simulating landslides, particularly when it comes to bank erosion and toe cutting (Sias and Miller, 1998).

The categories of drainage density map have been chosen for landslide hazard zonation purposes: very low <0.1, low 0.1–0.2, moderate 0.2–0.4, high 0.6–0.8, and very high >0.8 were considered in landslide hazard evaluation by Verma (2017). According to S.Sackar et al. (2020), the drainage density map can be categorized into five class such as, very low < 2, low 2-3, moderate 3-4, high 4-5, and very high >5 for landslide hazard zonation evaluation.

2.3.2 External factor

2.3.2.1 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).

2.3.2.2 Seismicity

Earthquake-induced shakings may lead to instability, particularly in loose and unconsolidated material on steep slopes. Landslides and slope failures are caused by the acceleration of the ground caused by seismic activity (Keefer, 2000; Parise and Jibson, 2000; Bommer and Rodrı guez, 2002). According to Hoek and Bray (1981), hill slopes that have an impact can collapse under strong loads brought on by seismic activity but remain stable under static stresses distributed across the surface material. Landslides may occur as a result of ground acceleration caused by seismic activity on the slopes (Reghuvanshi et al., 2014). The ground acceleration that corresponds to the estimated severity of the earthquake, as per the ISEP rating scheme, may serve as the foundation for incorporating the seismic triggering effect on slope in the evaluation of landslide hazards (Raghuvanshi et al., 2014).

2.3.2.3 Man-made factors

Instability hill side may arise from undercutting hillsides for the purpose of constructing roads or railroad tracks (Anbazhagan, 2014). Slope instability results from the river's undercutting movement, which eliminates the toe supporting the slope (Kanungo, 2015). There may be changes in land use, such as deforestation, resource extraction, turning vegetated slopes into developed areas, etc (Kanungo et al., 2006). Remondo et al. (2005) report has been a noticeable rise in the incidence of landslides in recent decades, with the majority of the increase being attributed to human activity. In many places, the main cause of slope failures is human intervention leading to the overburdening of slopes or the elimination of lateral support. The two main human-caused activities that destabilize slopes in hilly areas are the construction of roads, which can have a widespread impact, and the cultivation of those slopes. Reghuvanshi et al. 2014 Slope cutting during road building can be accomplished mechanically or by blasting, which is typically done randomly cause landslide.

2.4 Landslide Inventory

A landslide inventory, which is based on any or all of the following: aerial photointerpretation, ground survey, and a database of past occurrences of landslides in an area, is the simplest method for landslide hazard zonation. The resultant output provides the geographic distribution of mass movements, which can be shown as either point symbols or affected areas to scale on a map (Wieczorek 1984).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; what type of landslides have occurred and with what causative and triggering factors that might have possibly resulted in landslides (Kumar *et al*., 2015). The resultant output provides the geographic distribution of mass movements, which can be shown as either point symbols or affected areas to scale on a map (Wieczorek 1984). In Bonga district and its surrounding there are so many event and past landslide inventories area. So, in this study landslide inventory data were collected and inventory map was prepared. It's possible that many landslides that happened before pictures were captured have since vanished from view. Consequently, refining is the process of creating maps of landslide activity that are based on the analysis of multi-temporal aerial photos (Canuti et al. 1979).

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, landsliderisk 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 landslide hazard analysis, the combinations of variables that have historically caused landslides are identified statistically, and quantitative projections are generated for regions that are landslide-free at the moment but contain conditions that are similar. Landslide hazard analysis employs bivariate and multivariate statistical techniques (Van Westen et al., 1997).

2.5.1.1 Bivariate statistical approaches

Each factor map (such as slope, geology, and land use) is paired with the landslide distribution map in bivariate statistical analysis, and weighting values based on landslide densities are computed for each parameter class (Brabb et al., 1972). This approach incorporates a variety of statistical techniques, such as weighted overlay methods, information value methods, and weight evidence methods (Kanungo et al., 2009). The landslide susceptibility method (Brabb 1984; van Westen 1992, 1993), the information value method (Yin and Yan 1988; Kobashi and Suzuki 1988), and the weight-of-evidence modeling method are some of the statistical techniques that have been used to determine weighting values (Spiegelhalter 1986).

(i) Frequency Analysis (likelihood ratio) method

Landslide occurrence is strongly correlated with a parameter class's frequency ratio greater than one, but landslide occurrence and factor class are less correlated when the frequency ratio is less than one (Chimidi et al. 2017; Girma et al. 2015; Lee and Min 2001). The following formula can be used to express the frequency ratio (FRd):

$$FRd = \frac{\%Ls}{\%Am}$$

Where %Ls is the percentage of landslides in a causative factor class, %Am is the area of the causative factor class as a percentage of the overall map, and FRd is the frequency ratio for the causative factor class. Additionally, the total overlapped pixels add up to the landslide susceptibility index (LSI) for each pixel, which is determined by

$$LSI = \sum_{d=1}^{n} FRd$$

There is a high LSI value. It is believed that there is a considerable risk of landslides. The landslide hazard index (LHI) is another way to represent the LSI (Pradhan and Lee 2009).

(ii) Weights of Evidence (WOE) method

The weight of evidence (WOE) method (Süzen and Doyuran 2004; Van Westen et al. 2003; Van Westen 1993) is a frequently used technique for predicting potentially sensitive locations for landslides. This technique employs a quantitative, data-driven strategy to merge the landslide dataset.

The following formula can be used to express the weight of evidence (WOE) method

$$Prior_P = P\{S\} = \frac{N_{Pix}(Slide)}{N_{Pix}(total)}$$

where P{S} is the conditional probability of having a landslide ('S'); NPix(slide) is the total number of pixels within the landslides in the study area; NPix(total) is the total number of pixels in the research area; and 'PriorP' is the prior probability.

$$Cond_P = P\left\{\frac{S}{B}\right\} = \frac{P\{SnB\}}{P\{B\}} = \frac{N_{Pix}\{SnB\}}{N_{Pix}\{B\}}$$

where "NPix{SnB}" is the total number of pixels of a parameter class "B" within the landslides, "Condp" is the conditional probability of having landslide "S" in a particular parameter class "B," and "NPix{B}" is the total number of pixels of that factor class "B" within the entire research region.

$$W_i^+ = In\left(\frac{P\left\{\frac{B_i}{S}\right\}}{\left\{\frac{B_i}{\overline{S}}\right\}}\right) \qquad W_i^- = In\left(\frac{P\left\{\frac{\overline{B}_i}{S}\right\}}{\left\{\frac{\overline{B}_i}{\overline{S}}\right\}}\right)$$

Where "In" denotes the natural log, "P" stands for probability, "Bi" denotes the presence or absence of a potential landslide predictive causative factor, "S" denotes the presence or absence of a landslide, "WÍ i" denotes a positive weight that suggests a predictable factor is present in the landslide, and "W− i" denotes a negative weight that suggests a predictable factor is absent in the landslide.

(iii) Information value (IV) method

The information value can be computed by utilizing (Yin and Yan 1988);

Conditional probability (cp) = $N_{pix}(SBi)/N_{pix}(Bi)$

Prior probability (pp) = $N_{pix}(TS)/ N_{pix(A)}$

Weight ratio (WBi) = $\frac{\text{(con\_prob)}}{\text{(prior\_prob)}}$

Information value = log (WBi)

The causative factor maps can further be processed in GIS environment and landslide susceptibility index (LSI) can be computed for each pixel with the help of raster calculated. Thus, this LSI will form the basis to produce the landslide hazard zonation map (Mengistu et al. 2019)

$$LSI = \sum IVB$$

Where; LSI is the landslide susceptibility index and ‘ ∑IVB′ is the sum total of information values for all causative factors

2.5.1.2 Multivariate statistical analysis

Models of multivariate statistical analysis, primarily created by Carrara (1983, 1988) and his associates (Carrara et al. 1990, 1991, 1992), are used to forecast unique events. All pertinent elements are sampled in morphometric units or on a large-grid basis in their applications. The presence or absence of landslides is also ascertained for every sampling unit.

Afterwards, discriminant analysis or multiple regressions are used to examine the generated matrix. As demonstrated by the work of (Jones et al., 1961), good results can be predicted with these strategies in homogeneous zones or areas with only a few types of slope instability processes. Large data sets are therefore required in order to gather enough cases for accurate results. Because complicated statistics do not employ selection criteria based on expert experience, their application necessitates extensive and time-consuming data collection.

2.5.2 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.

2.5.3 Heuristic approach

These approaches combine the primary input aspect for hazard determination the mapping of mass movements with their geomorphologic context. It is possible to distinguish between two types of heuristic analysis: qualitative map combination and geomorphic analysis Kienholz (1977). The geomorphologist determines the hazard firsthand in the field. This makes it challenging to create the decision rules because they differ depending on the situation. This approach of assessing a terrain's vulnerability to slope instability are particularly prevalent in Europe, where there is a wealth of knowledge regarding geomorphic and engineering geologic mapping (Carrara and Merenda 1974; Kienholz et al. 1983, 1988; Ives and Messerli 1981; Rupke et al. 1988).

2.5.4 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).

2.6 Previous studies about the landslide in Ethiopia

Ethiopia is a country with great geographic diversity with mountains, high plateaus, deep gorges, river valleys, and lowland plains (Aregay Waktola, 1999). Landslides are very common in the mountainous areas of the country and along the rift margin. These landslides are caused by many influencing factors such as geology, human activities, topography, heavy rainfall, land use conditions, and also seismicity (Raghuvanshi et al., 2014; Birhanu Ermias et al., 2017; Kifle Woldearegay., 2013; Dai and Lee., 2000). Landslides have become a common problem which can even cause life loss. Due to this problem, landslide hazard studies have become mandatory. 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.

Tilahun Hamza and Raghuvanshi (2017) used a GIS-based statistical and probability technique to perform research on LHZ in the Jeldu locality in southeast of Ethiopia. As conditioning elements, employed aspect, slope, height, lithology, soil, and land use. The determination of research work was calculating the landslide hazard zonation frequency ratio. The researchers used a bi-variate statistical approach. According to the findings, 8% of area is in a very high hazard zone, 21% is in a high hazard zone, 32% is in a moderate hazard zone, 27% is in a low hazard zone, and 12% is in the no hazard zone.

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.

Gemechis Chimidi et al. (2017) conducted a study in and around Gimbi town in western Ethiopia to evaluate and zone landslides. This investigation was carried out using a GIS-based statistical approach. 12.2 percent of the area is classified as very high hazard, 30.7 percent as high hazard, 24.3 percent as moderate hazard, 23.3 percent as low hazard, and the remaining 9.5 percent as no hazard.

Landslide danger zonation was carried out by Birhanu Ermias et al. (2017) along the route from Alemketema Town to Ambat Village in North Shewa, Ethiopia. In this investigation, the Slope stability susceptibility evaluation (SSEP) assessment scheme was used. The developed LHZ map shows two zones: high danger (66.6 percent) and moderate hazard (33.3 percent) (33.1 percent). When the LHZ map was overlaid with data from previous landslide incidents, 80.3 percent of the area fell into the high-hazard zone.

Fikire Girma et al. (2015) used a GIS-based statistical approach to conduct a study on landslide hazard zonation in the Ada Berga district, central Ethiopia. The purpose of this work is to calculate the landslide hazard zonation frequency ratio. The researchers used a bi-variate statistical approach. In the study area, causal elements included elevation, aspect, slope, curvature, soil and lithology, land use, land cover, and hydrogeology. According to the conclusions of this study, 24% have no hazard, 32% have a low hazard, 17% have a moderate hazard, 25% have a high hazard, and 2% have a very high hazard.

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.

Raghuvanshi et al. (2015) used grid overlap and GIS modeling methodologies to generate an LHZ map in the Meta Robi district, Oromiya, Ethiopia. The grid overlay method was found to be more time-consuming and cumbersome, while GIS modeling provided a superior landslide danger zonation map. Using remote sensing and a GIS technique, Shiferaw Ayele et al. (2014) identified landslide hazard zones in the Gohatsion-Degen sector. To conduct landslide hazard zonation in this study, the method of the analytical hierarchy process was used. Causative factors included slope, structures, aspect, geology, groundwater, land use and land cover, and drainage. According to the landslide danger zone map, 67 percent of past landslide locations are located within the maximum hazard zone.

Landslide danger zonation mapping was carried out by Engdawork Mulatu et al. (2009) in the Gilgel Gibe II area of southwestern Ethiopia. The landslide hazard evaluation factor rating scheme (LHEF)-an expert evaluation technique suggested by Anbalagan (1992) was used in this work to carry out landslide hazard zonation. They divided landslide hazard zones into three categories: high-hazard zones, moderate-hazard zones, and low-hazard zones.

In the area of Kindo Didaye Woreda, southwest Ethiopia, Zerihum Dawit (2016) did a study on landslide hazard evaluation and zonation. This study was conducted using an integrated SSEP technique and a raster-based information value model approach. The findings revealed that man-made activities such as agriculture, deformation, and modification of slopes, as well as heavy rainfall and groundwater, are the most relevant factors in the incidence of landslides in the area.

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.

CHAPTER THREE

3. OVERVIEW OF STUDY AREA

3.1 Description of the study area

3.1.1 Location of the study area

One of the districts of the southern nations and nationalities people regional states, Bonga Town is located in the southwest Keffa zone, which is about 449Km far to the southwest of the capital city from Addis Ababa. It is lies between 7°15'25" -7°16'00" latitude and 36°14'55" – 36°15'25" longitude and it covers a total area of 13.7 km^2 (Fig.3.1).

Figure 3.1 location map of the study area

3.1.2 Physiography

The present study area is categorized as volcanic rock mountain topography with high to low hills, and the landscape is moderate to gentle sloping and rippled. The lowest and the highest peak elevation of the study area is 1600m a.s.1 and 1940m a.s.1 respectively an elevation difference is 340m (fig.3.2). The land use is coffee, maize plantations, and dense tropical forests, primarily junipers, and olive trees, cover the highest elevations. This physiographic feature is mainly a result of transitional landslide. The study area landscape covers the middle to lower hill slopes.

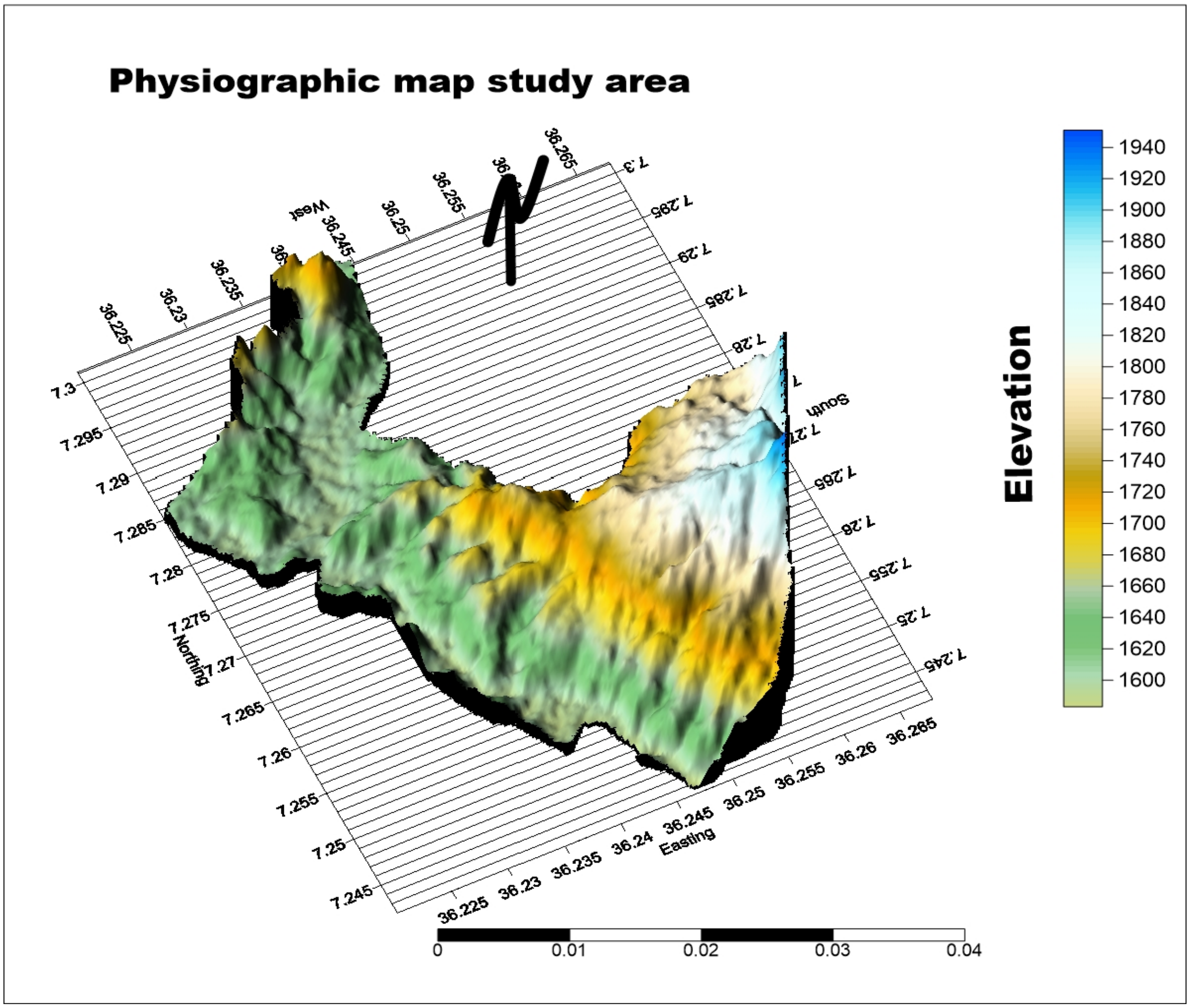


Figure 3.2 Physiography 3D map of the study area

3.1.3 Climate

The variable in topography has an influence on the climate of the study area. The elevation of the study area ranges from 1600m to 1940m above sea level. According to Danel Demechu (1997) climate can be classified five elevation groups: desert (Breha), tropical (Kola), subtropical (Weynadega), temperate(Dega), and alpine (Kur) (Table 3.1). The present study area elevation ranges from 1600m to 1940m above sea level. The study area is located in the southwestern Ethiopian highlands, which have a warm, humid, and wet subtropical climate. As a result, the research area's climate zone is categorized as follows:

Table 3.1 Climatic zones of Ethiopia and their physical characteristics. (Source: Ethiopia treasury, 2023)

Climate zones	Elevation
Desert (Breha)	< 800
Tropical (Kola)	< 1830m
subtropical (Weynadega)	1500m to 2300m
Temperate (Dega)	2300m to 3300m
Alpine (Kur)	>3300m

3.1.3.1 Rainfall and Temperature

Bonga town is grouped under subtropical climatic zones. The average monthly rainfall of the study area is 1470 mm for the years 2000–2019. The high monthly rainfall is recorded in from July to September, and the second is from April to May (Fig 3.3). So, in the winter was the main rainy season in the area and the highest stream flow; spring was the second maximum rain season. The annual mean average temperature is minimum 10^0C to the maximum reaches up to 23°C (computed from NMA 2000-2019).

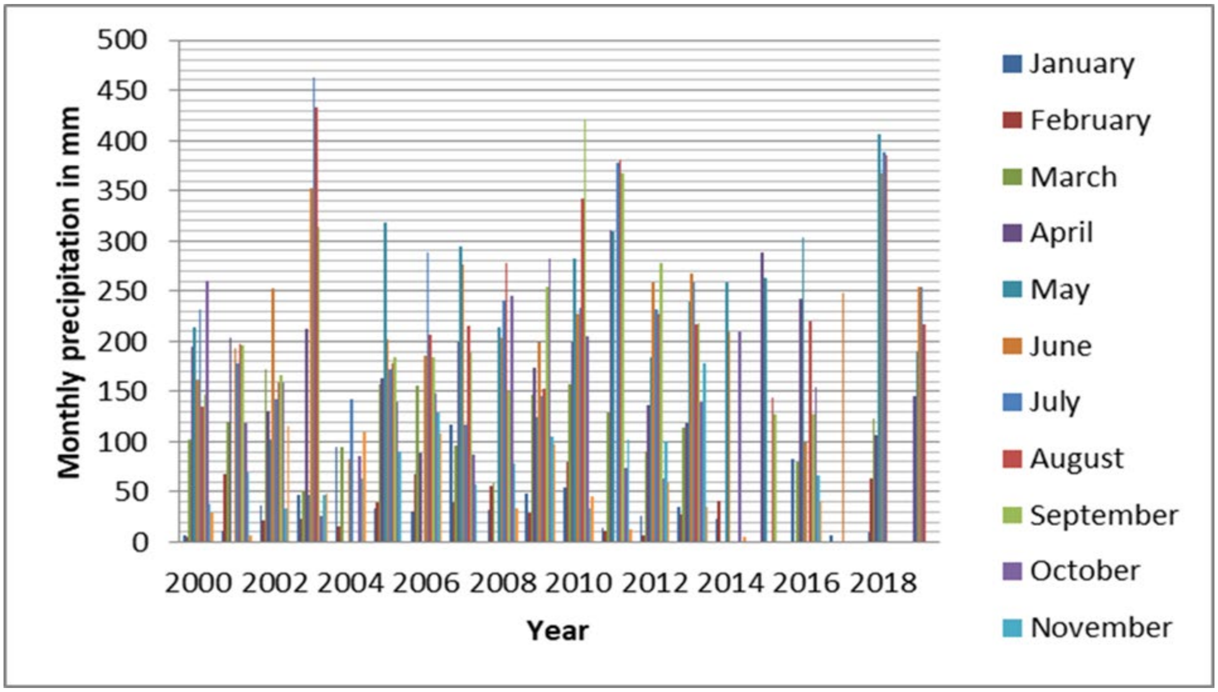


Figure 3.3 Monthly precipitation of the study area (source: MOA), 2000-2019)

3.1.4 Seismicity

The ground motion brought on by natural phenomena, infrastructure with human origins, and public safety is known as seismicity (Crozier, 1986; Alexander, 1993). Earthquakes frequently occur at rift margins and active plate boundaries. Seismic hazard zoning was in the Ethiopian Building Code Standard (EBCS, 1995), which divided into four main seismic danger zones (Fig 3.2). The Zone 4 areas are those that are most susceptible to earthquakes. This zone includes the entire region covered by the Afar Depression and the great Ethiopian Rift. Zone 1 locations are the least susceptible to the threat. The current study area is in zone 1, which has a seismic and ground acceleration of 0.03 coefficients, based on the seismic hazard map (table 3.2).

Table 3.2 Ground acceleration of earth quake that should be considered in each seismic zone (source: EBCS, 1995)

Zone	**4**	**3**	**2**	**1**	0
g (cm/sec^2)	**0.1**	**0.07**	**0.05**	**0.03**	Seismic free

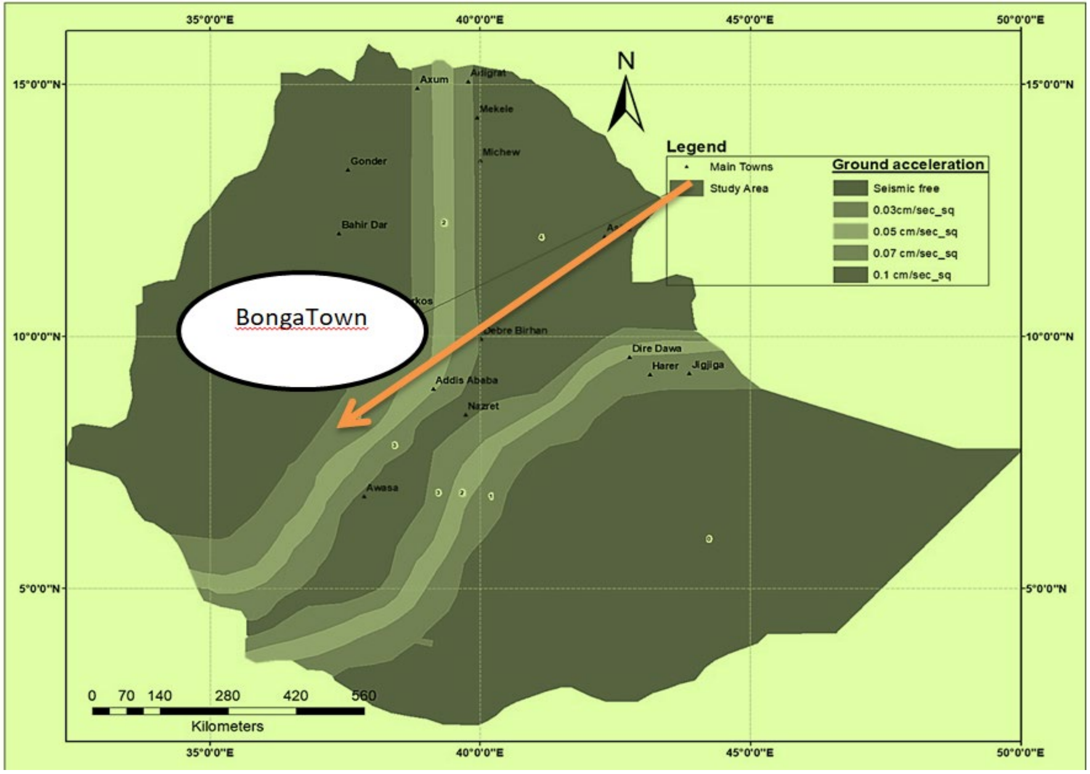


Figure 3.4 Ground acceleration of earth quake that considered seismic zone of Ethiopia (source (EBCS, 1995))

3.2 Geology

The studied region is in Ethiopia's Jimma volcano (upper series), which contains trachyte, ignimbrite, rhyolite, and tuff, as well as basalt. The general geology of the region prepare at the scale of 1:250,000 for the purpose of providing information about basic lava flow and pyroclastic debris formed by tertiary volcanism dominated the area. Fine-grained and porphyritic basalts make up the basic lava flows, while fine and coarse tuffs and agglomerates make up the pyroclastic eruptions. The most recent quaternary deposits are alluvial, colluvial, and residual soils. The volcanic rock units are displaced by NE-SW faults, resulting in a distinct scarp zone at the study area's eastern and southeastern ends (EGS, 1999).

3.2.1 Regional geology

Ethiopia's Cenozoic volcanic rocks, according to Mohr (1963), are split into two series: the Trap series and the Aden series. The Tertiary flood basalt stage with felsic lava and pyroclastic rocks is known as the trap series volcano (commonly in the upper part). The Aden series is limited to mafic lava flows within the younger Afar depression. The plateau's massive volcanic pile can reach a thickness of up to 3 kilometers in some areas. The trachyte basalts and rhyolites that cover most of southwestern Ethiopia were given the name "Jima Volcanic" by Merla et al. (1979). The Jima volcanics are assumed to be analogs of Davidson's main sequence, consisting of thick successions of basalt and felsic rocks, with basalt dominating the bottom section. The majority of the sections, the lower Jima volcanic, mostly basalts, and the upper Jima volcanic, which includes trachyte, rhyolites, ignimbrites, and uncommon tuffs, have a conformable relationship Magdela Group of Kazmin (1972). The Nazareth series forms rift shoulder deposits, a thick succession of welded ignimbrite, minor basalt, and rhyolite flows (EGS, 2014).

3.2.1.1 The Precambrian basement

The high-grade terrain in southern Ethiopia is characterized by the existence of hypersthene-bearing rockslides east of the Omo River, which is localized in two areas: the Hamar range and the surrounding Konso (Davidson, 1983). As a result of considerable retrogression, several rocks that originally had granulite facies assemblages have been reduced to middle and lower amphibolite facies, and even locally to greenschist facies. Hypersthene relicts have been preserved in various rocks due to incomplete retrogression, which explains the existence of hypersthene close to two-pyroxene hornblende granulite and epidote green hornblende amphibolite, for example. The formation of lower-grade minerals in and around minerals like hypersthene causes partial retrogression in many rocks. In the region of two-pyroxene, another, for example, two-pyroxene hornblende granulite and epidote green hornblende amphibolite are found near one another. The formation of lower-grade minerals in and around minerals like hypersthene causes partial retrogression in many rocks. Around augite grains, both green amphibole rims are particularly abundant. In some instances, retrogressive amphibolite facie zones can be found inside granule facie rocks. These localized retrogressions are notably related to these constrained zones of ductile shear zones (EGS, 2014).

3.2.1.2 Late Tertiary to quaternary volcanic rock

The Omo Group Sediments are made up of four formations (Mursi, Nkalabong, Usno, and Shungura) Davidson (1983). The Mursi Formation is made up of roughly 150 meters of clay, silt, and sand, with subordinate tuff and pebble beds, and it lies unconformably on a tilted pre-rift rhyolite that is most likely Miocene in age. The Mursi Basalts are overlain by the Nkalabong Formation, which is 90 meters thick and consists of gray-brown river clastic deposits, eolian sands, water lain tuff, and tuffaceous sediments. The formation is made up of about 200 meters of alternating fluvial and lacustrine sediments with tuffaceous layers and a solitary basalt flow at the bottom (Davidson, 1983). The Shungura Formation, which is the youngest of the Omo Group deposits, comprises at least 750 meters of clay, silt, sand, gravel, tuff, marl, and freshwater limestone in brown, gray, and buff colors that were deposited by varying fluvial and lacustrine cycles.

3.2.1.3 Quaternary volcanic rocks

Quaternary alkaline basalt and trachyte erupted along preexisting structures on the northwesterly and southeastern plateaus. Although they have not been dated, their relatively unaltered geomorphological features, such as the presence of large cinder cones and minor collapse craters, particularly in a location with considerable rainfall and perennial streams, indicate that they are very young. Tena Graben alkaline basalts and trachytic lavas, as well as Batu Mountain's youthful trachyte flows and Sanete basalts, are all part of this unit (Kazmin, 1979; Merla et al., 1973). All of these rocks appear to be Pleistocene in age, based on field data. Volcanic cones and coriaceous basalt flows have been preserved in the Lake Tana graben. The Tepi basalts, which were formed by a Holocene central-type eruption in southeastern Ethiopia, are another younger similar unit (Davidson, 1983). These alkaline quaternary basalt flows could be the last basaltic volcanism on the Ethiopian plateau.

3.2.1.4 Tertiary volcanic

The trachyte basalts and rhyolites that cover most of southwestern Ethiopia were given the name "Jima Volcanic" by Merla et al. (1973). The Jima volcanics include a deep succession of basalts and felsic rocks, with basalts dominating the lower part of most sections, and are regarded to be comparable to Davidson's (1983) Main Volcanic Sequence. A conformable link has been discovered between two units (Jima Basalts and Jima Rhyolites). In southwestern Ethiopia, the Jima Rhyolites, the younger of the two sections, are similar to the Kazmin Magadala Group (1972). The Jima Volcanic nearly invariably sits on a Precambrian basement, and the unconformity is marked by basalt residual sandstone. The basalt flows form an unbroken succession several hundred meters thick in certain locations. Other felsic rocks are intercalated with basalt flow towards the base or form a thick succession just above the basal basalts GSE (2014).

3.2.2 Local geology

Tertiary volcanic rocks and quaternary soils, such as basalt, tuff, colluvial, and alluvial deposits cover the current study area. Alluvial and colluvial deposits make up the quaternary sediment. Basalt and tuff deposits are makeup of the tertiary volcanic. The study's local geology is detailed further as follows

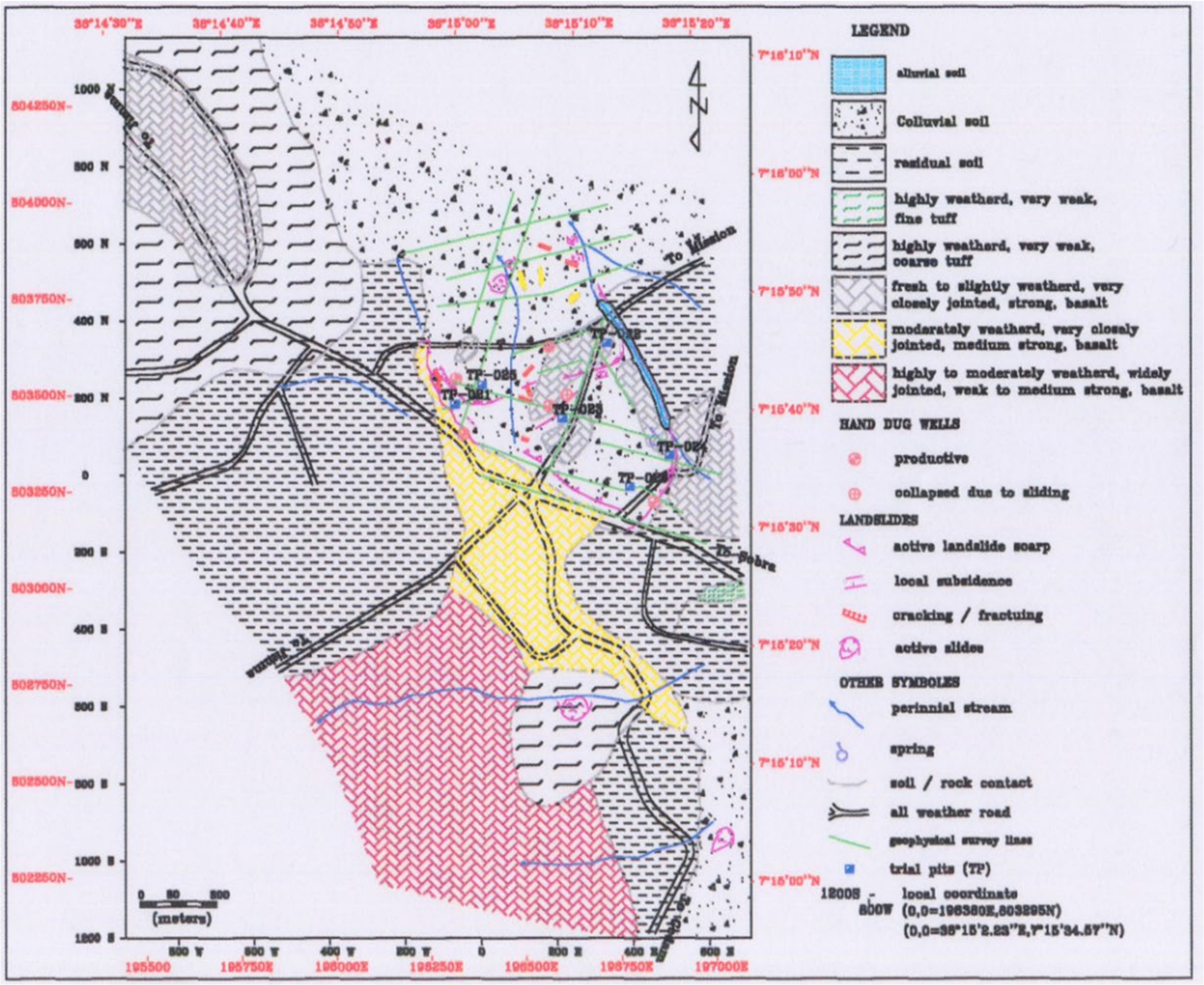


Figure 3.5 Local geological maps from the geological map compiled by the Geological Survey of Ethiopia (GSE, 1998)

3.2.2.1 Basalt

The middle flow basalt unit is exposed in the southern and western parts of Bonga town. The unit is porphyritic, with abundant coarse-grain and a black to dark gray color. It is moderately with slight weathering, which accounts for the blocky outcrop appearance and the presence of fresh rounded to elongated very strong core stones.(plate 3.1E)

3.2.2.2 Tuff

This type of rock can be found in the current study area's northern, eastern, and southeastern high-elevation mountains. Fresh fine-grain tuff is light gray to pale blue, but when exposed to weather, a variety of colors are formed, such as white, pink, green, and ash gray(plate 3.1D). Plagioclase mineral and earthy brown to gray volcanic ash are incorporated in the fine-grained bulk. It becomes enormous, has extremely weak strength, where weathering is intense.

3.2.2.3 Alluvial and Colluvial deposits

Alluvial soil is the result of water deposition along river or stream beds and bank. In the study area alluvial soil is mapped along Gincha river and along one of streams at the causality area.as described of the river bank, the soil is silty_clay, dark gray, soft, slightly plastic, moist and composed of very few and rounded sand. Along the river bed and one of the streams in the causation region, alluvial deposits are the result of water deposition in the study area (plate 3.1B).

Colluvial soil is formed as a result of transportation down slope by gravity surface water wash also play major role in the formation of colluvial soli. At the study area, the colluvial soil is occupy the moderately steep slopes of the southern and the gentle slopeing northern part. As indicated by test pit and natural stream cuts the colluvial soil has a multi-colored color, heterogeneous mixture of fine particles and coarse to rock fragment and general loose. (plate 3.1A). This indicates that a heterogeneous mixture of small particles and coarse rock fragments might be found in the surface water that was eroded from sliding land.

3.2.2.4 Residual soil

Residual soil is an in situ developed soil which has not undergone significant transportation. In the study area the residual soil covers the flat to gentle sloping area. At the eastern and western part of Bonga town it forms bench like morphology where its thickness reaches up to 10m.

Generally, the residual soil is silt clay, reddish brown. The residual soil is covering the entire resettlement area and it is clay with sand, reddish brown, firm and plastic. The sand size fractions are quartz and black rounded and string mineral. The thickness of the residual soil at resettlement area is approximately more than 6m. At the southern and southwestern part of Bonga town residual soil is developing from basalts fragments area contained within the soil. This land forms the south-western and north-western parts of the study area. Residual soil is light brown, silty clay, and reddish brown in comparison to other soil types. It has slope instability and is subjected to many transportation characteristics in the area it covers (plate 3.1c).

3.3 Geological structures in the study area

Colluvial deposits in Mission and 980 area (A), Alluvial soil in the study area (B), Residual soil (C) Fine and coarse Tuff (D) and Boulder of Basalt (E)Plate 3.1 lithology of study area

Faults, fractures, and joints are among the linear features evaluated and ascribed to structures found mostly in exposed rocks in the study area.

3.3.1 Faulting/fracturing

Faulting and fracturing are two structures found in the east and south-eastern parts the study area. It causes litho-unit displacement as well as the production of scarp zones and waterfalls (GSE 1999). Fracture is making up of weathering and erosion processes for the gentle to moderate slope where slope instability processes are active. Normal faults are caused by the relative vertical displacement of the rock units in the study. The fault runs NE-SW and NW-SE in general geological structure report GSE (2015) (Plate3.2).

3.3.2 Joint

The study area contains a variety of joints, including rock bed joints. Geological features have been observed in the southwest and west rock determines the nature of the joints. Strong rocks such as basalt the joint is well developed, tightly spaced, tight, and three-set (Plate 3.2).

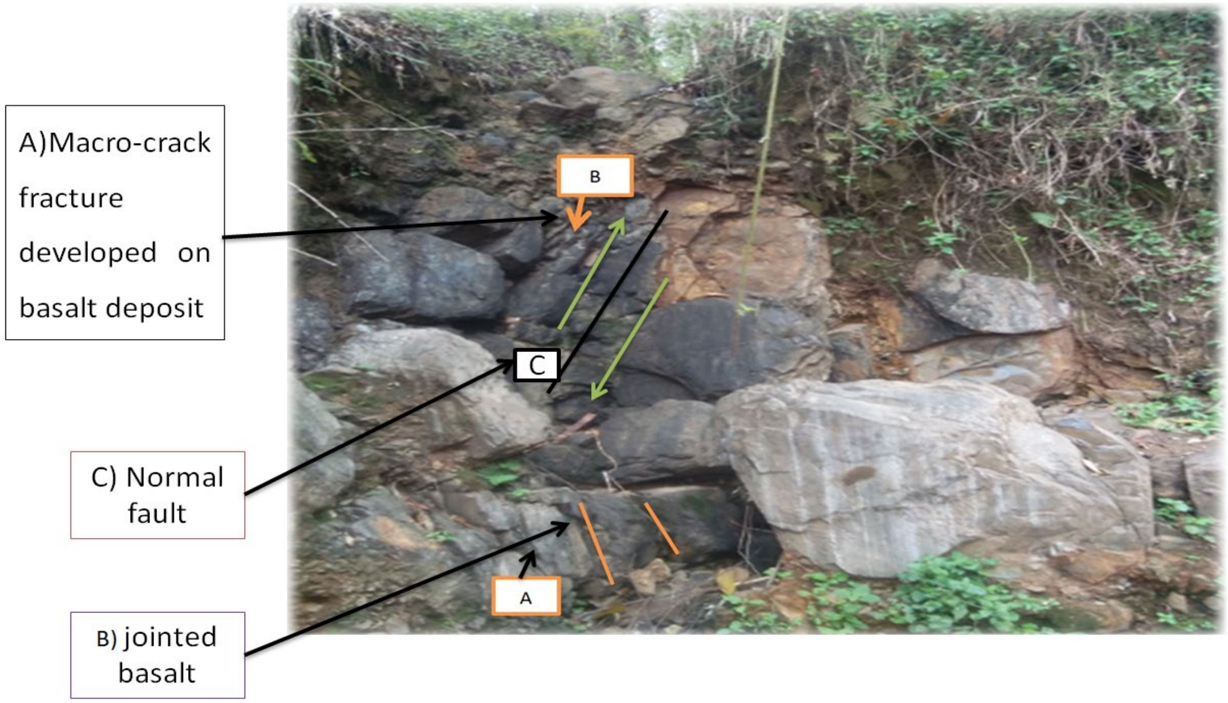


Plate 3.2 the geological structure of joint (A), fracture (B) exposure and (c) Normal fault

CHAPTER FOUR

4. METHODS AND MATERIALS

4.1 Data collection

4.1.1 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.

1 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.

2 Remote sensing data

Landsat 8 OLI/TIR image of was downloaded from USGS website which is cost freely available data with no cloud cover with spatial resolution of 30m for multispectral band. This data was used to extract information about LU/LC of the study area. As well, ASTER DEM of 30m resolution was downloaded from USGS website to extract, slope, aspect, drainage density and relative relief was prepared.

3 Geological data

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

4 Rainfall data

Annual rainfall data of the study area was obtained from National Metrological Agency (NMA). The data was taken from one station those are Bonga town.

5 Topographic

For this research, the identified topographic factors were slope, aspect, drainage density, and relative relief. All topographic factors were generated from the DEM while land use/ land cover from Landsat 8

Table 4.1 Data Types and Sources

No.	Data type	Data source	Data format	Scale	purpose
1	Boundary data	CSA	Shape files		Delinated study area
2	Inventory data	Field work	Row data		Landslide inventory map
3	DEM (ASTER)	USGS	Raster data	30m	FOR Preparation slope, aspect, drainage density, and relative relief map
4	Geological map	EGC	Raster	1:250,000	Lithological factor study
5	Climate	NMA	tabular		Rainfall data
6	Landsat 8	USGS	Raster	30m	For preparation LULC map

4.1.2 Software and tools

To achieve the objective of the study, software like Arc GIS 10.8, surfer 2015, Google Earth 2019, and materials like handheld compass, GPS, excel, and Digital Camera were used.

4.2 Data Analysis

In the present study used the information value model (IVM) which has already been proved to be a useful method in determining the degree of influence of individual causative factors responsible for landslide occurrence Yin and Yan (1988). The information value model which is a statistical analysis method proposed by Yin and Yan (1988) and modified by van Westen (1993) was first used in the prospecting field and was later applied to spatial prediction of geological hazards and disaster risk assessment. In this method, the weighted class value is determined based on the density of landslides in each causative parameter (Lin and Tung, 2003).

In IVM method, six causative factors were used as input for the landslide hazard zonation which includes: slope, aspect, lithology, land use/land cover, drainage density and relative relief. 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. Accordingly, the classes of each factor that have the maximum impact of landslide was assigned the positive value, whereas classes in which less impact of landslides were assigned with a negative value (Ayele, 2014).

4.3 Landslide Inventory Mapping

The beginning of any landslide hazard zonation 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, 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. central and western. Of the total sample points of landslide prone areas, about five (5) and two (2) points were purposively collected from the western and central zone respectively. Lastly, landslide inventory map was prepared using ArcGIS 10.8 software.

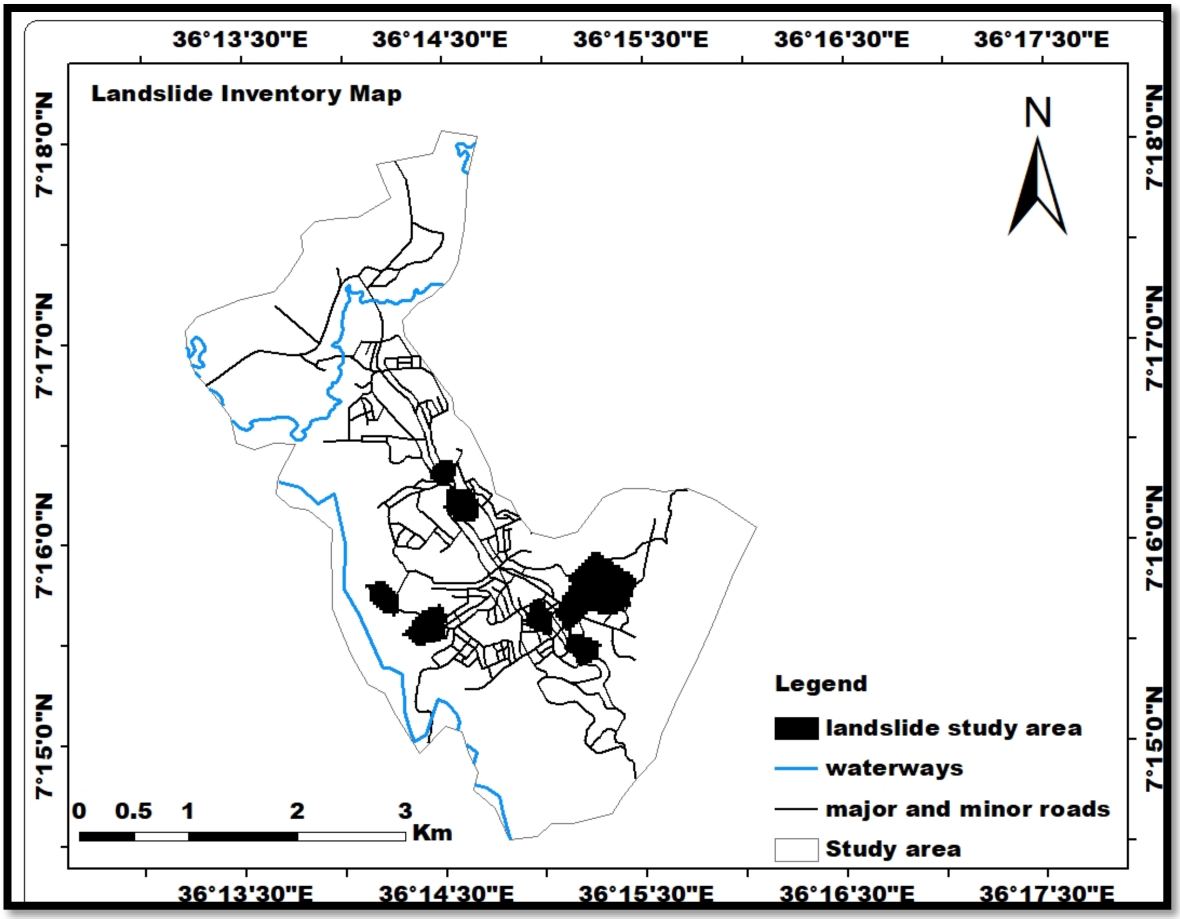


Figure 4.1 Sample polygons of landslide inventory points

4.3.1 Landslide distribution in the study area

Understanding the types of landslides that have previously happened in the study area was the first step in preparing the landslide hazard zonation. The historical landslide serves as helpful proof of a potential landslide location. The study area's landslide incidents were gathered via a field survey employing a handheld GPS device. During the field inquiry, travers mapping and significant field observation were used to identify every previous landslide in the studied region. Utilizing a digital camera, an image of the research area's landslide distribution was captured. The landslide's location, the failure process, and the materials used were all noted in this study. Ultimately, layer analysis and the picture of the recorded data location modified utilizing Arc-GIS.

4.3.2 Landslide and cause of material in the study area

Due to topography, nature of geological material and annually high/intense rainfall Bonga town is highly prone to mass movements. Tertiary volcanic, namely basalt and tuff, are the main rocks covering the research area landslide. These rocks were affected by high degree of weathering that is responsible for the formation of different grade, from weak to relatively strong basalt and fine to coarse-grained tuff (GSE, 2014). Colluvial, alluvial, and residual soils are found in the area covering gentle to moderately sloping topography results in the area are determined to have a major contribution to landslide processes (plate 4.1).

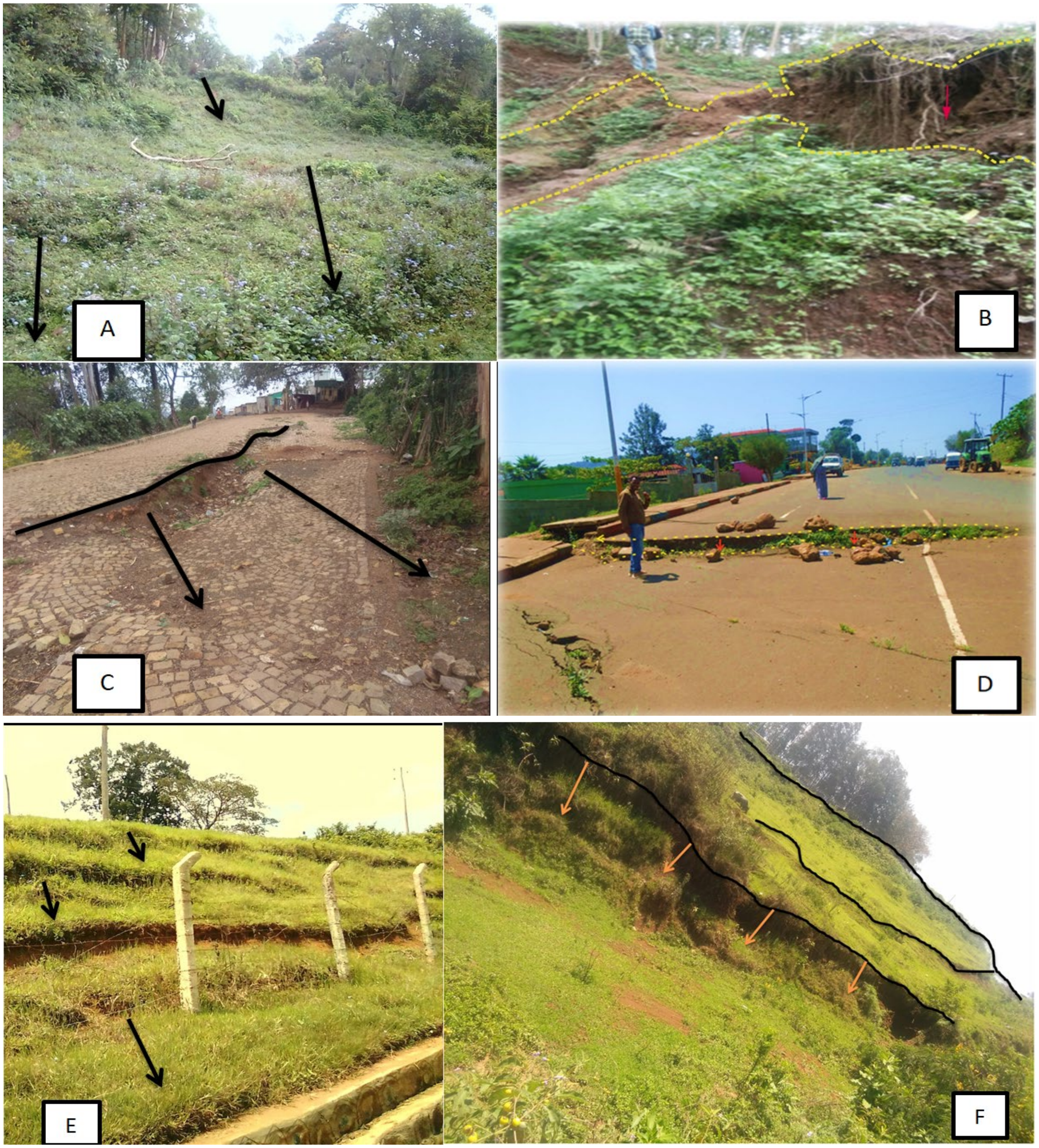
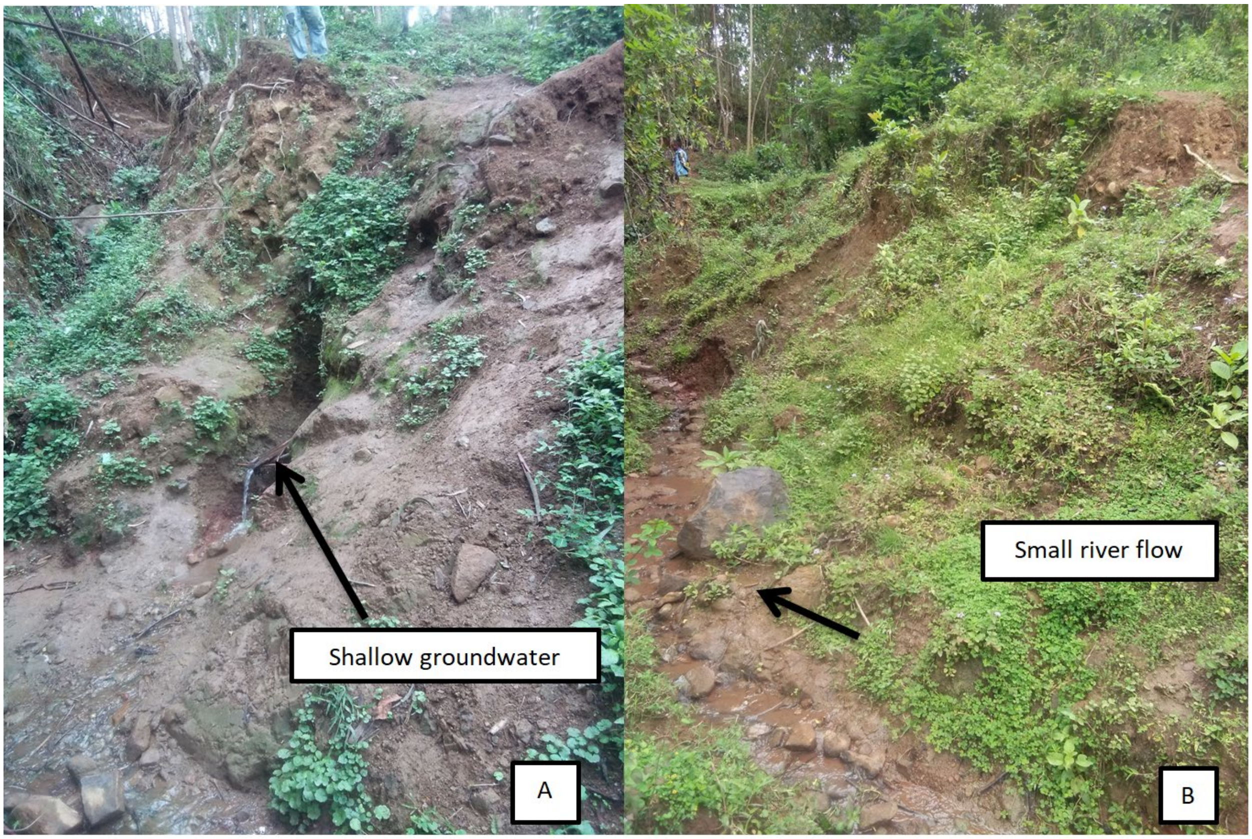


Plate 4.1 Landslide and cause of material in the study area

(A) Mass of residual soli slide near to 980locality, (B) residual of soil slides a round mission and 980, (C) coble stone cracks ready to slide road around a round Mikael church, (D) Landslide along main road crack near Kebele 02, (E) Transitional soil slides along a gentle slope Around 02 kebele at Kidanemihiret church and (F) Transitional soil slides along a gentle slope near to near to police office.

4.3.3 Failure mechanisms in the study area

According to Fuchu et al. (1999) the failure mechanisms of landslides are controlled by number of factors. The quaternary colluvial and residual soils are found in the area covering the volcanic on the gentle to moderately sloping topography, whereas the alluvial soil is occupying the river plains. Slope geometry and causative factors and the high intensity and long term rainfall in the area are determined to have a major contribution to landslide processes failure mechanisms. Shallow groundwater is also cause of landslide in the area. The sliding failure mechanisms which are observed in the study area indicate translational movement.



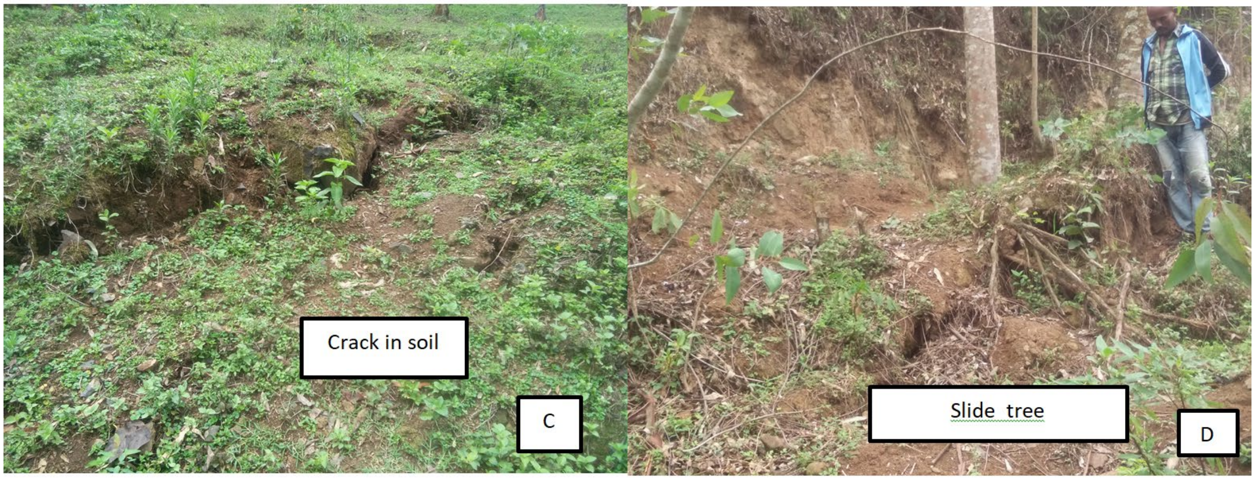


Plate 4.2 Landslide manifestations in the study area

(A) Groundwater near to mission locality (B) River erosion a 980 locality (C) Soil cracks near 980 locality and (D) Tree fall by landslide at mission locality

4.3.3.1 Transitional slide

Translation slides occur when the mass moves out and down a long a planar surface as compared to rotational slides with minimal rotational movement. According to Raghuvanshi et al. (2015), Translational is typically fails around geological features such joints, bedding surfaces, faults, and the interfaces between bedrock and soil components. In the study area, where moderate gentle slopes and gentle slopes are existing, transitional type slides are common. It is extent range from low to medium landslide for large distance.

The materials in the research area slide range from large rock slabs to unconsolidated soils, or both. Seven (7) translational slides were found during the field survey, and the majority of them as results of the saturation of unconsolidated colluvial and alluvial soil and the highly weathered volcanic formations of basaltic origin and the high intensity rainfall.

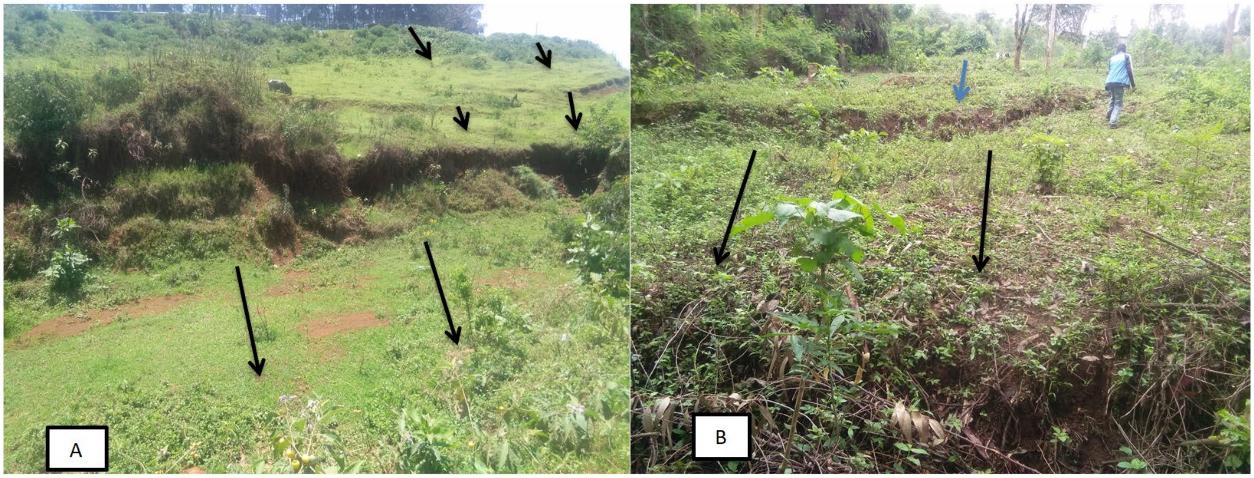


Plate 4.3 Translational slides

A and B show Transition slide surface down word moving residual soil

4.3.3.2 Landslide Triggering Factors

Based on field observations, the study area's topography, six causal elements were chosen. It was determined that these elements which included drainage density, aspect, slope, lithology, relative relief, and LULC are causal triggers landslide cause in research area.

4.3.4.1 Slope

The slope is an important component in the stability of soil or rock reflection; as the slope angle increases, so does shear stress in the soil or rock material (Lee et al., 2004). The slope is a key factor in the majority of landslide occurrences, as the slope angle increases, so do the occurrences of landslide movement or slope failures. From the **(**table 4.2**)** show that out of the total 44.43 % (6.09km^2) cover slope angle very low (0°-5°), 45.09% (6.18km^2) low (5°-12°), 9.24% (1.26km^2) slope angle medium (12°-30°), 1.08% (0.15km^2) slope angle high (30° -40°) and 0.16% (0.02km^2) slope angle very high (>40°) respectively. 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 4.2 slope class and area coverage

number	slope	Area coverage(Km^2)	Percentile (%)
1	0° - 5°	6.09	44.43%
2	5°-12°	6.18	45.09%
3	12°-30°	1.26	9.24%
4	30° -40°	0.15	1.08%
5	>40°	0.02	0.16%
total		13.7	100.00%

4.3.4.2 Aspect of slope

Aspect is one of the most crucial elements in the creation of zonation maps for landslide hazards. According to Clerici et al. (2006), aspect (slope direction) influences exposure to winds and sunshine, which in turn influences other elements that cause landslides, such as soil moisture, vegetation cover, precipitation, and soil thickness. Coverage from solar radiation, rainfall, and discontinuities, all of which are aspect influence factors, aid in the prevention of landslides (Singh et al. 2014; Bera et al. 2018). The degree is divided into flat, north, east, south, and west aspect classes. Aspect map is a critical parameter for understanding the impact of the sun on the local climate. ASTER DEM 30m x 30m was used to generate the aspect map. The aspects have the percentile area coverage: flat 0.80% (0.12km2), north 8% (1.1km2), north-east 7.70% (1.05km2), east 8.40% (1.15km2), south-east 9.40%(1.29km2), south 15.70% (2.15km2), south-west 19.40% (2.65km2), west 19% (2.61km2), and north-west 11.60% (1.58km2) the distribution of such different percentage aspect and coverage area in present study area is described in (**table 4.3**)

Table 4.3 aspect class and area coverage

number	aspect	Area coverage(Km^2)	Percentile (%)
1	flat	0.12	0.80%
2	North	1.1	8.0%
3	Northeast	1.05	7.70%
4	East	1.15	8.40%
5	Southeast	1.29	9.40%
6	South	2.15	15.70%
7	Southwest	2.65	19.40%
8	West	2.61	19%
9	Northwest	1.58	11.60%
Total		13.7	100.00%

4.3.4.3 Lithology

The area coverage of the current research small location, the lithological class can be divided into seven classes from the regional map found from the geological survey. The noticeable rock types exposed in the study area are covered by middle basalt flow and middle trachyte. A thick quaternary deposit of basalt, trachyte, colluvium, alluvial, tuff, and residual deposits covers the current study area. Residual soil is composed of the entire middle basalt flow and is formed from highly weathered basalt rock. The rock-covered middle basalt flows 21% (2.89); Middle trachyte 34.80% (4.74km2) cover of the study area, colluvium deposit 6.30% (0.86km2) of the study area, alluvial deposit 1.39% (0.19km2), weak and strong residual soil cover 14.8% (2.01km2) and 13.3% (1.82km2) of the study area figure 6.3 (**table 4.4)**

Table 4.4 Lithology class and area coverage

Number	slope material	Area coverage(Km2)	Percentile (%)
1	Middle basalt	2.89	21%
2	Middle trachyte	4.74	34.6%
3	colluvial deposit	0.86	6.3%
4	Alluvial deposit	0.19	1.39%
5	Strong residual soil	1.82	13.3%
6	Weak residual soil	2.01	14.8%
7	Fine to coarse tuff	1.19	8.7%
		13.7	100%

4.3.4.4 Land use and Land cover

Land use and land cover of the current research area was prepared from high-resolution image through supervised classification using ArcGIS. It is shown that the stability of the downward movement of slope material indirectly controls the rate of landslide movement underlying rock formation (R.K. Lallianthangaet al, 2013). The current research region's LULC was determined using satellite images, and supervised classification was carried out using Landsat 8. Different forms of area cover and land use were recognized based on the results of the Google Earth image processing system viewed with Arc GIS v10.8. It was classified into three classes namely; barren land, building area, and forest area. The percentile area coverage of 15.6% (2.13km2) barren land, 41% (5.62km2) building area, and 43.4% (5.95km2) forest area covered (Table 4.5), respectively. When a hillside becomes unstable due to deforestation or land becomes barren and the amount of rainfall increases, a landslide occurs.

Table 4.5 Land use/land cover and area coverage

Number	land use and land cover	Area coverage(Km2)	Percentile (%)
1	Barren land	2.13	15.6
2	Forest land	5.95	43.4
3	settlement area	5.62	41
		13.7	100%

4.3.4.5 Drainage density

The drainage density is the basic factor in the majority of landslide occurrences, as the flow density increases, so the occurrences of landslide movement or slope failures increase because drainage erodes slopes, there is an increased chance of slope failure. Rocks and soils lose some of their shear strength as a result of drainage. Drainage density was categorized into five subclasses very low (<2), low, medium (2-3), high (3-4), and very high (>5) respectively**.** In the case drainage density has the area coverage and parentage value from very low(<2) to very high (>5) drainage density of 10.18km2 (74.4%), 2.87km2 (20.9%), 0.37km2 (2.7%), 0.21km2 (1.5%) and 0.07km2 (0.5%) respectively **(Table4.6).** Reclassification and rating of classes for each criterion to be considered were performed based on S.Sackar et al. (2020).The current study area is separated by various perennial and seasonal stream flow occurrence of landslides against drainage density class. So, drainage density is one of the important factors in the instability of soil and weathered rock.

Table 4.6 drainage density class and area coverage

Number	Drainage density(Km/Km2)	Area coverage(Km2)	Percentile (%)
1	Very low (<2)	10.18	74.4
2	Low (2-3)	2.87	20.9
3	Medium (3-4)	0.37	2.7
4	High (4-5)	0.21	1.5
5	Very high (>5)	0.07	0.5
		13.7	100%

4.3.4.6 Relative relief

Relative relief is also one of the causative factors for landslide, which could be used for the calculation of the rating range value between higher and lower altitude. Relative relief indicated that 21.60% (2.96km2) of the area under in (<50), 60.70% (8.32km2) (50-100**)**, 15.40 % (2.1km2) (101-200**)**, 1.93 %(0.27km2) (201-300**)** and 0.37% (0.05km2) (>300) relief respectively **(Table 4.6).** Reclassification and rating of classes for each criterion to be considered were performed based on (Anbalagan, 1992).

Table 4.6 relative relief class and area coverage

Number	**Relative Relief(m)**	**Area coverage(Km^2)**	**Percentile (%)**
1	<50	2.96	21.60%
2	50-100	8.32	60.70%
3	101-200	2.1	15.40%
4	201-300	0.27	1.93%
5	>300	0.05	0.37%
Total		13.7	100.00%

4.4 Information value model

GIS- based statistical bivariate methods were applied to calculate weights for each causative factors maps using information value modeling. In the present study used the information value model which has already been proved to be a useful method in determining the degree of influence of individual causative factors responsible for landslide occurrence (Arora et al., 2004; Champatiray et al., 2007; Kanungo et al., 2009). Landslide hazard zonation may be made easier by using the information values of the numerous causative elements to identify potential landslide occurrence regions. The information values can be ascertained based on whether the causative factor classes were present in the previous landslides or not Raghuvanshi et al. (2020).

The information value model which is a statistical analysis method proposed by Yin and Yan (1988) and modified by van Westen (1993) was first used in the prospecting field and was later applied to spatial prediction of geological hazards and disaster risk assessment. In this method, the weighted class value in the information value (IV) method is calculated using the density of landslides about each causative cause Leulalem Shano et al. (2020)

Landslide hazard distribution and the causative factor are merged in bivariate statistical procedures, and for every parameter class, weighting values based on landslide densities are computed. An essential tool for doing a quantitative analysis of landslide is the statistical information value model. When IV is negative, a variable has no significant impact on the development of landslides; nevertheless, IV (information value) is positive, a variable does have a substantial impact on the development of landslides (Yin and Yan, 1988). The consistency ratio was calculated using the formula below.

Conditional probability (cp) = $N_{pix}(SBi)/N_{pix}(Bi)$……………………………………………………..eq. (1)

Prior probability (pp) = $N_{pix}(TS)/ N_{pix(A)}$……………………………………………………………eq.(2)

Weight ratio (WBi) = $\frac{(con\_prob)}{(prior\_prob)}$…………………………………………………………….....eq. (3)

Information value = log(Con_prob)/(Prior_prob)……………………………………………………..eq.(4)

Whereas:

- "NPixA" represents the overall sum of pixels
- "NPixTS" is the overall sum of landslide pixels
- "NPixBi" is the sum of pixels inside each causative factor class, and
- "NPixSBi" is the sum of landslide pixels inside each causative factor class.
- Wi indicates the ratio relationship between the conditional and prior probability factor Weight-causative factor

The logarithm Wi ratio calculation is negative value when the landslide density is lower than average; positive weights values are determine density is higher than average (Yin and Yan, 1988). The values of the gathered data were allocated to each component in order to create the weight-causative factor maps. This study was used bivariate method of, information value model to combine the factor maps by calculating the landslide hazard zonation value for every pixel using a raster calculator.

LSI = Slope Material(Iv) + Lulc(Iv) +Slope(Iv) +Relative Relief(Iv) +Aspect(Iv) +Drainage Density(Iv)………………………………………. ………………………………………Eq.(5)

Where; LSI is the landslide susceptibility index, LULC is land use and land cover and, IV is the information value.

Finally, Three classification of LHZ were created and mapped out: these are high hazard zone, moderate hazard zone and low hazard zone

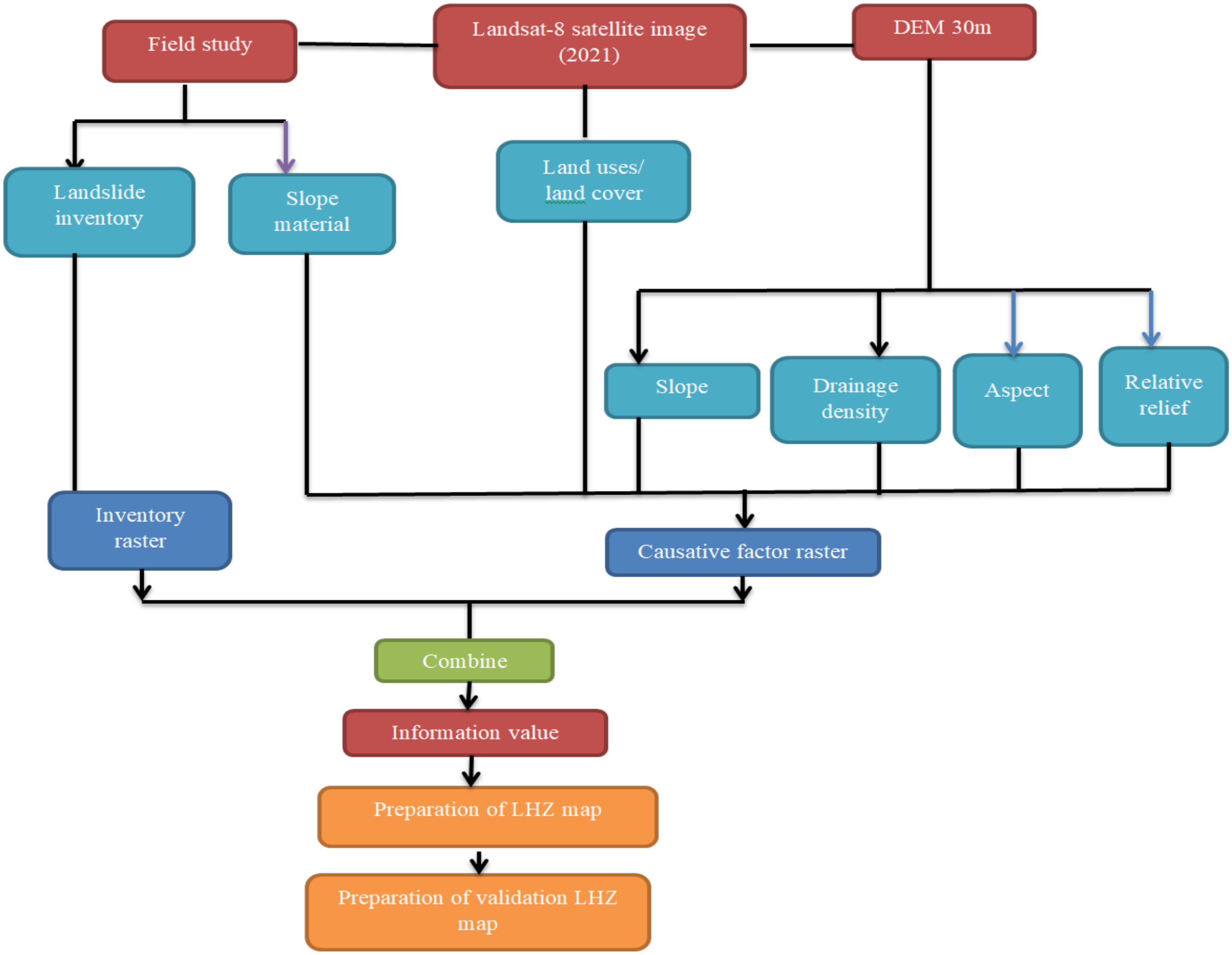


Figure 4.2 Methodological follow diagram of the study

CHAPTER FIVE

5. RESULT AND DISCUSSION

5.1 Landslide Inventory map

Finding the ground truth of seven (7) landslide inventory points collected, most landslide were occurred around western part and few of them are in central part of the study area. From the total inventory points, five (5) landslides were falls under moderate slope. According to (Dai *et al.*, 2001; Woldearegay, 2005) landslides were occurred in the slope ranges of 12-30^0 with in irregular topographic setup very regularly directly related to the slope angle. Thus, collecting landslide features is a necessary step before doing any kind of slope stability study or making maps of landslide inventories. The inventory map is also used an input map for verification of landslide hazard zonation for the study area (Fig 5.1).

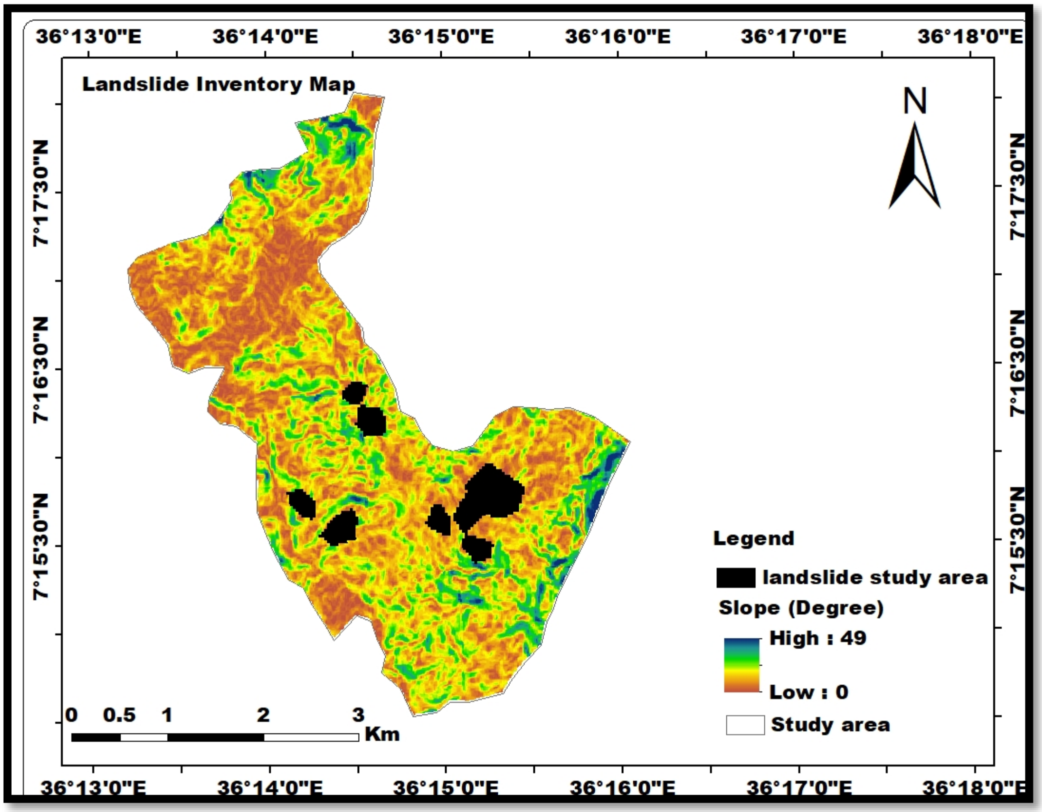


Figure 5.1 landslide inventory maps of study area

5.2 Landslide correlation with Triggering Factors

Using the statistical information value model, the relationship between six causative elements and previous landslide events has been examined to analyze the incidence of landslides and their causative components. The weight assigned to each causal component is separated into statistical IV models. The spatial relationship between the causative factor class contribution and the landslide occurrence are represented by the weight values obtained from the statistical IV model. The classes' computed statistical IV values are either positive or negative. According to Yin and Yan (1988), a causative factor has an impact on the incidence of landslides when its statistical IV value is positive while the causative factor's statistical IV value is negative, it does not affect landslide occurrences. The values of the statistical IV technique are computed.

5.2.1 Landslide correlation with slope

The slope morphology classes (0° - 5°), (5°-12°), (12°-30°), (30°-40°) and (>40º) expression of statistical information value (IV) -0.011, 0.0524, -0.193, 0 and 0 respectively. As a result comparison was slope with landslide using information value; it was the first major involvement relation with landslide. The slope angle in the given information value classes (0° - 5°), (12°-30°), have negative value represent; this indicates that the class has a low influence. Incline classes (5°-12°) indicate positive (IV) 0.0524 respectively, as result it is a strong relationship with landslides and a strong impact. The possible reasons for instability in (5°-12°) slope classes are related to the poor characteristics of the slope material. The slope angle indicates (30°-40°) and (>40°) IV have 0 and 0 respectively and they have no link between landslide and caustic factor because of information value is shown as zero in **(table 5.1).** If the statistical information value is positive indication that classes have contributed to the landslide (Yin and Yan, (1988)). According to Raghuvanshi et al. (2015), these slope materials are largely disintegrated, have low shear strength, high porosity, and are substantially more permeable.

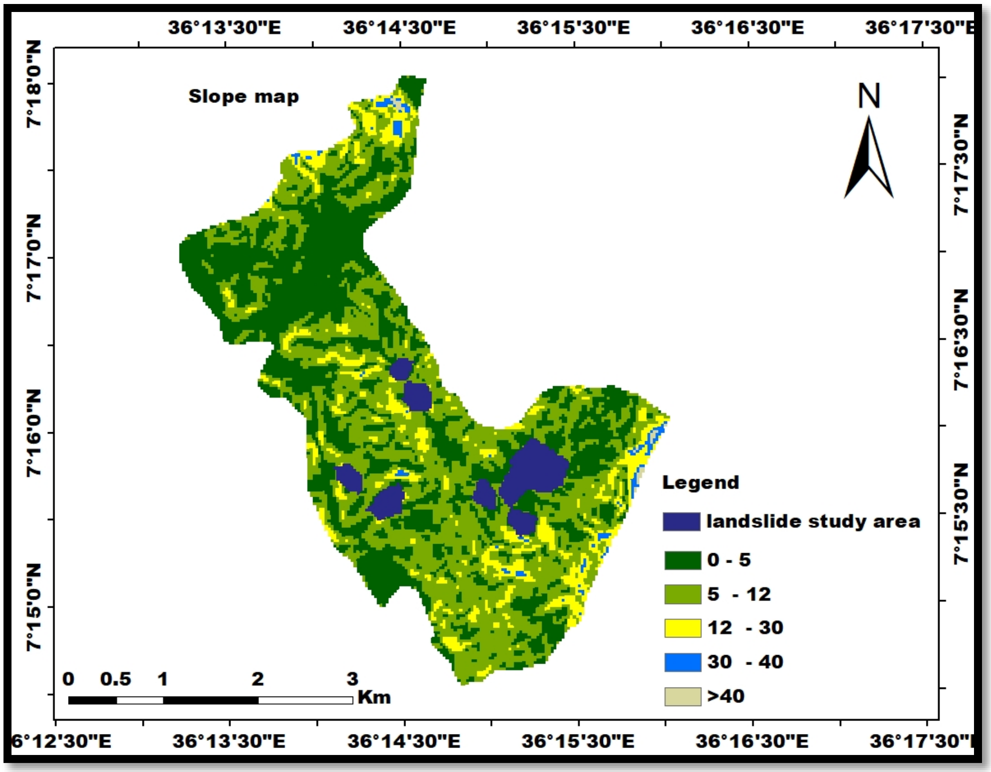


Figure 5.2 slope map of study area

Table 5.1 Information values (IV) for slope

Slope	Npix {Bi}	Npix {SBi}	Npix {A}	Npix {TS}	CP	PP	WBi	IV
0°-5°	6041	329	14531	811	0.0545	0.056	0.976	-0.011
5°_12°	6813	429	14531	811	0.063	0.056	1.128	0.052
12°-30°	1482	53	14531	811	0.0358	0.056	0.641	-0.193
30°-40°	195	0	14531	811	0	0.056	0	0
>40°	33	0	14531	811	0	0.056	0	0
	14531	811						

5.2.2 Landslide correlation with aspect

Aspect (slope orientation) affects_the exposure to sunlight and winds, affecting indirectly other factors that contribute to landslides, such as precipitation, soil moisture, vegetation cover and soil thickness (Clerici et al., 2006). The aspect slope orientation northeast, east, southeast south, and southwest, have a lass correlation concerning landslide and have statistical information values

-1.413,-1.138,-0.759,-0.401, and -0.019 such negative information value (IV) indicates less influence **(table 5.2).** The aspect classes facing are flat, north, west, northwest, and north with statistical information values of 0.22, 0.16, 0.105, and 0.064, expressions positive value representing the highest probability contribution. Generally, the IV has negative values showing a weak correlation with landslide and less influence. This can be the result of the slopes facing flat terrain receiving a lot of sunlight and precipitation. Because of the faster rate of saturation and weathering, especially in loose pyroclastic rock masses and disintegrating slope material, this promotes land sliding.

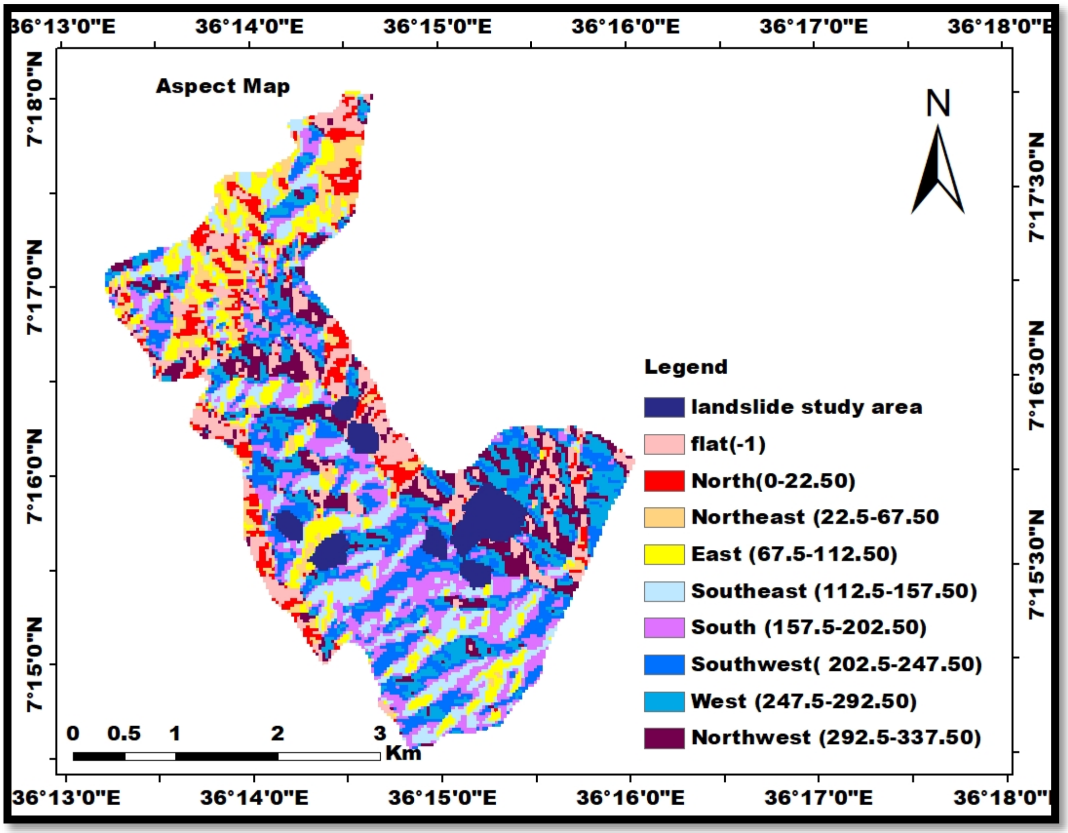


Figure 5.3 aspect map of study area

Table 5.2 Information values (IV) for aspect

Aspect Slope	Npix {Bi}	Npix{SBi}	Npix{A}	Npix {TS}	CP	PP	WBi	IV
Flat	971	90	14531	811	0.093	0.056	1.661	0.22
North	1705	203	14531	811	0.119	0.056	2.133	0.329
Northeast	928	2	14531	811	0.0022	0.056	0.039	-1.413
East	984	4	14531	811	0.0041	0.056	0.073	-1.138
Southeast	1235	12	14531	811	0.0097	0.056	0.174	-0.759
south	1803	40	14531	811	0.0223	0.056	0.398	-0.401
Southwest	2153	115	14531	811	0.0534	0.056	0.957	-0.019
west	2166	154	14531	811	0.0711	0.056	1.274	0.105
Northwest	1757	143	14531	811	0.0814	0.056	1.458	0.164
	14531	811						

5.2.3 Landslide correlation with lithology

As a result of the comparison of the six caustic factor information value models, lithology has the highest contribution to landslides. The lithological causative factors are divided into six classes: weak residual soil, strong residual soil, alluvial, colluvial deposits, trachytes, and basalt, respectively (fig.5.4). The landslide occurrence and the causative components lithological relationship are indicated (table 5.3).Strong residual soil and trachyte have the statistically negative IV (-1.187 and -0.023), respectively, while the statistical IV values of tuff, weak residual soil, colluvial deposit, and basalt are 0.593, 0.154, 0.458, and 0.023, respectively. The IV values of positive lithological units have a strong correlation with landslides, while the IV values of negative lithological units have a weak contribution. The slope material value of the alluvial deposit does not correlate to a landslide because the result value shows zero.

From this, it can be concluded that the slope material classes with higher statistical IV values contribute more to the incidence of landslides, whereas the slope material classes with lower statistical IV values subsidize less. Fine to coarse grain tuff deposits have the greatest frequency of landslides among the seven classes, and their statistical IV is 0.595. The material factor classes' alluvial deposit covers an area of 0.19 km2 of the total study area, which has a statistical IV of 0. The greater IV value is calculated for fine to coarse grain tuff deposits, colluvial soil, and weak residual soil. So the probability of a landslide occurring is high. This slope material unit is unconsolidated because the landslide is higher.

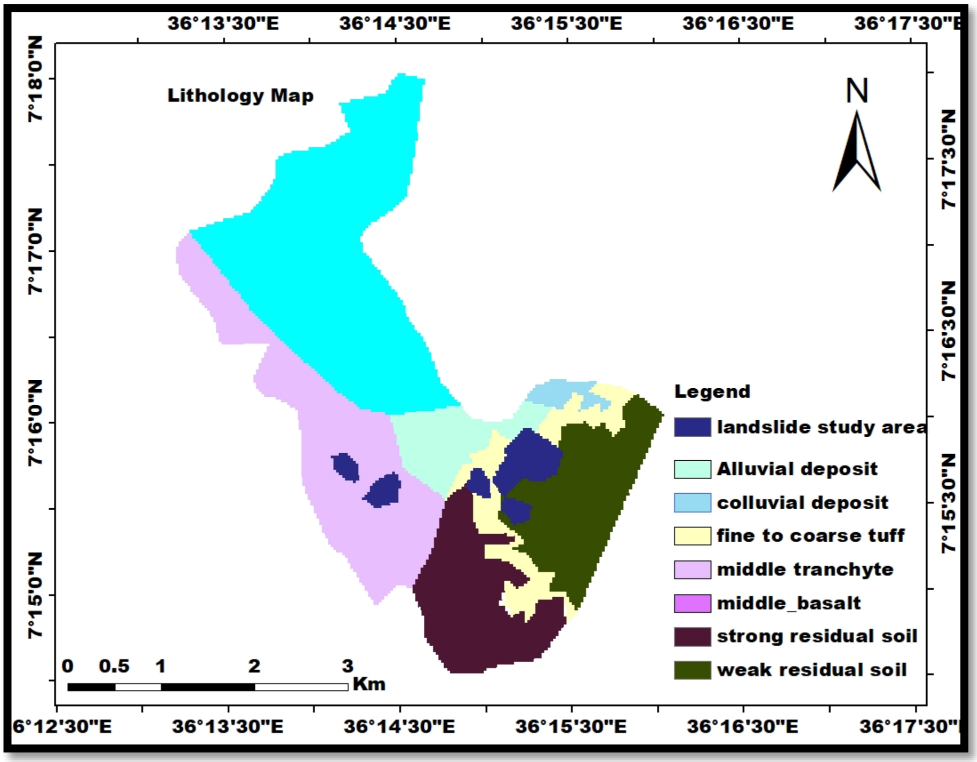


Figure 5.4 lithological map study area

Table 5.3 Information values (IV) for lithology

Lithology	Npix {Bi}	Npix {SBi}	Npix {A}	Npix {TS}	CP	PP	WBi	IV
Middle basalt	3060	180	14531	811	0.0588	0.056	1.054	0.023
Middle trachyte	5030	144	14531	811	0.0286	0.056	0.513	-0.29
Alluvial deposit	909	0	14531	811	0	0.056	0	0
colluvial	206	33	14531	811	0.16	0.056	2.87	0.458
Strong residual soil	1927	7	14531	811	0.0036	0.056	0.065	-1.19
Weak residual soil	2138	170	14531	811	0.0795	0.056	1.425	0.154
Tuff	1261	277	14531	811	0.2197	0.056	3.936	0.595
	14531	811						

5.2.4 Landslide correlation with land use and land cover

Using the Maximum Likelihood classifier in ArcGIS v10.8, supervised classification was used to create the land use/land cover map from the landsat-8 data. It is represents the most contributing element to the landslide, resulting from the six caustic factors. LULC was divided into three categories: built-up areas, bare land, and forest land (fig.5.5). The forest land IV mode shows a weak correlation (-0.042 IV value) between landslide occurrence and lass influence. Building areas and bare terrain have a strong correlation with landslides; the statistical IV is 0.0003 and 0.04 positive values (Table 5.4). Thus, the areas with the highest prospect of experiencing landslides are those with bare soil and built-up areas. Slope instability is increased on barren or thinly vegetated slopes because they are typically subject to erosion (Sharma et al., 2012). Cliffs and grassland areas that are typically subject to erosion are considered bare lands. Ground sliding has a greater impact on cliffs and barren ground without any grassland than it does on other types of land usage.

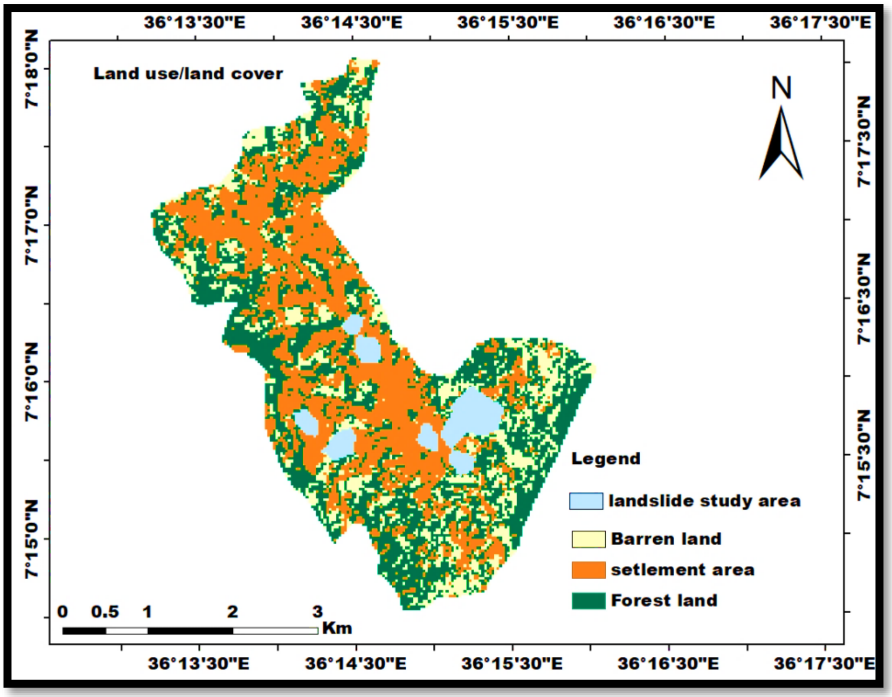


Figure 5.5 land uses and land cover map study area

Table 5.4 Information values (IV) for land use land cover

Land use land cover	Npix {Bi}	Npix {SBi}	Npix {A}	Npix {TS}	CP	PP	WBi	IV
Barren land	2256	126	14531	811	0.056	0.056	1.001	0.0003
Forest land	6312	320	14531	811	0.051	0.056	0.908	-0.042
Settlement Area	5963	365	14531	811	0.061	0.056	1.097	0.040
	14531	811						

5.2.5 Landslide correlation with drainage density

Drainage flow erodes slopes; there is a greater chance of slope failure in the locality of drainage density. As the end result of the IV correlation caustic factor, drainage density has a fourth contribution to landslide occurrence in the study area. The drainage density is classified into five classes based on literature, such as very low (<2), low (2–3), medium (3–4), high (4-5), and very high (>5) **(Table 5.5).** The information value model has a very low drainage density statistical value of -0.033, presenting a negative value indicating less correlation and a weak contribution of landslide occurrence. The drainage density has an information value of 0.679, and the 0.376 low and moderate drainage value shows a positive IV, which is greatly correlated and has a strong contribution Weathering rocks and soils lose their current research area because some of their shear strength is a result of drainage. The drainage density, both high and very high, has no correlation to landslides, indicating a null value.

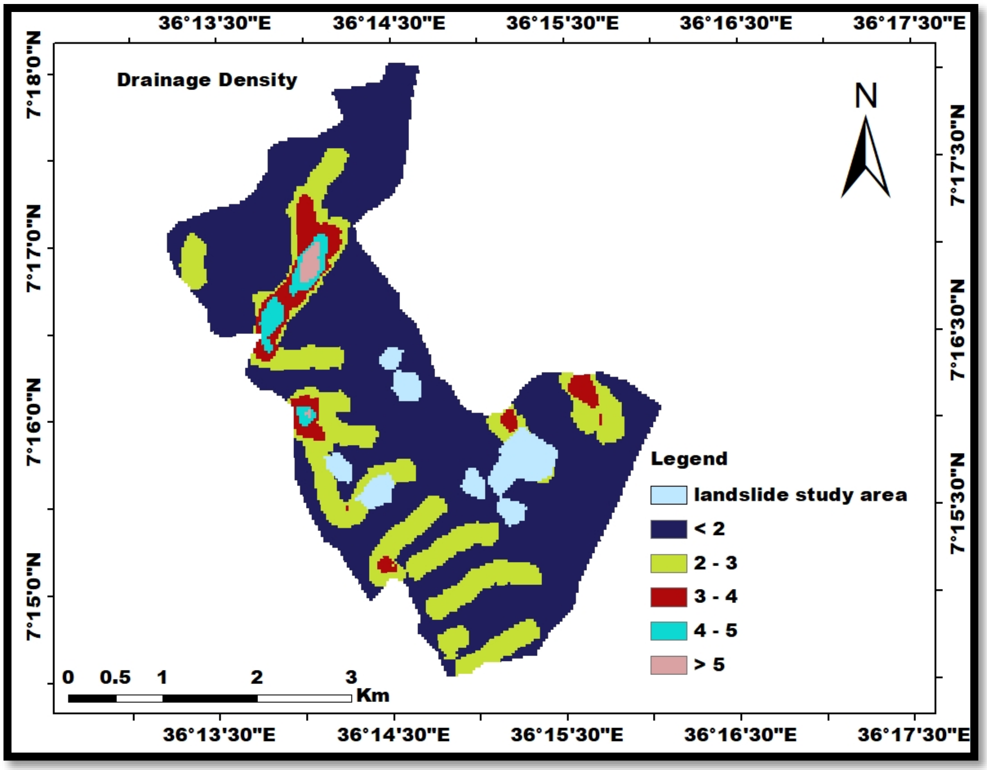


Figure 5.6 drainage density map study area

Table 5.5 Information values (IV) for drainage density

drainage density(km/km2)	Npix {Bi}	Npix {SBi}	Npix {A}	Npix {TS}	CP	PP	WBi	IV
<2	10797	559	14531	811	0.052	0.056	0.928	-0.033
2-3	3043	200	14531	811	0.083	0.056	4.775	0.679
3-4	391	52	14531	811	0.133	0.056	2.375	0.376
4-5	224	0	14531	811	0	0	0	0
>5	76	0	14531	811	0	0	0	0
	14531	811						

5.2.6 Landslide correlation with relative relief

There are five ranges in the relative relief class that correspond to the various appearances of lithological units, taking into account variations in thickness at both the highest and lowest point of the level. In comparison have six caustics factor information value models, with this relative relief as the least influence of landslide. It classes range values according to literature review is indicated; <50 m, 50-100m,101-200m, 201-300m, and >300m. The information value model calculation positive value shows great relation with landslide and strong influence in landslide occurrence whereas negative value indicates less influence. The relief classes are 50-100 m and have positive statistical information values of 0.123m respectively and high contribution. Relative relief class ranges <50 m and 101-200 m have statistical IV values -0.876 and -0.079 are negative indicating a weak correlation as shown below **(table 7.6).** The range value 201-300 m and >300 m do not correlate landslide because the result value show zero.

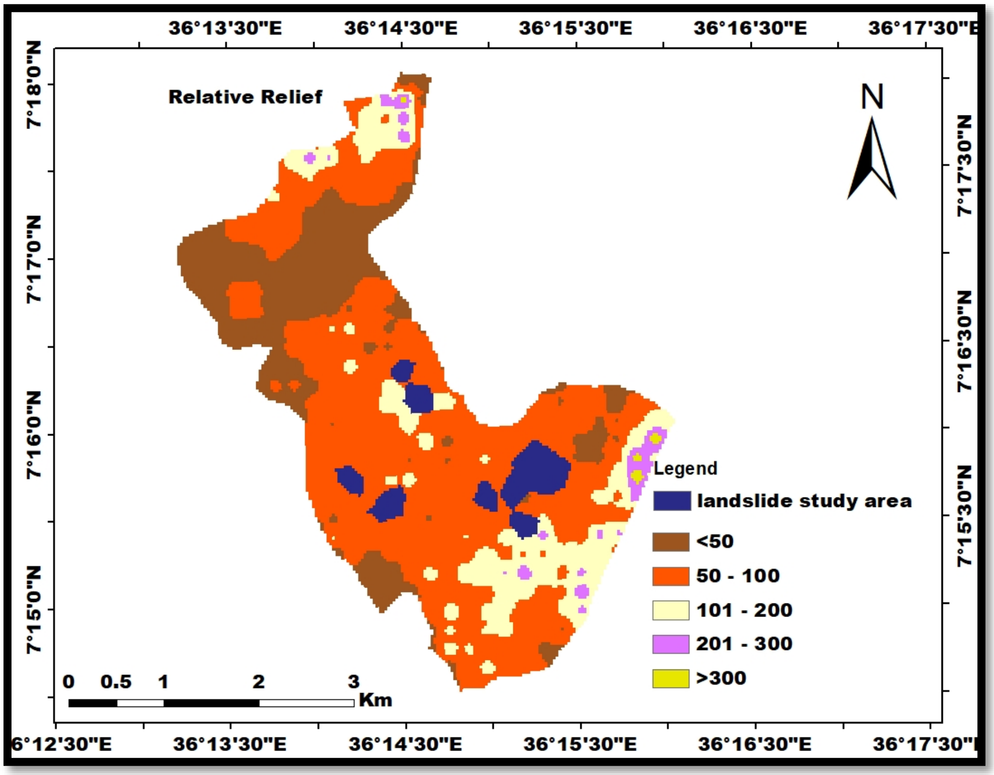


Figure 5.7 relative relief map of study area

Table 5.6 Information values (IV) for relative relief in the study area

Relative Relief	Npix {Bi}	Npix {SBi}	Npix {A}	Npix {TS}	CP	PP	WBi	IV
<50m	3122	24	14531	811	0.0077	0.056	0.138	-0.861
50-100m	9077	686	14531	811	0.0756	0.056	1.354	0.132
101-200m	2169	101	14531	811	0.0466	0.056	0.834	-0.079
201-300m	124		14531	811	0	0.056	0	0
>300m	39		14531	811	0	0.056	0	0
	14531	811						

5.3 Prominent Classes among Various Causative Factor Class

A landslide is a difficult process, and different causative factors contribute to its occurrence. Information value calculated (Table 5.7) indicates the relative importance of the factors in contributing landslide hazard zonation. From the result, The factor class with the highest information value shows slope angle (5^0-12^o) is more disposed; the slope aspect, which is trending towards the north, is highly disposed; similarly, building and barren land, tuff, low drainage density (2-3) km/km2, and relative relief (50-100)m, whose values contain 0.0401, 0.595, 0.679, and 0.132, are highly prone to slope instability. But, the remaining others factors were taken as medium to the lowest influencing factors in this work. However, they play their own contribution on the formation of existing landslidein the study area

Table 5.7 the highest information value class of study area

Causative factor	Class causative factor	Information value
slope	5° -12°	0.0524
land use /land cover	Building area	0.0401
Slope material	fine to coarse tuff	0.595
Drainage density	(2-3)km/km2	0.679
Aspect	North	0.329
relative relief	(50-100)m	0.132

5.4. Weighted layers Combination Using raster calculation

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 hazard zonation. Statistical information values are assigned to each factor class to obtain weighted factor maps. These weighted factor maps were rasterized using look-up tool in a spatial analysis. After rasterizing all causative factor maps the landslide susceptibility index map for each pixel were formed by summing-up using a raster calculator in Map Algebra

LSI= IV slope +IV aspect +IV lithology + IV LuLc + IV drainage density+ IV relative relief

Finally, the landslide hazard zonation map is classified into three zonal class levels, low zone, moderate zone and high zone

5.5 Landslide hazard zonation and its distribution

The landslide hazard zonation map prepared for this study was classified into three classes and its area coverage was calculated. Accordingly, 3.64 km2 (27%) falls into the low zone class, 5.9 km2 (43%) of the area falls into moderate zone class, and 4.2km2 (31%) of the area falls into high zone class of the total study area respectively (Table). Based on the result obtained, the final map was prepared (Fig 5.7). The result of the study shows that the spatial distributions of landslide hazard are distributed throughout the study area. However, landslide hazard areas were mostly inhabited towards the northwest and western part of the study area. The moderate danger zones in the present study area are generally characterized by relatively softer slopes with unconsolidated material. The slope material in this zone is composed of colluvial soil, residual soil deposit, and weathered rock mass, with a relatively high degree of weathering. Slopes that are moderately steep to steep are a common indicator of high-hazard zones. As result many researchers agree with that landslide hazard is a product of many factors particularly slope which has a great influence (Teferi, 2005; Chen et al., 2016; Ermias et al., 2017; Mengistu et al., 2019). The landslide-prone area relative to the entire area is used in the relation analysis; a greater value relative to other classes implies a greater correlation, while a lower value suggests a lesser correlation. LSI range value is indicated from 1.8 the maximum to -3.5 minimum. From the range value result LHZ was prepared and distribution was categorized into three classes: low, moderate, and high.

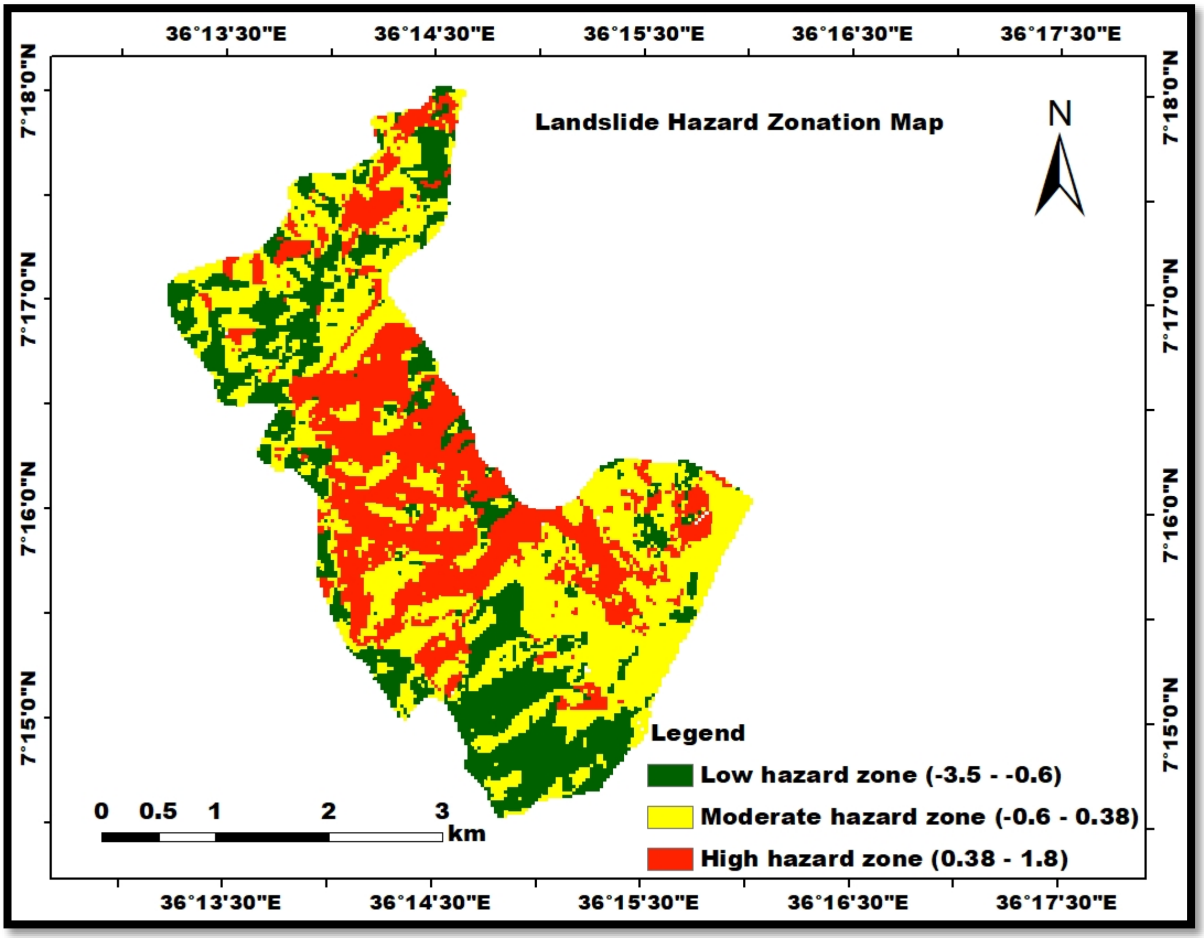


Figure 5.8 Landslide Hazard Zonation Map of Study areas

Table 5.8 Landslide hazard zonation class based on landslide susceptibility index

Landslide hazard zonation class	**The landslide susceptibility index rang**	**landslide hazard zonation class coverage**			**past landslide class coverage**			**landslide density (B/A)**
		pixel count	Area (km2) (A)	Area in (%)	pixel count	Area (km2) (B)	Area in (%)	
Low	-3.5 - -0.56	3863	3.643	26.6	30	0.51	3.7	0.139098
moderate	-0.56 - 0.38	6248	5.892	43	319	5.389	39.3	0.914481
high	0.38 – 1.8	4415	4.164	30.4	462	7.80	57	1.874289

5.6 Validation of Landslide Hazard Zonation Map

The landslide hazard analysis result is verified using known landslide locations (Woldearegay, 2005). In this present study about seven (7) ground truth data showing the existing landslide were collected. Accordingly, the inventory data was overlaid with landslide hazard map and it was used as LHZ validation (Fig 5.8). 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, (71%) of five of past landslides fall within moderate zone of the prepared landslide hazard zonation map while (21%) of two past landslides fall in high-hazard. The remaining of (8%) one past landslides fall in low-hazard. Generally 96% of the old landslides were validated by the landslide hazard zonation map prepared in the study area (figure.). Furthermore, according to the value calculation of the landslide density result classified LHZ as medium, high, and low zones classes are 0.915, 0.139 and1.87 respectively (Table 5,8), According to Sarkar et al. (2008), there is a direct correlation between the density of landslides and the degree of hazard to them. From a level of low to high zone, and vice versa the landslide density value has grown. It was also confirmed in the field that the study areas are sensitive.

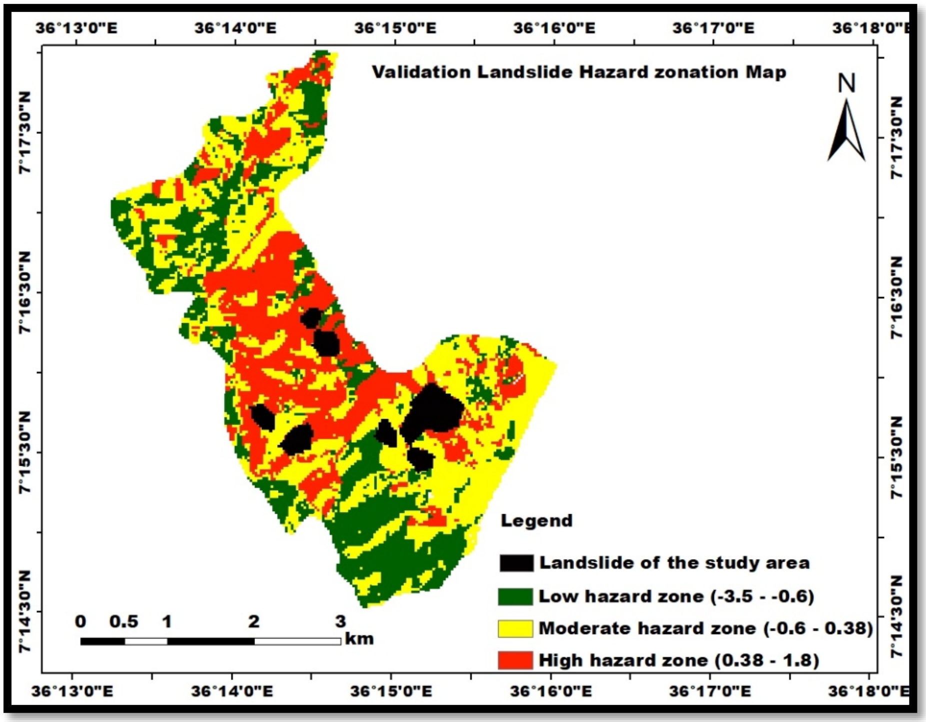


Figure 5.9 Validation of Landslide Hazard Zonation Map of Study Area

CHAPTER SIX

. 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The present study area is located in south western Ethiopia plateau with keffa zone the total surface area 13.7 square kilometer. It is characterized by uneven topography with maximum elevation of 1940m. The area is fall under woynadega (subtropical) climate zone and the mean annual rainfall 1470mm.the regional geology of the area Tertiary volcano rocks, Precambrian crystalline basement and quaternary alluvial and colluvial sediment. The local geology of the study area composed of unconsolidated alluvial, colluvial and residual deposits; tuff, trachyte and basalt. The main objective of the present study is to prepare landslide hazard zonation map in the area Bonga town, southwest. Landslide hazard zonation of the study area carried out based on information value model approach. The study was carried out in pre field, field and post field investigation.

The bivariate statistical method, information value model decision analysis, and the available spatial datasets were used to prepare a landslide hazard zonation map in the Bonga town southwestern Ethiopia. For the present study six causative parameters selected such as; slope, aspect, lithology, land use/ land cover, drainage density and relative relief considered. Later information value was calculated based on relative influence causative factors on past landslide. Seven past landslides in the town are mapped to prepare the landslide inventory mapping of the study area. This landslide inventory map was finally used to verify the prepared landslide hazard map of the Bonga town. The causative factors were reclassified and the values were assigned for each classes of the factors based on their landslide hazard zonation. Their weights which were derived by information value model process indicate that the influence of each factor for Landslide hazard zonation value for each pixel within the study area has been obtained using by summing up the weight derived for that pixel in all of the factor maps. The result of landslide susceptibility index map has been classified in three landslide hazard zonation class. The factor class with the highest information value shows slope angle (5^0-12^o) is more disposed; the slope aspect, which is trending towards the north, is highly disposed; similarly, building and barren land, tuff, low drainage density (2-3) km/km2, and relative relief (50-100) m, whose values contain 0.0401, 0.595, 0.679, and 0.132, are highly prone to slope instability.

Lastly, the sum totals of all weighting parameters were developed to prepare the LHZ map using raster calculation Arc-GIS software. Accordingly, 3.64 km2 (27%) falls into the low zone class, 5.9 km2 (43%) of the area falls into the moderate zone class, and 4.2 km2 (31%) of the area falls into the high zone class of the total study area respectively. As a result, from the total number of landslide inventory data, (71%) of five past landslides fall within the moderate zone of the prepared landslide hazard zonation map while (21%) of two past landslides fall in high hazard. The remaining (8%) one past landslides fall in low-hazard. Generally, 96% of the old landslides were validated by the landslide hazard zonation map prepared in the study area. So, the factors that were taken to model landslide hazard and the method that was used in the study are in satisfactory agreement with the prepared landslide hazard zonation map.

6.2 Recommendations and Mitigation

- Given the variety and broad nature of the causes of slope instability in the current study area, an integrated remedial approach may be a better option to reduce the possibility of a landslide in the area.
- At the base of weak tuff, residual-colluvial soils, accumulations can have a sizable volume and a poor stability reserve. More detailed slope stability studies are required along the main road which falls in the high landslide hazard class to suggest the remedial measures or to manipulate the main road.
- There is a likelihood of future slope instability issues in areas classified as high landslide hazard zones. Therefore, it is advised to do a more thorough slope stability analysis before moving forward with any future settlements and infrastructure development in this class.
- Educating the urban community to take care of forests and soil to reduce the damage caused by the ruggedness of the land in the town and other landslides combined with the weakness of the underlying soil.

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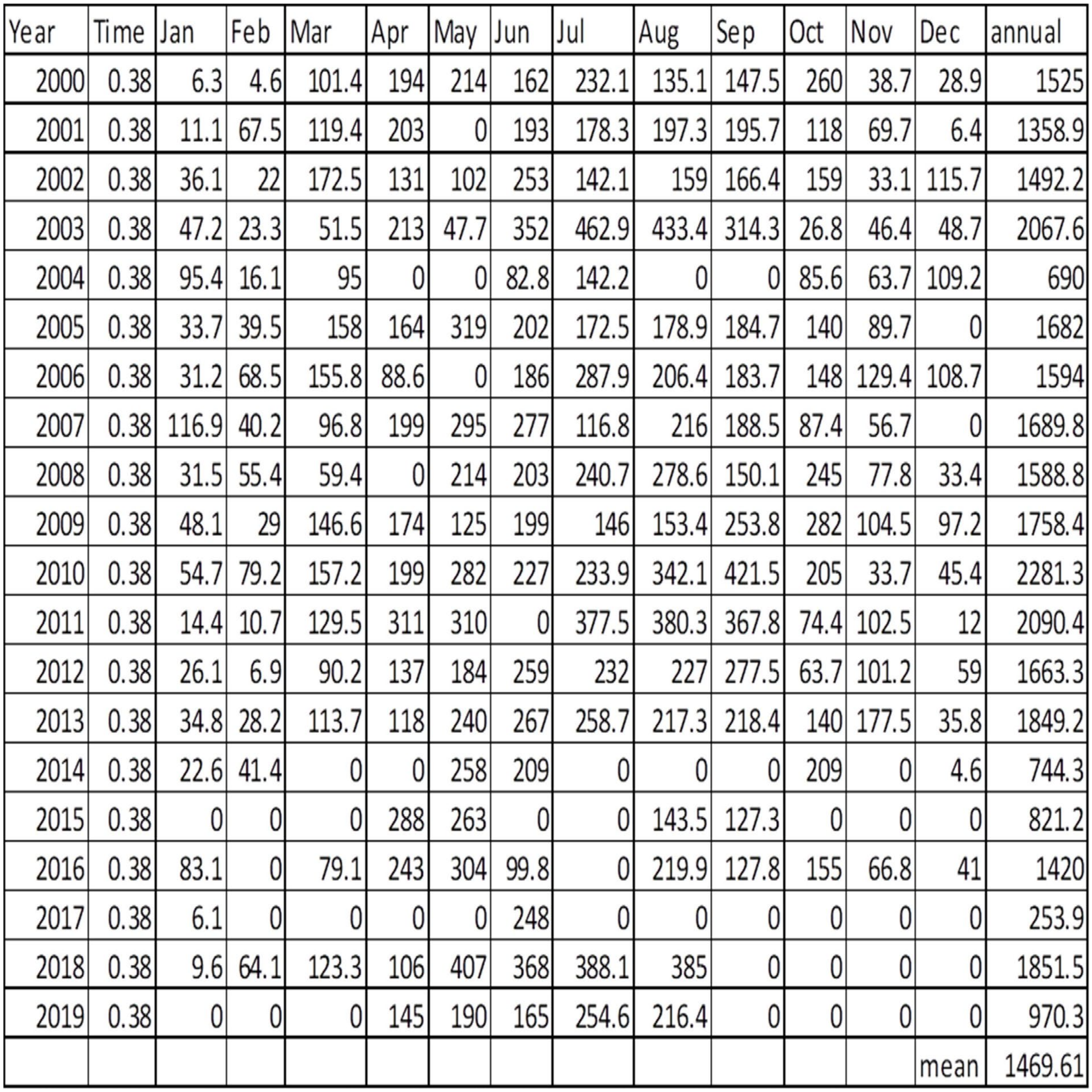
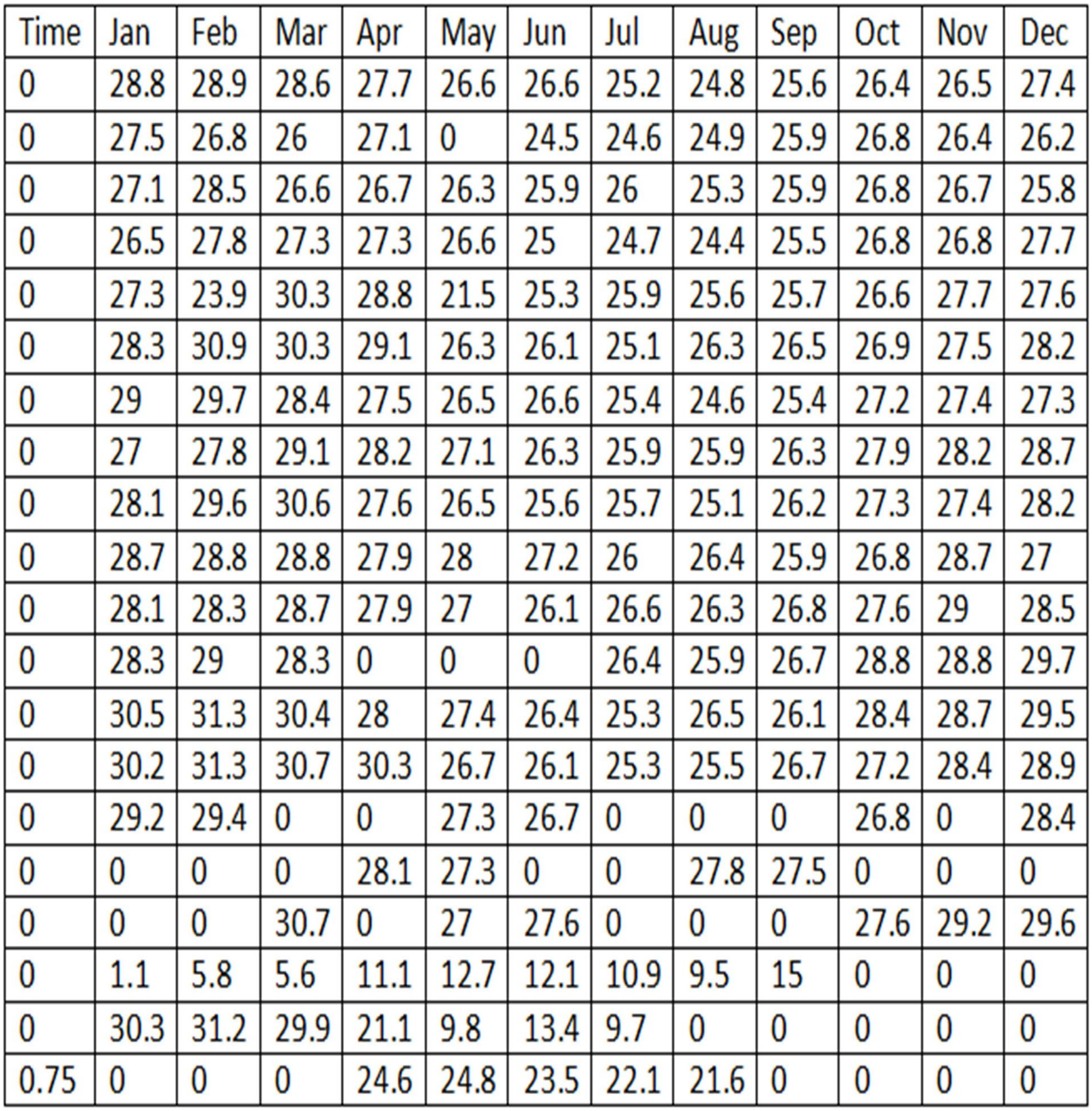
APPENDIX

Appendix-i: **Monthly rainfall distribution source from the meteorology agency of Ethiopia for Bonga Town station**



Year	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
2000	0.38	6.3	4.6	101.4	194	214	162	232.1	135.1	147.5	260	38.7	28.9	1525
2001	0.38	11.1	67.5	119.4	203	0	193	178.3	197.3	195.7	118	69.7	6.4	1358.9
2002	0.38	36.1	22	172.5	131	102	253	142.1	159	166.4	159	33.1	115.7	1492.2
2003	0.38	47.2	23.3	51.5	213	47.7	352	462.9	433.4	314.3	26.8	46.4	48.7	2067.6
2004	0.38	95.4	16.1	95	0	0	82.8	142.2	0	0	85.6	63.7	109.2	690
2005	0.38	33.7	39.5	158	164	319	202	172.5	178.9	184.7	140	89.7	0	1682
2006	0.38	31.2	68.5	155.8	88.6	0	186	287.9	206.4	183.7	148	129.4	108.7	1594
2007	0.38	116.9	40.2	96.8	199	295	277	116.8	216	188.5	87.4	56.7	0	1689.8
2008	0.38	31.5	55.4	59.4	0	214	203	240.7	278.6	150.1	245	77.8	33.4	1588.8
2009	0.38	48.1	29	146.6	174	125	199	146	153.4	253.8	282	104.5	97.2	1758.4
2010	0.38	54.7	79.2	157.2	199	282	227	233.9	342.1	421.5	205	33.7	45.4	2281.3
2011	0.38	14.4	10.7	129.5	311	310	0	377.5	380.3	367.8	74.4	102.5	12	2090.4
2012	0.38	26.1	6.9	90.2	137	184	259	232	227	277.5	63.7	101.2	59	1663.3
2013	0.38	34.8	28.2	113.7	118	240	267	258.7	217.3	218.4	140	177.5	35.8	1849.2
2014	0.38	22.6	41.4	0	0	258	209	0	0	0	209	0	4.6	744.3
2015	0.38	0	0	0	288	263	0	0	143.5	127.3	0	0	0	821.2
2016	0.38	83.1	0	79.1	243	304	99.8	0	219.9	127.8	155	66.8	41	1420
2017	0.38	6.1	0	0	0	0	248	0	0	0	0	0	0	253.9
2018	0.38	9.6	64.1	123.3	106	407	368	388.1	385	0	0	0	0	1851.5
2019	0.38	0	0	0	145	190	165	254.6	216.4	0	0	0	0	970.3
													mean	1469.61

Appendix-ii**: Mean monthly maximum and minimum temperature source from the meteorology agency of Ethiopia for Bonga station**



Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	28.8	28.9	28.6	27.7	26.6	26.6	25.2	24.8	25.6	26.4	26.5	27.4
0	27.5	26.8	26	27.1	0	24.5	24.6	24.9	25.9	26.8	26.4	26.2
0	27.1	28.5	26.6	26.7	26.3	25.9	26	25.3	25.9	26.8	26.7	25.8
0	26.5	27.8	27.3	27.3	26.6	25	24.7	24.4	25.5	26.8	26.8	27.7
0	27.3	23.9	30.3	28.8	21.5	25.3	25.9	25.6	25.7	26.6	27.7	27.6
0	28.3	30.9	30.3	29.1	26.3	26.1	25.1	26.3	26.5	26.9	27.5	28.2
0	29	29.7	28.4	27.5	26.5	26.6	25.4	24.6	25.4	27.2	27.4	27.3
0	27	27.8	29.1	28.2	27.1	26.3	25.9	25.9	26.3	27.9	28.2	28.7
0	28.1	29.6	30.6	27.6	26.5	25.6	25.7	25.1	26.2	27.3	27.4	28.2
0	28.7	28.8	28.8	27.9	28	27.2	26	26.4	25.9	26.8	28.7	27
0	28.1	28.3	28.7	27.9	27	26.1	26.6	26.3	26.8	27.6	29	28.5
0	28.3	29	28.3	0	0	0	26.4	25.9	26.7	28.8	28.8	29.7
0	30.5	31.3	30.4	28	27.4	26.4	25.3	26.5	26.1	28.4	28.7	29.5
0	30.2	31.3	30.7	30.3	26.7	26.1	25.3	25.5	26.7	27.2	28.4	28.9
0	29.2	29.4	0	0	27.3	26.7	0	0	0	26.8	0	28.4
0	0	0	0	28.1	27.3	0	0	27.8	27.5	0	0	0
0	0	0	30.7	0	27	27.6	0	0	0	27.6	29.2	29.6
0	1.1	5.8	5.6	11.1	12.7	12.1	10.9	9.5	15	0	0	0
0	30.3	31.2	29.9	21.1	9.8	13.4	9.7	0	0	0	0	0
0.75	0	0	0	24.6	24.8	23.5	22.1	21.6	0	0	0	0

Appendix-iii: **Field visiting GPS data collection**

Station No.	location		place	Damage on property
	Northing	Easting		
1	0196759	0803581	980 is a unique name area around the mission area	Destruction of houses and property.
2	0196727	0803701	980 is a unique name of an area	It caused damage of house property
3	0196968	0803642	980 is a unique name of an area	It caused damage on house property. The people changed his settlement to other place.
4	0196959	0803664	980 is a unique name of an area	150 people displaced their home.
5	0196396	0803681	An old clinical health office	It caused damaged house
6	0196379	0803705	Mikael church	It caused damaged coble stone road and house
7	0195751	0804462	Kebele 02 in front of administration place	It caused damaged the main asphalt road
8	0195669	0804552	Kebele 02	It caused damaged infrastructure and fiancé
9	0194880	0803794	Police station Brethren area	It is caused damaged old asphalt and house
10	0194921	0803766	Brethren area	It caused damaged farm land