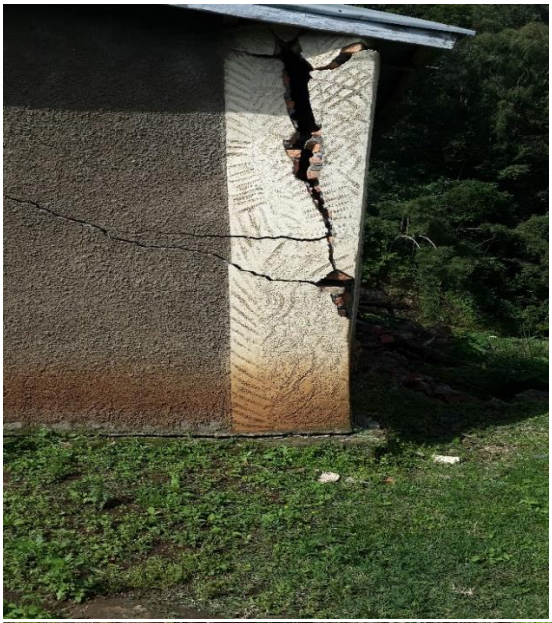
Landslide Hazard Zonation around Ameya Town Konta Special Woreda, South Nation Nationality People Region, Ethiopia

Awoke Feleke

A Thesis Submitted to

School of Earth Sciences





Presented in partial fulfillment of the requirements for the degree of Masters of Sciences Engineering geology (Environmental Geology and Geo-hazard).

ADDIS ABABA UNIVERSITY

Addis Ababa, Ethiopia

May 2021

Landslide Hazard Zonation around Ameya Town Konta Special Woreda,

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This is to certify that the thesis prepared by: **Awoke Feleke**, entitled: "*Landslide Hazard Zonation around Ameya town Konta special Woreda S/N/N/P/Region, Ethiopia*" and submitted in partial fulfillment of the requirements for the Degree of Master of Science Engineering Geology (Geo-Hazard) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

In the present study, Landslide Hazard Zonation (LHZ) mapping around Konta special woreda Ameya town is carried out by applying Slope Stability Susceptibility Evaluation Parameter (SSEP) rating scheme. The main objective of the study was to prepare the LHZ map of the study area. A field survey was conducted to map the distribution of existing landslides and the factors that affect the landslide occurrences. Field measurements on structural discontinuities and observation on field manifestations for landslide and related slope instabilities were carried out. For digitizing, data processing, and analysis purposes, A GIS environment was used. In applying the SSEP rating scheme, the relative contribution of each of the intrinsic causative and extrinsic triggering factors were evaluated and ratings were assigned for each factor facet-wise. The intrinsic parameters considered are; slope geometry, slope material, structural discontinuities, land use land cover, and groundwater condition whereas, the external triggering factors are; seismicity, rainfall, and man-made activities. The total of all ratings for causative intrinsic parameters and external triggering factors are represented as Evaluated Landslide Hazard (ELH) established on which the study area is divided into different hazard zones as per the SSEP rating scheme. Then after these the LHZ map of the study area was produced. The prepared LHZ map has identified three zones, namely Very High Hazard (5.12%), High Hazard (66.73%) and Moderate Hazard (28.15%). Finally, the LHZ map was overlaid by past landslide event data out of which 12 % have fallen in the Very High Hazard zone, 72% High Hazard zone the rest 16 % fall in the moderate hazard confirming the validity of the prepared LHZ map. Thus, the satisfactory validation confirms the rationality of considered parameters, the adopted SSEP technique, and the tools and procedures in developing the LHZ map of the study area.

Keywords: Landslide Hazard Zonation (LHZ), Evaluated Landslide Hazard (ELH), Intrinsic, Extrinsic, Ameya Ethiopia.

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LIST OF ACRONYMS

DEM	Digital elevation model
FAO	Food and agricultural organization
ELH	Evaluated Landslide Hazard
GIS	Geographic information system
GSE	Geological Survey of Ethiopia
GPS	Global positioning system
LHZ	Landslide Hazard Zonation
TLSI	Total landslide susceptibility index
USGS	United States of Geological Survey
VHH	Very High Hazard
HH	High hazard
MH	Moderate hazard
LH	Low hazard
SSEP	Slope Stability susceptibility Evaluation parameter
VLH	Very low hazard
DRM	Disaster Risk management office

CHAPTER 1 -INTRODUCTION

1.1 Background

Landslides are basically mass-movements of rock, earth, and debris downslope (Cruden and Vernes, 1996). It is occurs in all earthly regions of the world in response to a wide variety of natural circumstances and triggered by the processes of seismic activities and in response to human activity.

Landslides are one of the most destructive phenomena of nature that cause damage to both property and life every year both developed and developing world. The study of landslides has drawn global attention mainly due to increasing awareness of its socio-economic impacts and also increasing pressure of urbanization on the mountain environment (Aleotti and Chowdhury, 1999 as cited in Kanungo et al., 2006).

Landslides are very common in many parts of the highlands and rift escarpment of Ethiopia (Bekele Abebe, et al., 2010; Raghuvanshi et al., 2014; Kifle Woldearegay, 2013). According to Kifle Weldaregay (2013), mostly landslides affecting rural communities' infrastructures, farmlands, dwelling houses, etc. Landslides are major threats to life and property in the mountainous terrains especially during uncontrolled excavation and land use change. Most of the landslides are also occurring in association with the fast-growing urbanization activities such as road construction on mountainous areas.

Ethiopia has been frequently affected from such natural hazards, especially at the foot of mountainous area and at the escarpment of the rift valley (Woldearegay, 2013). Landslide in most parts of the country causes loss in farm production, substantial damage to houses and other properties, besides human injury and fatalities every year(Perissin et al., 2008). The major component that adds to the increase in number of landslides in Ethiopia is rural road construction, rapid change in land use and land cover as well as intense rainfall. Further, complex geologic and geomorphic factors have also been contributed significantly to the landslides in the highlands of Ethiopia(Greif et al., 2015).

The southern south western Highlands of Ethiopia have been repeatedly experiencing large-scale of landslide events. The Konta special woreda is one of the most landslide prone areas located at the west of the southern rift margin of Ethiopia.

1.2 Statement of the problem

According to Eberhardt (2003), Landslides, continue to have a significant social, economic, and environmental impact in mountainous areas despite advances in identification, prediction, and mitigation steps. He attributes this to the difficulty of the processes that cause slope failures, as well as our lack of understanding of the underlying mechanisms. Experts are increasingly being called upon to determine and forecast the stability of a given slope, determining its risk, potential failure mechanisms and velocities, areas at risk, and possible remedial steps, he added.

The southern and south western part of Ethiopia is known for its dense forest and mountain ranges and high lands. According to Lulseged (L. Ayalew, 1999) the Ethiopian Highland is a highly populated region, in which more than 60% of the country's population is settled. Due to this and other causes and triggering factors, landslides are observed in different places of this region. Konta special woreda is amongst towns of Ethiopia, which are located in high lands and the area is covered with thick forest and have a visible signs of landslide in different places which some of them affect the infrastructures and others remain in areas with no major infrastructures. Like most parts of Ethiopia, this area lacks proper investigation of landslide, mapping and zoning.

Landslides are the major geological hazards in the study area. This phenomenon is mainly associated with misplaced settlements, failure of infrastructures (road and buildings), Farmlands, and poor (no) zoning (evacuation zone, alert zone and safe zone) are observed facts in the area. This in part has its own impact on the socio economic aspect of the society. Therefore, this studies will reduce those problems by zoning the landslide susceptible area investigation and identification of the landslides and landslide susceptible areas. In the study area in September 2019 there was a high landslide was occurred and there was 23 people died and 5 house was completely destroyed. The present study have prepared landslide hazard zonation map to minimize such kind of problem and the area covers around Ameya town which include the five neighboring kebele.

1.3. Objectives

1.3.1. Main objective

- The main objective of the present study is to evaluate the landslide hazard in the area and to produce the landslide hazard zonation (LHZ) Map.

1.3.2. Specific objectives

- To identify the types of landslides occurring in the study area,
- To carry out landslide inventory of the study area.
- To assess the causative and triggering factors responsible for landslides.
- To produce landslide hazard zonation (LHZ) of the study area.
- To validate the LHZ map with prepared general inventory of past landslide activities.

1.4. An overview of the study area

1.4.1 Location

The present study area is located in south western Ethiopia, South Nations Nationalities Peoples Regional State (SNNPRS), and Konta special Woreda. Geographically the study area is located between 7°3'N to 7°9'N latitude and36°37' E to 37°43' E longitude with a total coverage area of 48km^2. The study area include five kebele as shown in the (fig 1.1) Chere kebele 15.84% of the study area, (in the northern and north eastern part) bubadamota kebele 14.81% of the study area (in the north western part), chekabocha kebele 36.69% of the study area (in the south western part), Ameya town 17.70% of the study area (in the central and eastern part), Dukazale kebele 14.98% (in the eastern part) of the study area.

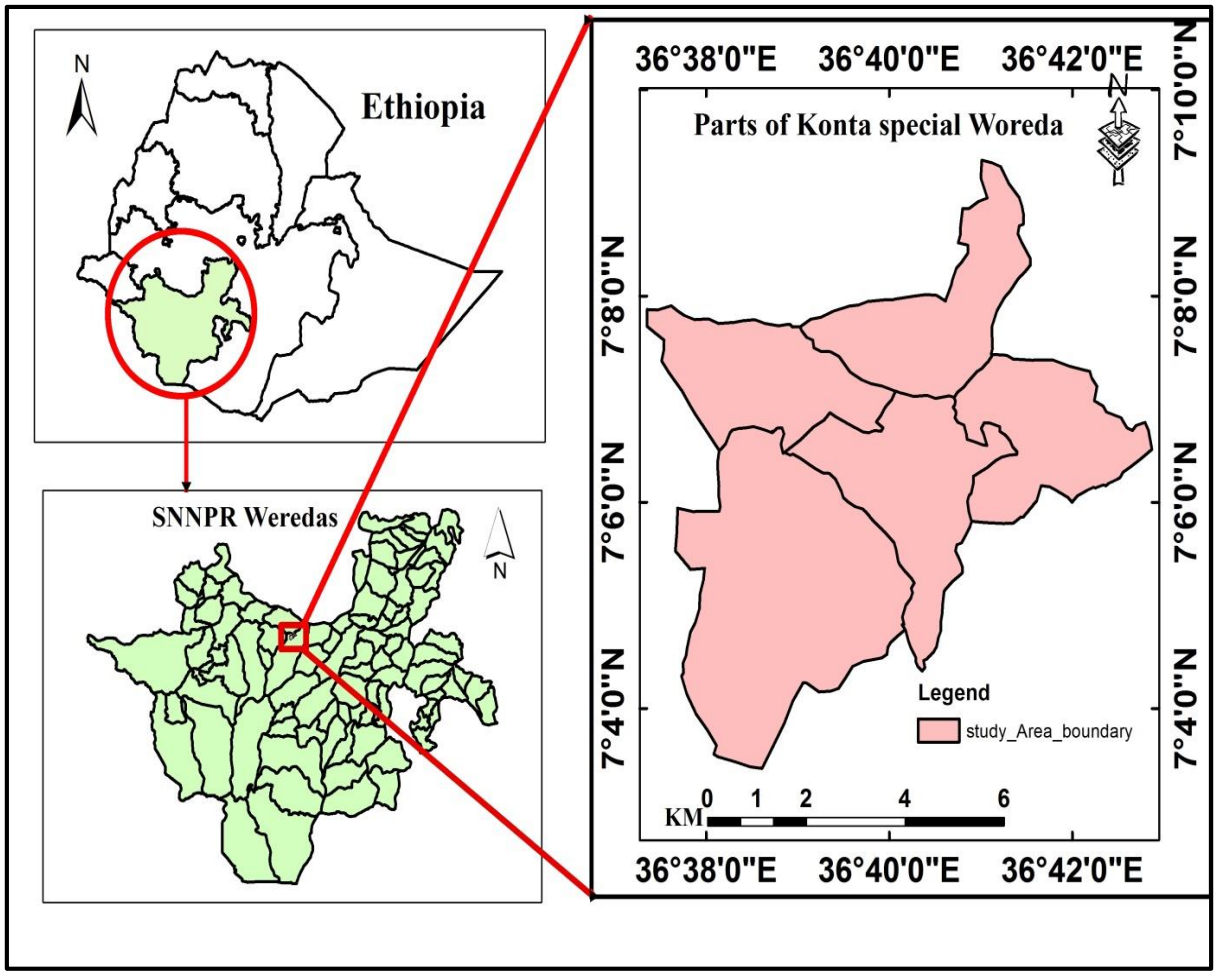


Figure1. 1 Location Map of the Study

1.4.2. Accessibility

The study area is located 458KM from Addis Ababa the capital city of Ethiopia (Fig 1.1). It is accessible by asphalt road from Addis Ababa to Jimma asphalted road covers 350Km while from Jimma- through Chida by gravel road then from Chida to Ameya by asphalt road. It covers 108Km. the study area currently, there is a new road alignment under construction that extends from Jimma –Chida town.

1.4.3 Climate

As metrological agency stated that Ethiopia has three seasons those are; Belg, (February-May) is the small rainy season in Ethiopia. Much of the northeastern, central, southern, southwestern, eastern and southeastern parts of the country receive considerable amount of rainfall during this season. The second one is Kiremt (June-September) is the main rainfall season for most parts of the country except for the lowlands of southern and southeastern Ethiopia, and the last one is Bega (October-January) is mostly a dry season for most parts of the country except for

southwestern as well as the lowlands of south and southeast Ethiopia (NMA, 2012). As stated in (Birhanu Ermias, 2014). In addition to this according to Danel Gemechu (1997) climate can be classified with respect to elevation as Desert climatic zone (Bereha), Tropical (Kola), Subtropical (Weynadega), Temperate (Dega), Alpine (Kur) with elevation <800m, from 800 m-1500 m, from 1500-2300 m, from 2300-3300 m, > 3300 m, respectively. The present study includes the three climate class these area Tropical Kola, sub-Tropical (weynadega) and Temperate (Dega), since it falls within the range of 1411-2891m.a.m.s.l. in elevation. According to Ethiopian Metrological station the maximum temperature recorded in the area is 30.7^0C and 14.9^0C as the minimum temperature

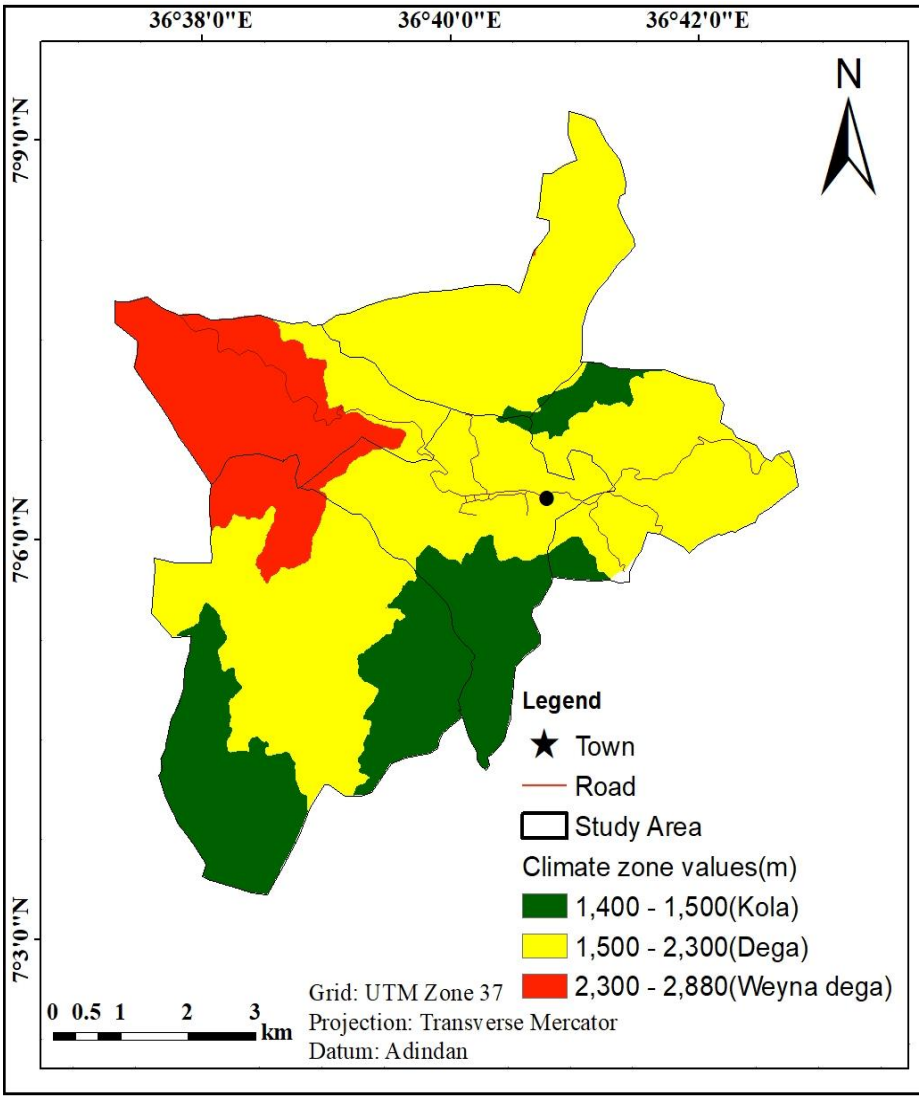


Figure1. 2 Climatic zoning map of the study area

The Chida Meteorological stations are located in the study area that are found in the towns Chida. The Years graph with a full set of data were listed from National Meteorological Agency

of Ethiopia, from the period of 1982 to 2018 for Chida 2003-2018. Long term temperature data is given in Annexure VI and Fig.1.3. The minimum and maximum temperature of Chida range from 11.69°C -25.01°C Annexure VII and Fig. 1.5

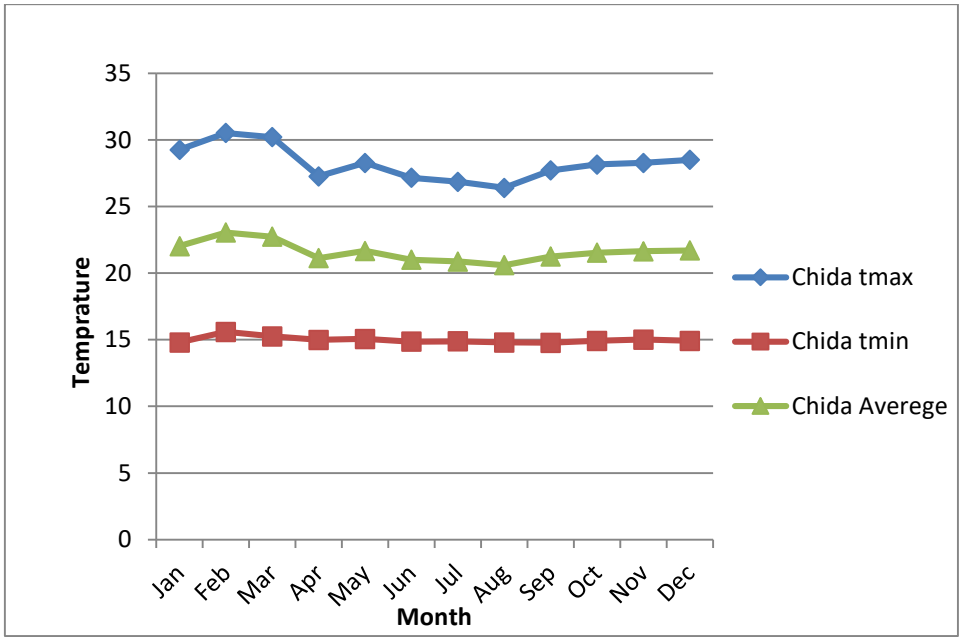


Figure1. 3 Temperature at Chida

Annexure VII and Fig. 1.6 Chida, show precipitation data. A complete set of data for thirty years was available from the Chida meteorological station, and the average precipitation for the thirty years was 1521mm/year.

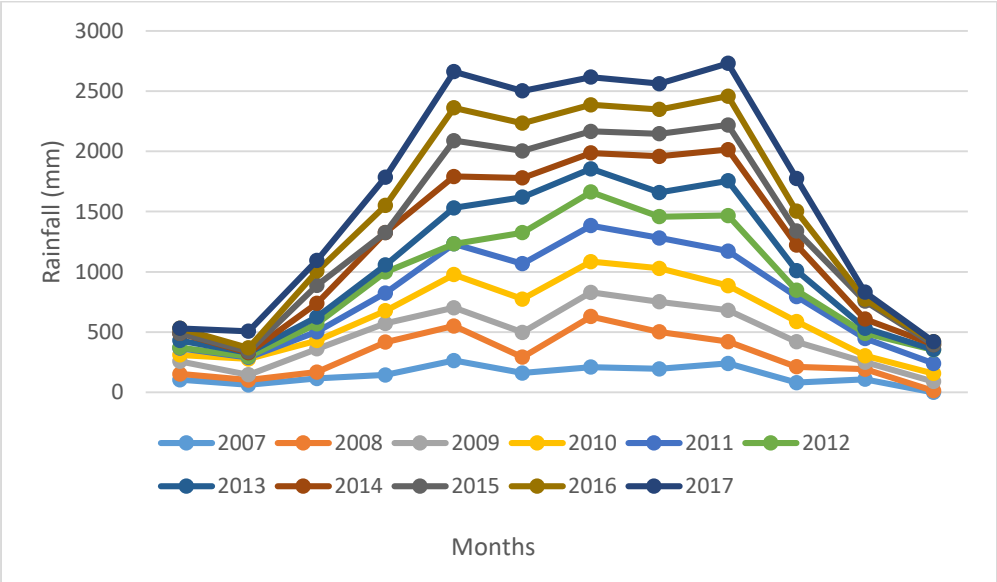


Figure1. 4 Graph showing Rainfall data for Chida town

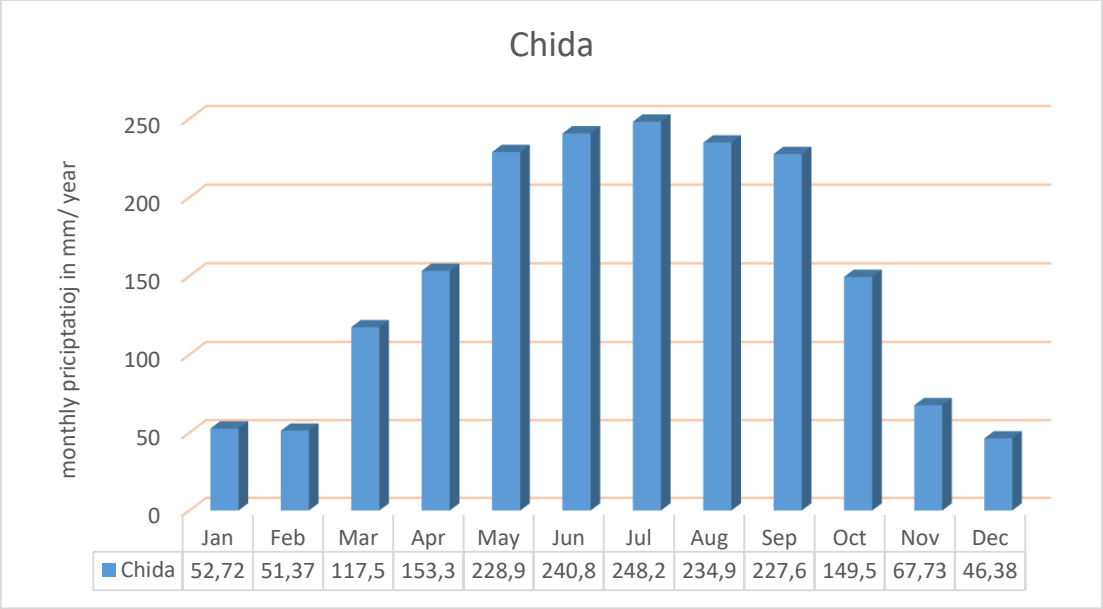


Figure1. 5 Graph showing long term fluctuation of precipitation at the study area

The majority of the significant rainfall in the study area, according to the results from such stations, occurs throughout the summer season, primarily from June to September (Fig 1.6). In November -February, however, rainfall is somewhat low. The rainiest months are July and August, with monthly rainfall ranging from 200 to 250 mm. On the other hand, rainfall tends to be modest during the dry season, which runs from October to May. Generally the prolonged and intensive rainfall has played a great role on aggravating the mass movement in the study area.

1.4.4. Physiography of the study area

The physiography of Ethiopia is an intimate expression of the underlying geology Mohr (1971 as cited in (Birhanu Ermias, 2014). In addition to the uplifting phenomena the present physiographical setting of the study area is also affected by various processes such as weathering and mass wasting activities. The study area is to the west of main Ethiopian rift. The area has a very high rugged topography with a maximum elevation of 2891m.a.s.l around bubadamota kebele whereas a minimum elevation value of 1411m.a.s.l. is found south tip of Ameya town around Chefecha River. The elevation difference between the maximum and minimum elevations with in this specific area is about 1468m which indicates the most likely condition for landslides and related movement to happen in the area. Based on the meteorological data recorded by the Ethiopian National Meteorological Service Agency for 13 years (January 2007 to December 2019), the study area have uni-modal rainfall distribution

with the highest rain falling from June to September. The mean annual rainfall of the study area was 1521.2 mm, and the mean annual temperature was 17.45°C.

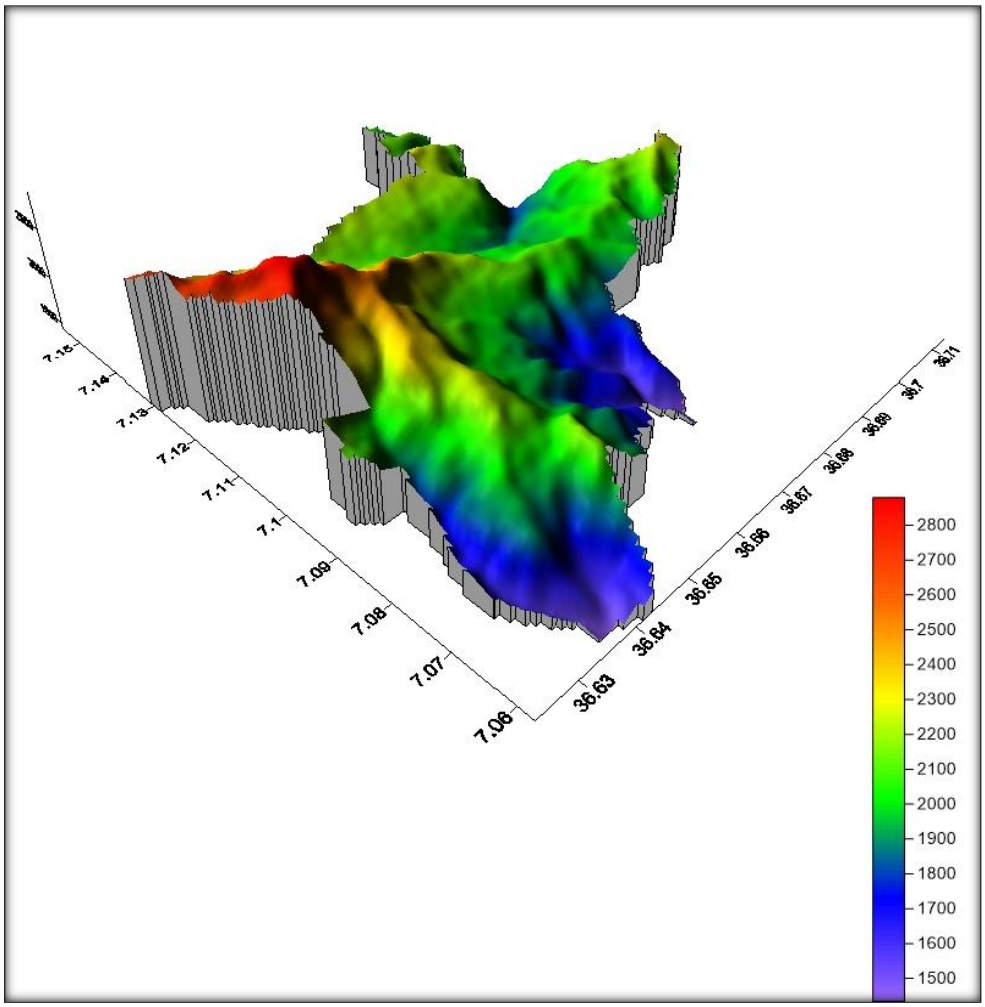


Figure1. 6 Physiographic Map of the study area

1.4.5. Vegetation

Depending on the widespread root system and local geology, vegetation cover can have various effects on land stability; in this case, dense vegetation appears to hold moisture in the soil, reducing shear strength and failure to the sloppy areas ((Lulseged Ayalew & Yamagishi, 2004) Abaynesh Mitiku., 2020).The study area is among the moderately densest forest covered areas as shown in Plate 1. 1

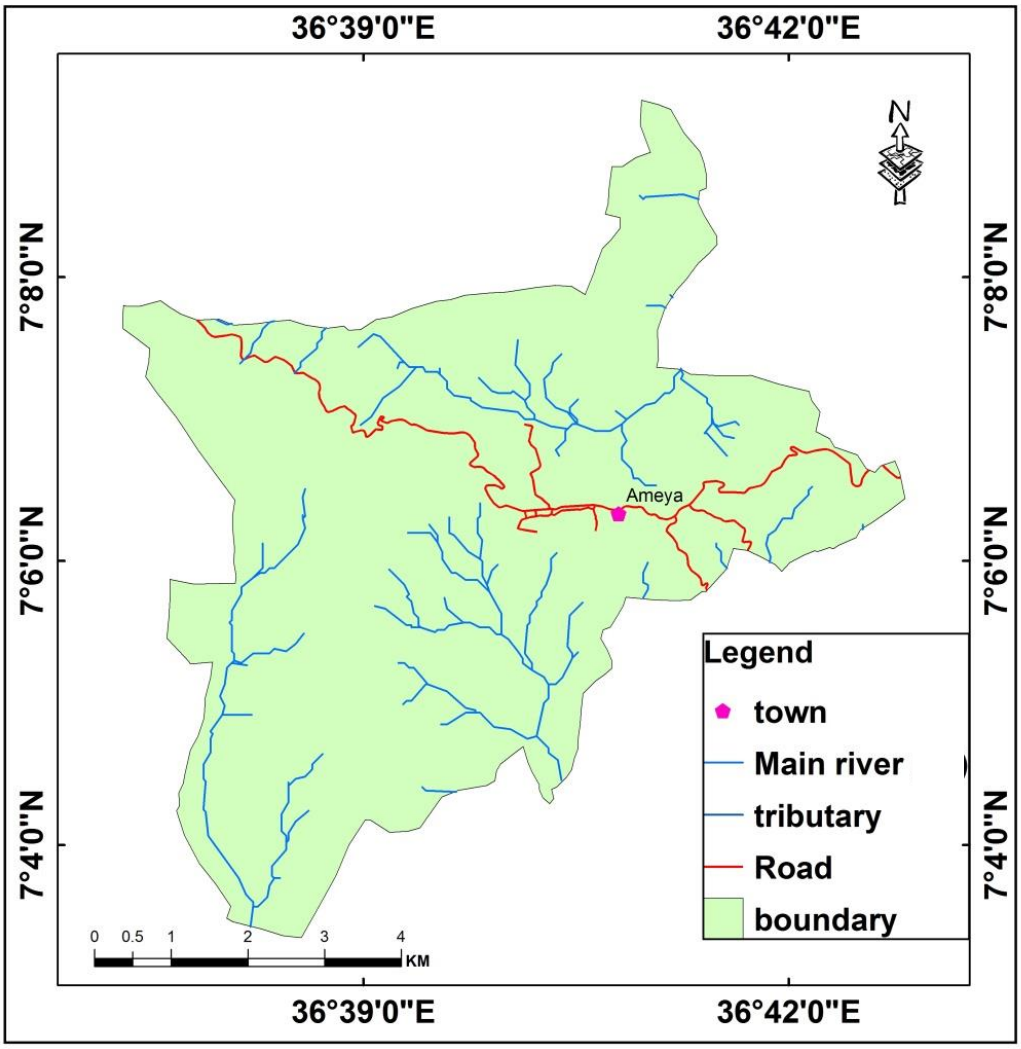


Figure1. 7: Drainage Map of the study area

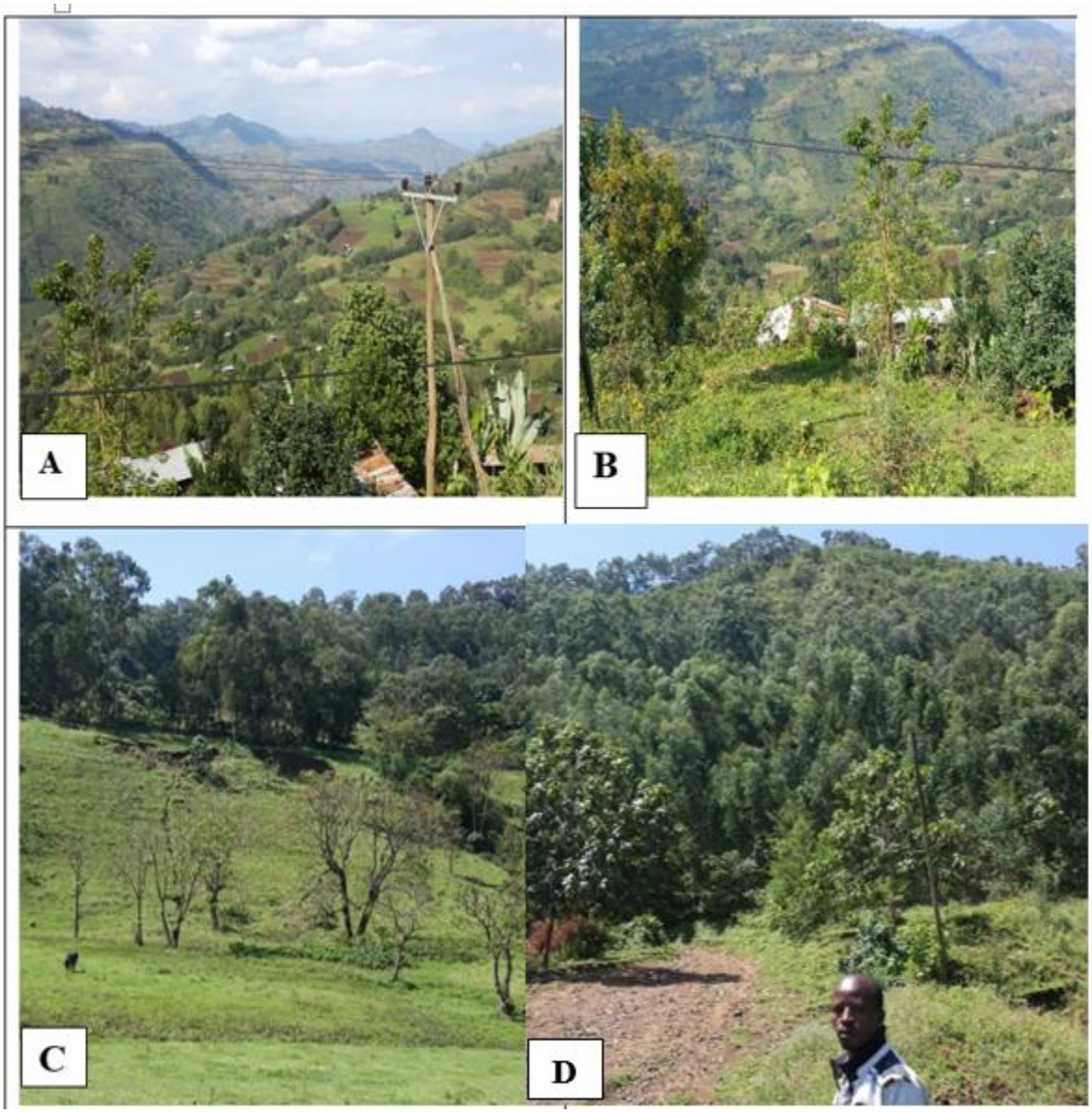


Plate 1. 2 Vegetation cover in the study area, where A&C is from Ameya town, B is Chare and D is Buba damota kebele

1.4.6. Seismicity

Slope composed of unconsolidated or surficial deposits sediment having steep slope, high seasonal groundwater levels, and shallow rooted or sparse vegetation area also prone for failure under seismic loading (Raghuvanshi et al., 2014). The earthquake intensity is determined by seismic map of the area. Seismic Risk Map produced by Pagani et al., 2018 shows that the likely peak ground acceleration (PGA) with a hundred year return period and 0.99 probabilities and the study area falls within 8 M.M scale (Fig.1.12A). Based on the Modified Mercalli intensity scale the estimated horizontal earthquake acceleration comes out to between 0.2-0.4 g, as

determined from the MM intensity graph (Johnson and Graff, 1988) (Fig 1.12 B). Thus the average value (that is 0.3g) has been utilized for the stability analysis of the slopes in the study area.

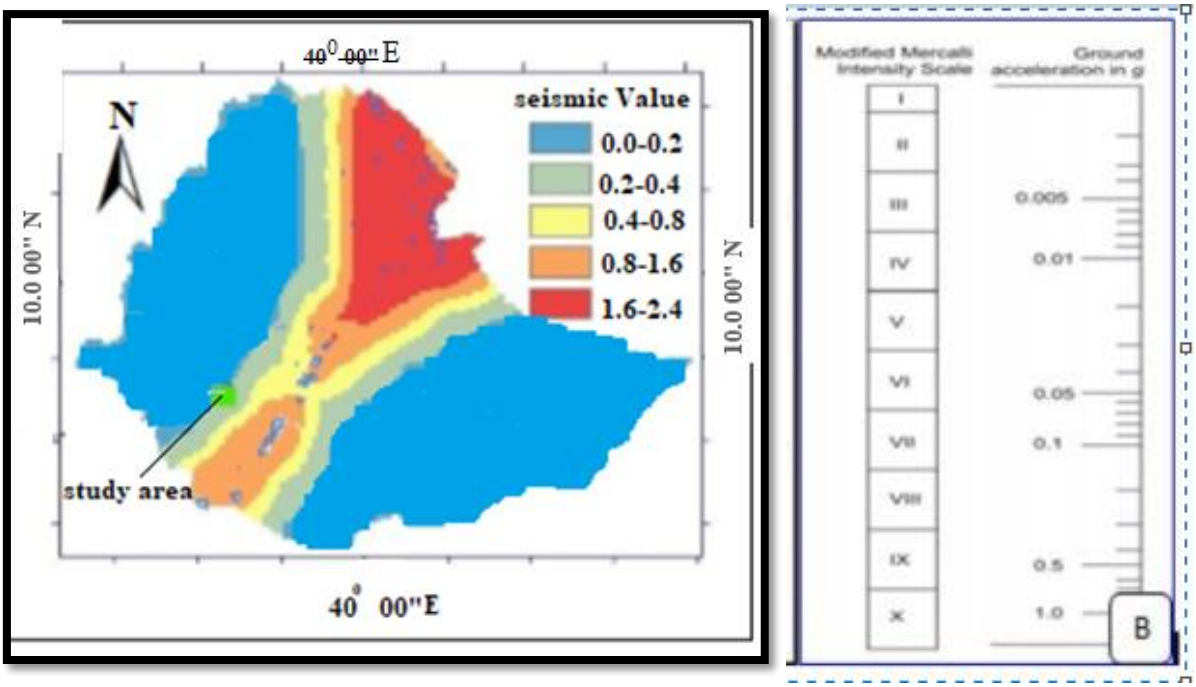


Figure1. 8: (A) Adapted from Pagani et al., 2018 B) Relationship between intensity of earthquake, based on Modified Mercalli Intensity scale and Ground acceleration (source: Johnson and Graff, 1988).

1.5. Significance of the study

The landslide hazard map of the study area can be used to recognize the spatial likelihood of landslide for safer strategic planning of future developmental activities, especially for the local people who have living on the affected area. Besides, results may be helpful to minimize the upcoming impact on landslide prone areas by providing important information for concerned bodies and local government in managing present and future land utilization.

1.6. Future study and extension of the research work

According to the African Press Agency 13 October, 2019 landslides in Konta Ameya has killed 23 people late on 13 October, 2019, after a period of heavy rain. This tells how much the area is hazardous to life and property. The landslide in the area is life threatening so that this study must have a continuation in the future in either assessment of vulnerability and risk to landslide hazard or other large scale study since to reduce the effects of landslide hazard on life and resources.

1.7 Thesis outline

The present study is organized into seven chapters.

Chapter one: deals with the introduction which starts with research background, problem of the statement, significance of the study, objectives of the research work, and descriptions of t he study area.

Chapter two: a detailed literature reviews on factors controlling landslide activity, landslide types, mechanisms of slope failures, landslide hazard mapping technique and landslide overview in Ethiopia are included.

Chapter three: deals with the geological set up of the study area. It gives an overview on general geological setting and brief discussion on local geological setting of the study area.

Chapter four: present the methodology followed during the present study. Descriptions are given on the general methodology followed, data procurement, data processing and analysis, landslide evaluation, and Landslide Hazard Zonation.

Chapter five: presents the landslides and slope instability in the study area. Discussions are also made on; landslide inventory, landslide distribution, types and manifestations of landslides, possible causes and potential slope instabilities in the study area.

Chapter six: discusses about Landslide Evaluation and Zonation. Evaluations are made on intrinsic causative factors and external triggering factors. It explains the landslide evaluation and zonation conducted and validation of the prepared landslide hazard zonation (LHZ) map.

Chapter seven: presents the conclusion and recommendation forwarded through the present study.

CHAPTER -2 - LITERATURE REVIEW

2.1 Preamble

Landslide hazard is, one of the crucial environmental problem for the development of Ethiopia, (Abebe et al., 2010). In Ethiopia, landslide-generated hazards are becoming serious concerns to the general public and to the planners and decision-makers at various levels of the government. However, so far, little efforts have been made to reduce losses from such hazards. (KifleWoldearegay, 2013). In general, heavy rainfall higher relative relief and complex fragile geology with increase manmade activates, such as road building construction and cultivation activities, have resulted in increased landslide activities in the highlands of Ethiopia. (Tilahun Hamzaand & Raghuvanshi, 2017; Girma et al., 2015; Raghuvanshi et al., 2014; Kifle Woldearegay, 2013)

2.2 Type of slope failure

A landslide is a downslope 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 downslope. The type of landslide will determine the potential speed of movement, likely volume of displacement, distance of run-out, as well as the possible effects of the landslide and the appropriate mitigation measures to be considered.(Highland & Bobrowsky, 2008) Landslide includes almost all varieties of mass movements on slopes, including such as rock fall, topples, debris flow that involve a little slide or no true sliding under influence of gravity (Varnes, 1984; Highland and Bobrowsky, 2008) (Table2.1) It can be categorized based on type of movement and kind of material involved into falls, topples, slides**,** spreads, flows and complex slope movements (Varnes, 1984; Wachal and Haduk, 2000 as cited in (Zerihun Dawit et al., 2016).

Table 2. 1 Types of landslide according to Varnes 1978

Type of Movement		**Type of Material**		
		Bedrock	**Unconsolidated Sediment or Soil**	
Falls			**Coarse**	**Fine**
Slides	Rotational	Rockfall	Debris Fall	Earth Fall
	Translational	rock Slump	Debris Slump	Earth Slump
Flows		Rock Block Glide Rock Slide	Debris Block Glide Debris Slide	Earth Block Glide Earth Slide
Complex		Rock Flow	Debris Flow	Earth Flow

2.2.1 Fall

A fall begins with the detachment of soil or rock, or both, from a steep slope along a surface on which little or no shear displacement has occurred. The material subsequently descends mainly by falling, bouncing, or rolling. (Fig 2.1) It is rapid down ward movement of slope material. In this type of failure there is no interaction between one failure and the next. (Demessie & Raghuvanshi, 2019)

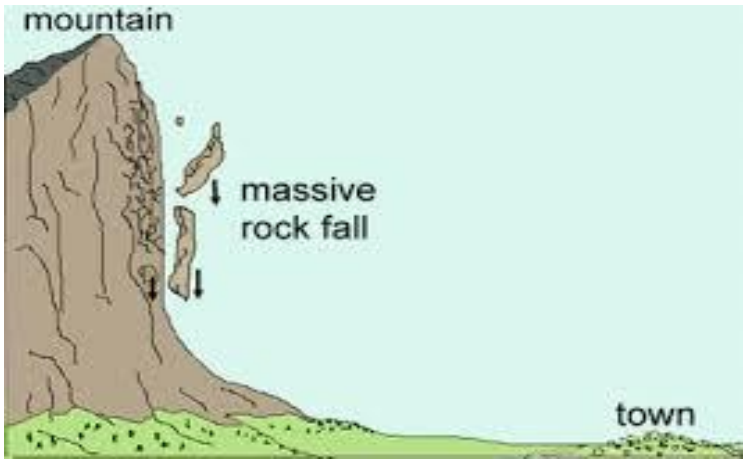


Figure 2. 1 Schematic representation of fall (Source: Highland and Bobrowsky, 2008)

2.2.2 Slide

Slides are the downslope movements of soil or rock along a surface and can be deep-seated or shallow. The initiation of slides, like flows or rock falls, is sensitive to steep slopes, the additional weight of water or other loads, and friction along their base. This type of movement has its own subdivision such as rotational, transitional failure (USGS, 2004).

2.2.2.1. Translational slides usually fail along geologic discontinuities such as faults, joints, bedding surfaces; Translational slides can contain loose sediments or large slabs of bedrock. (Fig 2.2).

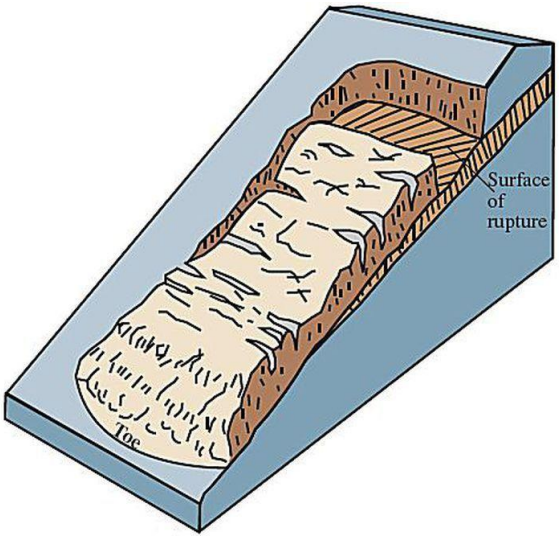


Figure 2. 2 Schematic representation of translational slide (Source: Highland and Bobrowsky, 2008)

2.2.2.2. Rotational slides (slump)

Slumps are landslides that occur along a curved or spoon-shaped surface (Fig 2.3). Back tilting may occur near the scarp of the landslide and there is often a toe of displaced material. Rotational slides often occur because the internal strength of the material is overcome by its own weight. They are usually composed of relatively loose or unconsolidated material.

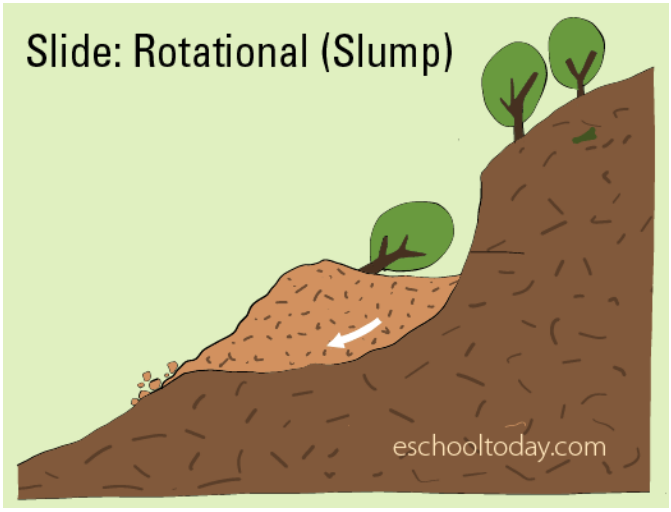


Figure 2. 3 Schematic representation of rotational slid (Source: USGS, 2004)

2.2.2.3. Block slides

Block slides are particular types of translational slide that occur when large and relatively intact slabs of rock or earth are rapidly transported down slope (Fig 2.4). These types of landslides can be large and damaging and occur where alternating layers of strong and weak rock slope downhill,

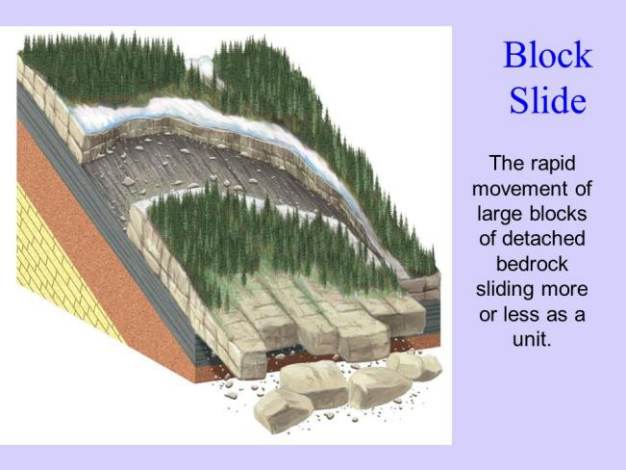


Figure 2. 4 Schematic representation of rotational blocky slide (Source: Highland and Bobrowsky, 2008)

2.2.3 Topple

A topple is a forward rotation, out of the slope, of a mass of soil and/or rock about a point or axis below the center of gravity of the displaced mass (Fig 2.5) the initiating mechanism of topples are gravity, water or ice occurring in the fissured place within the mass, vibration, undercutting, differential weathering, excavation or stream erosion. It occurs in columnar jointed volcanic terrain, as well as along streams and river courses where the banks are steep. It can contain of rock, coarse and fine materials. The rate of movement range of the fall material is from extremely slow to extremely fast rate.it can be extremely dangerous especially when the failure occur suddenly and its velocity may be very fast.(Highland & Bobrowsky, 2008)

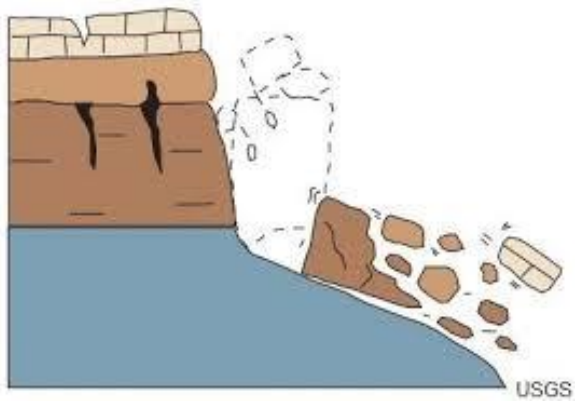


Figure 2. 5 Schematic representation of rotational blocky slide (sources USGS, 2004).

2.2.4 Flow

There are various types of flow based on the material and speed of the movement, such as; debris flow, debris avalanche, earth flow, mud flow and creep. Even if each type of flow has its own characteristics dominantly the materials involved are water saturated with fine grain

dominated and running out leaving a basin shaped depression. Debris flows is a form of rapid mass movement in which loose soil, rock and sometimes organic matter combine with water to form slurry that flows downslope (Fig. 2.6). They are commonly caused by intense surface water flow, due to heavy precipitation or rapid snow melt, which erodes and mobilizes loose soil or rock on steep slopes. They are unconsolidated at the time of flow but may consist of variety type of material like rock fragments, fine material, and debris. (Highland and Bobrowsky, 2008).

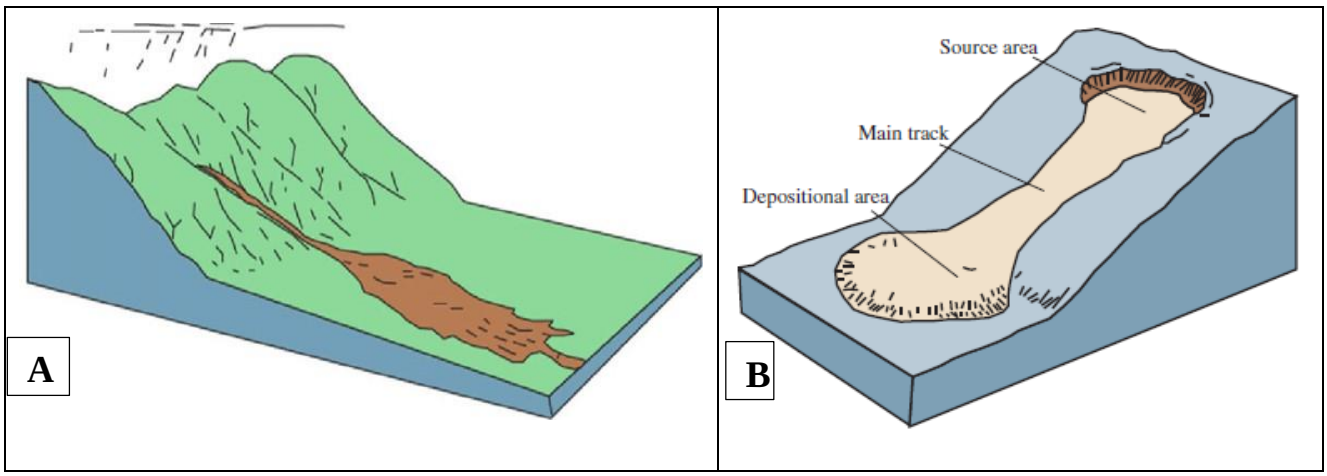


Figure 2. 6 Schematic representation of A Debris flow, B Earth flow *(sources USGS, 2004).*

2.2.5 Complex type of movement

Complex movement is a combination of falls, topples slides, spreads and flows (Highland and Bobrowsky, 2008). This type of combination of failure may happen at the same time or during the life time of a slope failure.

2.3 Factor Influencing Landslide

2.3.1 Intrinsic Factors

The intrinsic factors that may have an influence on these stated slope are mainly slope material (lithology or soil), structural discontinuity, ground water condition, geometry of the slope and land use /land cover (Tilahun Hamzaand, Raghuvanshi, 2017; Anbalgan, 1992). These intrinsic parameters may be favorable or unfavorable for the stability conditions of the slope (Raghuvanshi et al., 2014a; 2014b). Depending up on the available conditions for each intrinsic factor they may have an influence on the stability conditions (Raghuvanshi et al., 2014a).

2.3.1.1 Slope Material

Slopes can be made up of rock mases, soils, or a mixture of the two. The intact rock strength and degree of weathering are used to assign ratings to subclasses of rock form. The strength of a rock has a big effect on its erodibility. High-strength rocks are more resistant to erosion than low-strength rocks. (Raghuvanshi et al., 2014a, Hoek and Brown (1997), Raghuvanshi et al., 2014b, (Varnes, 1978). Shear strength, permeability, and resistance to chemical and physical weathering are all affected by the structure, texture, and other properties of slope material. Unconsolidated slope materials are more vulnerable to instabilities than consolidated slope materials because they have less stability and friction, as well as higher infiltration rates (Sendu Demessie and Raghuvanshi T. K., 2019), Zerihun Dawit, 2016). Avalanche, earth flow, and mud flow are typical forms of failure if the slope is covered by highly weathered unconsolidated material (Birhanu Temesegen et al., 1999). Rotational slide is popular on alluvial and coluvial soils at the foot of steep slopes (Varnes, 1978). The risk of failure for a slope covered by soil is related to the depth of the soil and the genetic origin of the soil material (Raghuvanshi et al., 2014a).

2.3.1.2 Structural Discontinuity

Structure of discontinuities in rocks are Bedding, joints, foliations and faults, are examples of main and secondary Structure of the slope material (Anbalagan, 1992; Sendu Demessie & Raghuvanshi, 2019).

These structural discontinuities are critical in determining the stability of rock slopes (Hoek and Bray, 1981). The orientation, spacing, continuity, surface characteristics, separation of discontinuity surfaces, and thickness and existence of filling material inside the discontinuity surfaces are all important factors that affect the rock mass's stability and thickness and nature of filling material within the discontinuity surfaces (Raghuvanshi, 2014a; Price, 2009; Johnson and DeGraff, 1991).

From the stability point of view, the extent of parallelism between the directions of discontinuity/ intersection of two discontinuities and slope are important points for the stability of the rock mass (Hoek and Brey, 1981). The spacing between two structural discontinuities also plays an important role for the stability condition. If the spacing between the discontinuities is less the rock masses will have high probability for failure (Johnson and DeGraff, 1991). The

continuity of the discontinuity of the slope also affects the stability condition of the rock mass. If the continuity of the discontinuity is more, the rock mass will demonstrate more instability (Raghuvanshi et al., 2014a; 2014b).

2.3.1.3 Ground Water Condition

The ground water condition has an important role by reducing shear strength of the material and by creating pore water pressure (Demessie & Raghuvanshi, 2019; Raghuvanshi et al., 2014a). The groundwater within the discontinuities develops water pressure which results in a decrease of shear strength on the discontinuity planes (Raghuvanshi et al., 2015). In soil slopes after rain-fed saturation the weight of soil mass increases and thus it adds to the instability of the soil mass. Besides, groundwater helps in pore water pressure development within the soil mass which again aggravates instability (Arora, 1997 as cited in Raghuvanshi et al., 2015). Damp, wet, dripping and flowing are the surface indications of Groundwater (Anbalagan, 1992). In addition to this ratings, algal growth and water marks has to be considered as such surface traces may give some idea about the degree of saturation of slope. (Raghuvanshi et al., 2014b).

2.3.1.4 Land use Land Cover

The stability condition of a hill slope to a large extent is influenced by land use and land cover (Raghuvanshi et al., 2015a). Bare land and sparsely vegetated areas and densely cultivated areas are more prone to erosion and have high instability as compared to less vegetated and less cultivated area. Areas which are thickly vegetated and generally less prone to have high landslide processes. Densely vegetated area has a well-spread root system and the roots of the plants can bind the soil mass and contribute it can increases the shearing resistance of slope material (Anbalagan, 1992; Raghuvanshi et al., 2014). The areas have barren land and grazing land showed a more probability of landslide occurrence and weathering Hamza & Raghuvanshi, 2017).Cultivation or agriculture has the main land use activity which influence the on the stability condition of the slop (Demessie & Raghuvanshi, 2019).

2.3.1.5 Geometry of the Slope

Slope geometry includes relative relief and slope morphometry of the slope. The difference between the highest and lowest point of the elevation in individual facet is Relative relief. Normally, if the relative relief is high the slope will be more prone to failure. On the other hand, slope morphometry describes the steepness of the slope. If the slope is steep there is an

increment in shear stress due to this the slope become more prone to failure as compared to gentler slope (Fikire Girma et al., 2015(Hoek and Bray, 1981, Sendu Demessie & Raghuvanshi, 2019).

2.3.2 External Factors

The most useful external factors which may aggravate the instability of slopes are rainfall, seismicity and manmade activities in addition to these Volcanism. (Demessie & Raghuvanshi, 2019).

2.3.2.1 Rain Fall

Ninety percent of landslides occurre during or after a heavy rainfall event, therefore heavy rainfall is considered to be the main triggering factor for landslide (Broothaerts et al., 2012). According to Kifle woldearegay (2013) the rainfall intensity and duration play an important role by triggering landslide like debris flows, mudflows, and medium to large-scale rockslides though it depends on climatic conditions, topography, the geological structure of slopes, and permeability of material. The impact of rain fall relates with other controlling parameters like discontinuity orientation, slope morphometry and types of slope material. In area covered by unconsolidated material, rainfall triggers slope failure as a result of decreasing angle of repose. Heavy rainfall increases the total weight of the slope material, causes the water table to rise and increases the pore pressure in fine-grained sediments, and can therefore trigger a landslide (Abebe et al., 2010).

2.3.2.2 Seismicity

Seismicity produces ground acceleration which results into landslides or slope failures (Keefer, 2000; Parise and Jibson, 2000; Bommer and Rodrı´guez, 2002 as sited in Raghuvanshi et al., 2014) Rapid slope failures such as rock falls and debris flows, are also triggered by earthquakes (Gouin, 1979) as cited in Slope under steep slope composed of unconsolidated soft sediment material, high level of ground water, sparsely vegetated area or shallow rooted forest have high susceptibility for landslide at the time of seismic loading (Raghuvanshi et al., 2014). The ground acceleration can affect the structural discontinuity by widening of the opened structure.

2.3.2.3 Volcanism

Volcanic activity represents some of the most devastating types of failures. Volcanic lava may melt snow or ice rapidly which can form a sudden fall of rock, soil, ash and water that accelerate

rapidly on the steep slope of volcanoes that can cause a lot of damage and destruction anything in its path. Volcanic edifices are young, unconsolidated, and geologically weak structures that in many cases can collapse and cause rockslides, landslides, and debris avalanche.(Highland & Bobrowsky, 2008)

2.3.2.4 Manmade Activities

Beside the natural triggering factor manmade activities also aggravate the potential of the instability of the slope (Raghuvanshi et al., 2014) Population interest increase on to new land and creating neighborhoods, towns, and cites are the first means by which human contribute to the occurrence of landslide. Disturbing or changing the direction of the drainage pattern, destabilizing the slope, removing or destroying vegetation are common human influencing factor that may initiate landslide (Highland & Bobrowsky, 2008) Manmade activities in hilly terrains which affect the slope stability conditions are the developmental activities such as; road or building construction and cultivation activities. All these activities results into increasing moisture in the soil or rock mass and in changing the slope form. (Raghuvanshi et al., 2014).

2.4 Landslide Hazard Mapping Techniques

According to Brabb and Carrara (1984; 1989 as cited in El Morjani, 2011), for the preparation of landslide hazard maps, either qualitative (direct) or quantitative (indirect) landslide hazard mapping techniques can be followed. However, there is no agreement among researchers on the best appropriate model to be used in order to identify and map landslide prone areas. This is because each technique and model has its owen unique set of advantages and disadvantages. Therefore, it is generally preferable to determine the frequency of land sliding in quantitative terms because this will enable the hazard from different sites to be compared, and consequently, the risks to be estimated in quantitative terms also. According to Leroi (1997) the various methodologies for determining potentially unstable areas or landslide hazard assessment method may be divided into expert evaluation, statistical methods, and mechanical approach.

2.4.1 Expert evaluation technique

Expert evaluation technique is the most widely used approach for landslide hazard evaluation. The expert evaluation techniques can include *landslide inventory mapping* and/or *heuristic* approaches. In landslide inventory mapping, emphasis is given for position causative factor, frequency of occurrence and mode of failure of landslide and dimension of recorded landslides hence, this technique can be used as an elementary form of susceptibility mapping (Dai and Lee, 2001 as cited in Fall *et al.*, 2006; Dai *et al.*, 2002). The shortcoming of this method is that

it shows susceptibility only for those areas where landslides have been observed; however, it may not provide information on landslide susceptibility for those areas which may have potential for future landslide activities (Casagli*et al.*, 2004). Whereas heuristic approach includes personal opinion on determining the type and degree of hazard (Dai and Lee, 2001). In this technique various causative factor maps are prepared (Dai and Lee, 2002).

2.4.2 Statistical analysis technique

Statistical methods are determination of the landslide by combination of the causative factor with the past landslide in the given area. The statistical approach is made by rule that is how the individual causative factors contribute to the instability of the active landslide (Van westen, 1994). The statistical methods for landslide hazard zonation can be divided in to two group:- Bivariate statistical analysis and Multivariate statistical analysis(Dae and Lee 2000). The major short coming of this method is problem of collection of data related with landslide and the problem of response of possible factor for large area which may incur relatively large time and cost (Raghuvanshi et al,. 2014). The statistical method result is depend on the quality of data (Van Westen et al,. 1997). But the statistical method it can avoid the subjectivity nature.

2.4.2.1 Bivariate statistical technique

The bivariate statistical approach is based on an inductive logic, which suggests that if a situation holds in all observed cases than the situation holds in all cases. Thus, these techniques are based on a general assumption that "past and the present are the key for future" as stated in (Demessie & Raghuvanshi, 2019) (Dai and Lee 2001)

The bivariate statistical analysis for slope suscplability compares each data layer of causative factor to the existing landslide distribution (Kanungo et al. 2009). The weight of causative factor were assigned

2.4.2.2 Multivariate statistical technique

The landslide susceptibility and hazard zonation through multivariate statistical approach is based on the relationship of relative contribution of each of the causative factor to the total landslide susceptibility in the area (Nandi and Shakoor 2009; Kanungo et al. 2009; Ayalew and Yamagishi 2005; Süzen and Doyuran 2004; Dai et al. 2001).

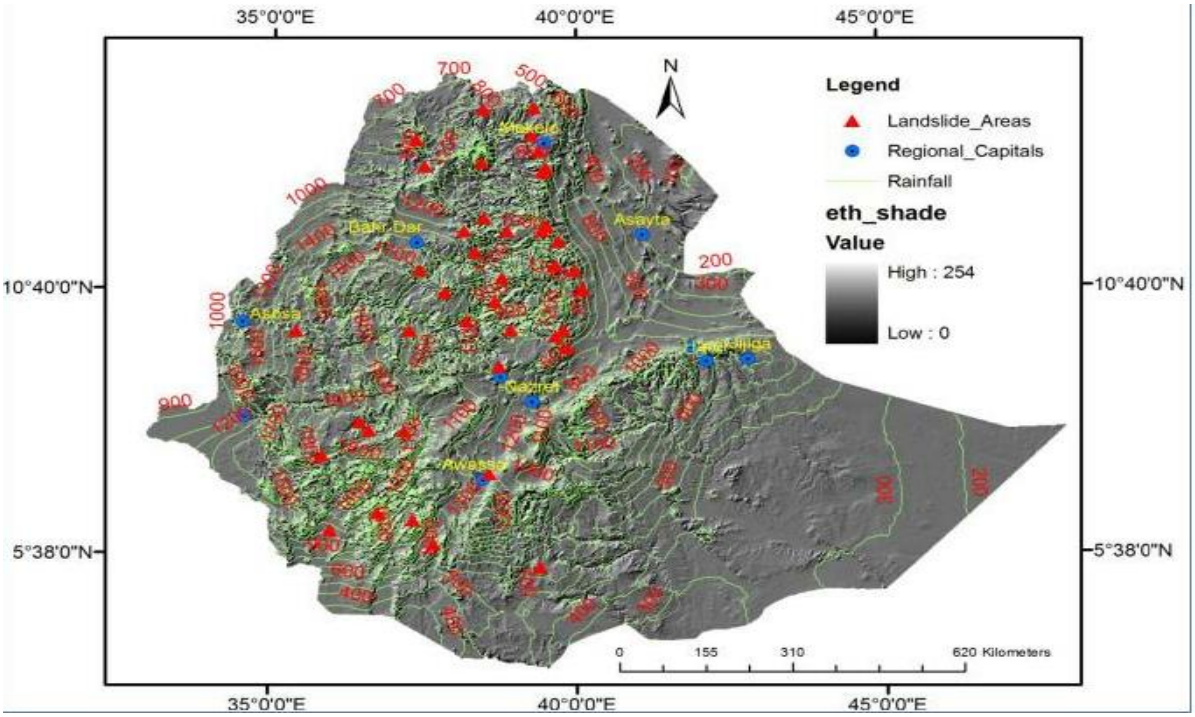


Figure 2. 7 Locations of landslide affected areas in the highlands of Ethiopia (Kifle Woldearegay, 2013)

2.4.3 Deterministic approach

This method generate hazard in absolute value in the form of safety factor (Raghuvanshi et al., 2014a). This approach provides quantitative result which is used for direct engineering designs (Fall et al., 2006). In mechanical method due to the high spatial variability of the geotechnical parameters and the laborious methods involved in acquiring input data, an acceptable approximation of the values is practically only attainable at the level of site investigation, which implies a serious limitation of these models in large area stability hazard zoning at a reasonable cost /benefit ratio (van Westen et al., 1997).

2.5 Methodology Adopted In the Present Study

As discussed above, each technique for landslide hazard assessment has its own advantages and disadvantages. From the review of various techniques it is well understood that landslide is a complex process and there is no straight forward approach available which individually or in combination may provide realistic results. Each method has some degree of subjectivity in recognizing various parameters responsible for slope instability, collection of data or assigning weight and ratings to various parameters. Thus, a technique is required which is relatively more practical, simple in its application and provide much more realistic field data well supported by experience of an expert.

A new slope stability susceptibility evaluation parameter (SSEP) scheme was proposed by Raghuvanshi et al., (2014) by considering both intrinsic (such as: slope geometry, slope material, structural discontinuities, land use and land cover and groundwater) and external (such as, seismicity, rainfall and manmade activities) triggering parameters that are responsible for slope instability.

The main advantage of this technique is that it considers both intrinsic (preparatory or causative) factors and external (triggering) parameters that are responsible for slope instability. Therefore, in the proposed research study, the slope stability susceptibility evaluation parameter (SSEP) has been preferred to be used for rapid assessment of slope stability condition (LHZ) in the study area; because, this technique is more practical, simple in its application and provide much more realistic field data well supported by experience of an expert. A detailed description on this technique is given in Chapter 4.

2.6 Landslide over view in Ethiopia

The Ethiopian highlands are highly populated and the area is highly characterized by variable topography like steep hill slope and incised valleys and gorges (Kifle Woldaregay, 2013) which shows past geological and erosional process. The steepness of the slopes in the highlands of Ethiopia is enough to aggravate instability. In addition to this, external factors like rainfall and manmade activities in the area initiate the instability of slope. As many studies suggest that the highlands of Ethiopia have high variable rainfall intensity.

Various studies are conducted on slope instability problem of different parts of Ethiopia among these some prominent studies are by; Asfawesen Asrat et al., 1996; Birhanu Temesgen et al., 1999; Lulseged Ayalew, 1999; Tenalem Ayenew, 2002; Kifle Woldaregay, 2005; Tenalem Ayenew and Barberi, 2005; Engdawerk Mulatu et al., 2009; Bekele Abebe et al., 2010; Kifle Woldaregay, 2013; Raghuvanshi et al., 2014; Henok Woldegyorgis et al., 2014; Birhanu Ermias 2014; Fikire Girma et al., 2015; Raguvanshi et al., 2015; Zerihun Dawit, 2016; ,Tilahun Hamaz and Raghuvanshi, 2017; Gemechis Chimindi et al., 2017; Berhanu Ermias et al., 2017 etc.

The above-mentioned studies followed different slope stability analysis (qualitative, analytical and empirical) techniques to assess the cause for slope failure and to delineate the areas in to different degree of susceptibility. Some of the studies and related techniques are described below.

LulsegedAyalew and Vernier, A. (1999), have studied the causes and mechanisms of slope instability in Dessie town. In this work, they examined the relationship between slope instability and seasonal rainfall in the area.By taking the variation in moisture content of soil, the rate of daily precipitation, the amount of cumulative precipitation, and mean annual rainfall as variable, they derived a simple equation that is useful to determine the likelihood of land sliding.

BerhanuTemesigen et al. (2001) conducted a research by using GIS and Remote sensing methods for natural hazard assessment to the landslide in the Wondo-Genet area. In their work they evaluated the occurrences of landslides and their relationships with various event controlling parameters using GIS and Remote Sensing techniques. Finally, a landslide hazard zoning prepared done through the statistical relationships of the parameters with landslide occurrence that were converted into risk susceptibility priority numbers.

Tenalem Ayenew and Barbieri G. (2004) have conducted a landslides inventory and susceptibility mapping in the Dessie area. During this study, four broad landslide susceptibility zones and 22 specific active landslide sites were identified. According to this research, the most important landslide types were complex earth and debris slides and flows in silty clay soils associated with alluvial and colluvial deposits overlying highly weathered basalts.

YoditTeferi (2005) conducted a research on Evaluation of Land Degradation and Landslide Using Integrated GIS and Remote Sensing Approach around Sodo-Shone Area, Southern Ethiopia. During her research she observed two types of mass movements; flow and rock fall in the area. Mud flow was induced by intensive rainfall and observed in gently sloping areas whereas the slope mainly ranges from 20^0-30^0 whereas the rock fall was common in areas where the slope angle exceeds 40^0.

K.Woldearegay (2008) carried out geological, geotechnical and geo-hydrological investigations to understand the causes and triggering mechanisms of the large-scale landslide in Tarmaber area, central highlands of Ethiopia. According to his research paper, the localities “YizabaWein” and “ShotelAmba” areas, with an estimated total area of 35 square kilometer, were completely affected by a single major deep-seated landslide which took place in September 12, 2006. More than 3000 people were displaced; 1250 dwelling houses were demolished; and 4 Churches, 4 Mills, and one elementary school were destroyed. The landslide also devastated about 1500 hectare of agricultural land and caused damage to the natural environment

Engdawork Mulatu et al. (2009) were carried landslide hazard zonation along the newly constructed road from Fofa town to Gilgel Gibe-II powerhouse in south western Ethiopia by using the landslide hazard evaluation factor rating scheme (LHEF) empirical approach proposed by Anbalagan (1992). The results indicate that 54% of the slopes in fall in High Hazard, 34% in the Moderate Hazard and 12% in the Low Hazard zone the area.

Bekele Abebe et al. (2010) conducted a review of landslide occurrences on the Ethiopian highlands and rift margins. They emphasized on the man-made triggering factors, which include increasing settlement on slope sides due population growth and expanding infrastructure, scarcity of agricultural area and construction material.

Raghuvanshi et al., (2014) made study on landslide hazard zonation using Slope stability susceptibility evaluation parameter (SSEP) expert approach in the area around Wurgessa Kebelle of North Wollo Zonal Administration, Amhara National Regional State in northern Ethiopia. The results obtained indicates that 8.33% of the area fall under Moderately hazard and 83.33% fall within High hazard whereas 8.34% of the area fall under Very high hazard.

Zerihun Dawit, 2016, conducts a study in the area Kindo Didaye Woreda, South West Ethiopia using SSEP expert technique. He delineates the area in different degree of susceptibility and evaluates the causative parameters. LHZ map of the study area through SSEP method shows validation of 90% and 94% validation in case of the landslide hazard map of the study area through integrated SSEP.

Tilahun Hamza and Raghuvanshi et al., (2117) made study on landslide hazard evaluation and zonation (LHZ) in Jeldu District in Central Ethiopia. The considered governing factors in this study are: aspect, slope and elevation, lithology, soil and land use/land cover. The results revealed that 12% of the study area falls under no hazard, 27% as low hazard, 32% as moderate hazard, 21% as high hazard and the rest 8% as very high hazard.

Sendu Demisse (2019) conducted landslide hazard evaluation and zonation of the Dilbe and surrounding area in north central Ethiopia by using GIS based grid overlay and statistical approach. The LHZ map shows that 11.64% of the study area has a ‘very high landslide hazard’ (VHH) potential and 19.86% area has ‘high landslide hazard’ (HH) potential. Whereas, the areas that account for ‘medium hazard’ (MH), ‘low hazard’ (LOH) and ‘very low hazard’ (VLH) are 14.3%, 38.2% and 16% respectively.

The current research conducted on selected failed sections by using expert evaluation SSEP i,e slope stability susceptibility evaluation parameter rating method.

CHAPTER 3 - GEOLOGY

3.1 Regional geology

3.1.1 Introduction

The study area is part of the Omo-Gibe River basin. The basin is bounded on the northeast by the Main Ethiopian Rift, on the southeast by the Chew Bahir rift systems, and on the south by the Lake Turkana rift, which stretches from Kenya into Ethiopia (Davidson, 1983). Precambrian crystalline basement, Tertiary volcanic rocks, and Quaternary alluvial sediments and volcanic flows make up the geology of the basin (Davidson, 1983). Pre-rift and post-rift successions exist in the Cenozoic rocks of southwestern Ethiopia.

The trap series (Mohr, 1963) are made up of Paleogene and Neogene flood basalts and intercalated felsic lava and pyroclastic rocks, Cenozoic rocks cover approximately 90% of the basin's floor, and there are no Paleozoic or Mesozoic sedimentary successions found elsewhere in Ethiopia (Davidson, 1983). Different paleo soil found in several volcanic layers and pulses can be used to identify volcanic quiescence. Volcanic activity began in the lower Tertiary period. Tertiary volcanic rocks rest directly on the Precambrian crystalline basement, with the exception of basal red sandstone, which is mainly found between Precambrian and Cenozoic rocks (Davidson, et al., 1973; 1976; 1983). Tertiary volcanic flows, pyroclastic flows, pyroclastic fall-outs, ash-flows, and to a lesser degree Quaternary ash-falls and Quaternary alluvial deposits cover the study region. The older tertiary rocks are heavily decomposed to soil, and the rock-to-soil relationship is difficult to discern.

Lower volcanic flows, Omo trachyte flows, lower basalt flows, lower trachyte flows, and lower pyroclasts, according to various researchers (Kazmin, 1972, Merla et al., 1979, Davidson 1983, and Mengesha et al., 1996), are pre Oligocene.

The Oligocene Period can be represented by the middle basalt and trachyte flows. The younger flows date from the Miocene to Pliocene epochs. The study area's main volcanic sequence is Eocene to Oligocene. Basalt, trachyte, rhyolite, tuff, and ignimbrite make up the surface. The entire study area was

mapped as volcanites, from Ameya to Chida Merla et al. (1979). The rhyolites and trachy-basalts that make up the Konta volcanites are Oligocene to Miocene.

3.2. The stratigraphy of the regional geology

A general stratigraphy scheme of the area with the lithological description of the formations and thickness of individual formations of a stratigraphy is suggested by Thomas et al., 2015 and it is presented in table 3.1 and discussed with the following paragraph.

The older unit encountered is Omo trachyte flows (TV1), Lower basalt flows (TV2), Lower trachyte flows (TV3), Lower pyroclastic deposit (TV4). These are assumed to be the older volcanic of the area and can be correlated to the Ashanghi Formation. The next volcanic rocks are Middle basalt flows (TV5) and Middle trachyte flows (TV6). These are assumed to be fissure eruption and can be correlated to the Aiba Formation. The younger units are Upper basalt flows (TV7), Upper trachyte flows (TV8), Upper rhyolite flows (TV9) and Upper pyroclastic rocks (TV10). These later ones cover highlands of the area and on the lithological basis can be correlated to the Alajae Formation. According to The Stratigraphy can be verified in table.

Table 3. 1 Litho stratigraphy of the study area (source Thomas et al, (2015),)

Age				Lithological unit	Description
Quaternary				Alluvial deposit	Composed of silt and clay which often change marsh bogs
				Stratified tuff (Qt1)	Loosely patched stratified tuff, lose or very slightly compacted.
	Upper	Miocene-	Central vol. com.)	Sentema basalt	Medium to coarse grained, massive hard and compacted rock composed of mainly of pyroxene, olivine and plagioclase.
				Trachyte plug (TV12)	Plugs are massive to columnar jointed, the rock is fine to medium grained contain sanidine crystal.
				Kobechphonolite (TV11)	The rock often contains sanidinephenocryst and mafic mineral.

			(Alaje F)	Upper pyroclastic (TV10)	Composed of mainly ignimbrite, coarse grained and show columnar jointing.
				Rhyolite flows (TV9)	Mainly rhyolite intercalated with tuff, coarse grained, the rock is often layered but mainly massive.
				Upper trachyte flows (TV8)	The trachyte is deeply weathered to various light grey to pinkish colors.
				Upper basalt flows (TV7)	The basalt is in most place aphanatic, fine grained and shows horizontal stratification (around Saja)
		Oligocene (Aiba F.)		Middle trachyte flows (TV6)	Mainly trachyte intercalate with ignimbrite rear basalt, the rock is often massive but at place show fractures.
				Middle basalt flows (TV5)	Mainly basalt with rear intercalation of trachyte. showing various grain size.
	Lower Tertiary	Pre- Oligocene (Ashangi F.)		Lower pyroclastic (TV4)	Mainly ignimbrite with minor stratified lithic tuff, the ignimbrite is medium to coarse grained, massive compacted and dense and contain fragments of tuff and pumice and filammes, the lithic tuff pinched out to the west up to scrap of the Omo valley.
				Lower trachyte flow (TV3)	Mainly ignimbrite with minor stratified tuff and lithic tuff, the ignimbrite is weathered and medium grained texture; it shows layering and often tilts to the East due to probable faulting.
				Lower basalt flow (TV2)	Fine grained, often scoriaceous and slightly weathered, it contains basaltic pyroclastic rocks
				Omo Trachyte flows(TV1)	Fine to medium grained and contains weathered sanidine, but can be also massive

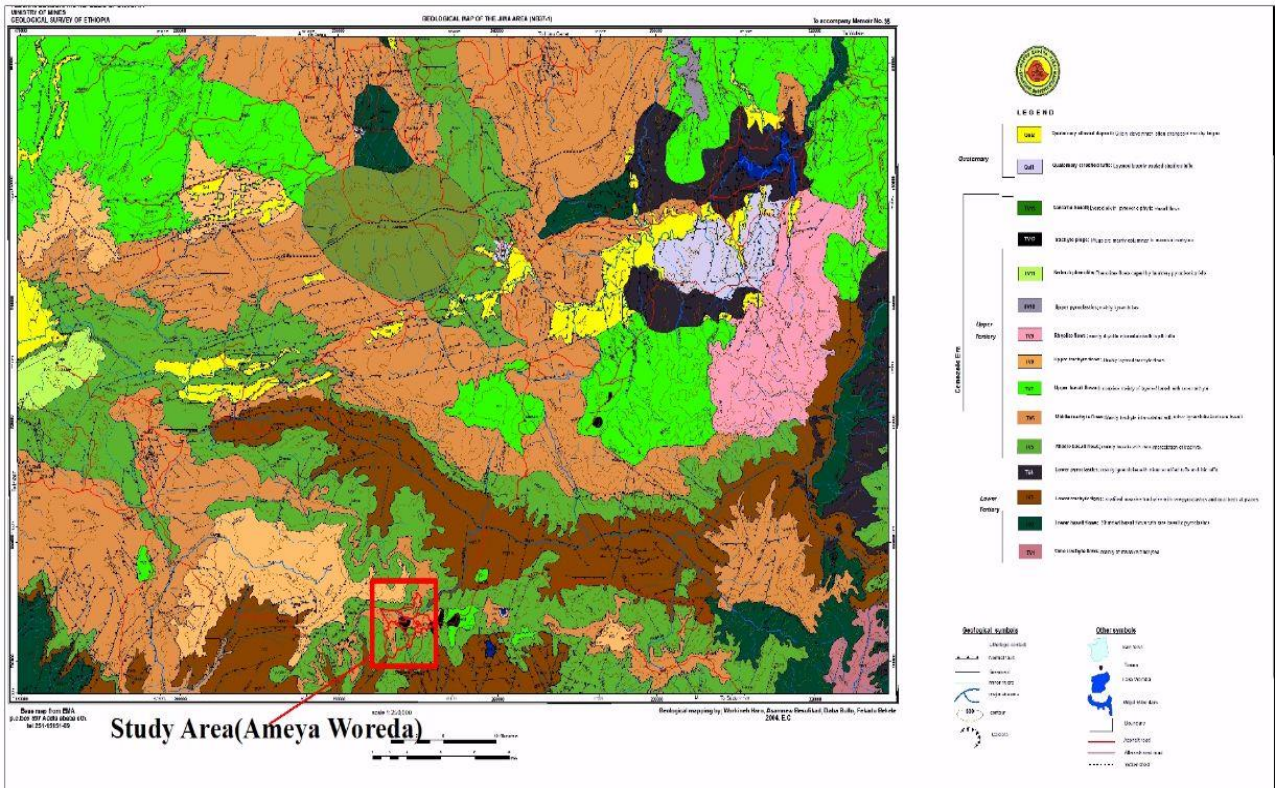


Figure 3. 1 Regional geologic Map of the study area (Adopted from GSE, 2012).

3.2.1 Omo trachyte flows (TV1)

This is exposed in the valley of Omo to the SE part of the study area. The trachyte forms steep slope to cliff around the river course. It is fine to medium grained and contains weathered sanidine. It is pinkish to light grey and forms thick massive flows. The contact with the overlying lower basalt is not exposed.

3.2.2 Lower basalt flows (TV2)

The TV2 also contains basaltic pyroclastics especially in the valley of Omo to the east and west lying on the trachte. The basalts in this area are fine grained, dark grey and slightly weathered, and show 7 to 6 meter thickness, with sharp contact forming successions of 12 layers. The pyroclastic rocks are topped by fine grained basalt layer. The TV2 often grades to scoriaceous basalt. The scoria is vesicular and shows fine texture, with rock fragments of scoria and basalt. It shows heterogeneous mixtures of rock fragments cemented by lesser size fragments.

3.2.3 Lower trachyte flows (TV3)

These are mainly exposed in the Valley of Gojeb River, around Chebera-Churchura National Park, south of FelegeSelam, and to the SW of the study area and also in Wukiro-Gera lowlands and it contains coal layers north of Chida. The light grey is often weathed color and when fresh it is dark grey with secondary zeolite and primary sanidine. To the northwest of Chida, the unit is intercalated with coal beds. The coal bed is horizontal and often friable

3.2.4 Lower pyroclastic deposits (TV4)

The TV4 is exposed to the eastern part of the study area, in the lowlands of Deneba& around Dimtu town continuing to the west. It is also exposed southwest of Nada and south of Ale. In these areas the major pyroclast is ignimbrite. There are also tuffs and lithic tuffs to some extent; as well as trachytic obsidian lenses. It is more than 100m thick and continues up to Gojeb-Gibe confluence.

3.2.5 Middle basalt flows (TV5)

To the east of Gibe, this unit directly overlies the lower pyroclast. In this area fine grained, dark grey basalts are separated by paleosoil. Horizontally layered basalts form 5 (five) lava layers. At places occurs intercalation of basaltic pyroclasts. The pyroclast contains boulders, blocks, cobbles & gravels cemented by fine grained material. Some of the fragments are scoriaceous basalts. These are exposed in Warwarsa River. Often they are cut by basalt dikes.

3.2.6 Middle trachyte flows (TV6)

The middle trachyte is southeast of Jima, in most areas of Gera and Belete Chaka, south of Bonga and DelbiMoye to Debo areas. The trachyte is associated with coal beds. The DelbiMoye coal mining is situated with this trachyte. The top and bottom of the coal bed is trachyte. The coal is horizontally stratified discontinuous beds (1.7m). It is soft friable and black. In many areas, fault breccias are observed with in such trachyte.

3.2.7 Upper basalt flows (TV7)

These basalts flow is exposed, around Sekoru north of Gilagel Gibe, Dedo areas, Kusaie, on slope west of Ameya, south of Bonga& NW of Gera up to Gatira. The upper basalt is continuation of plateau basalt of centeral Ethiopia. They are fissure eruption covering vast areas. At places similar rock units form

minor hill tops. The basalt is at places interlayered with thin trachyte flows and lesser pyroclasts (subaerial tuffs) and ash flow tuffs. The TV7 around Genji area is underlain by horizontally stratified lahar of which thickness is about 15m.

3.2.8 Upper trachyte flows (TV8)

The upper trachyte flow is exposed at higher altitude north of FelegeSelam, east of Bonga. The exposure is rare due to thick saprolite and dense vegetation cover. The trachyte is deeply weathered to various light grey to pinkish color.

3.2.9 Rhyolite flows (TV9)

Rhyolite forms, the high mountain ranges of Woserbi, east of Nada. This occurs to the northeast of the map area. The rhyolitic ignimbrite is pyroclastic flow containing rock fragments of pumice and trachyte gravels. The rock is often layered, but is mainly massive. This type is exposed forming Meda Bora mt.

3.2.10. Trachyte plugs (TV12)

Trachyte plugs are exposed in the southern part of the map sheet south of Chida on the way to Ameya. These plugs are associated with TV6. The trachyte plugs form sub circular outline of bare rocky surfaces. Plug is massive to columnar and forms steep sided rocky surface devoid of soil and vegetation. It often rises above the ground for 50 to 70 meter. In most of the case it is columnarly jointed. The rock is fine to medium grained and contains sanidine crystals. The rock is light grey to greenish grey.

3.3 Local Geology

The geology of the study area has been worked with based on the study of the geological survey of Ethiopia 2012 and by field observation. The geologic units present in the study area are: lower trachyte flow, middle basalt flow, middle trachyte flow and trachyte plug. The geology of the area is well exposed along river, road, and natural hillside in the study area.

3.3.1 Lower trachyte flow

These are mainly exposed at the tip of Cheka Bocha south west of the study area, it is well stratified and is well exposed following road cut. The light grey is often weathering color and when fresh it is dark grey with secondary zeolite and primary sanidine. This trachyte cover an approximate area of 13 sq. km in the study area.

3.3.2 Middle Basalt Flow

This unit directly overlies the lower pyroclast. In this area fine grained, dark grey basalts are separated by paleosoil. At places occurs intercalation of basaltic pyroclasts. The pyroclast contains boulders, blocks, cobbles & gravels cemented by fine grained material. Some of the fragments are scoriaceous basalts. This basalt flow cover an approximate area of 17km^2.

3.3.3Middle trachyte flow

The middle trachyte covers many areas of the study. It is exposed west of Ameya North and northeast of Ameya, southwest of Ameya, at the center of Cheka Bocha areas. In most of its exposure the middle trachyte flow is light grey, fine to medium grained trachyte. The rock is often massive, but at places show fractures. The color often changes to dark grey or greenish to grey. In the study areas, such units are intercalated with ignimbrite and are separated by paleosoil.

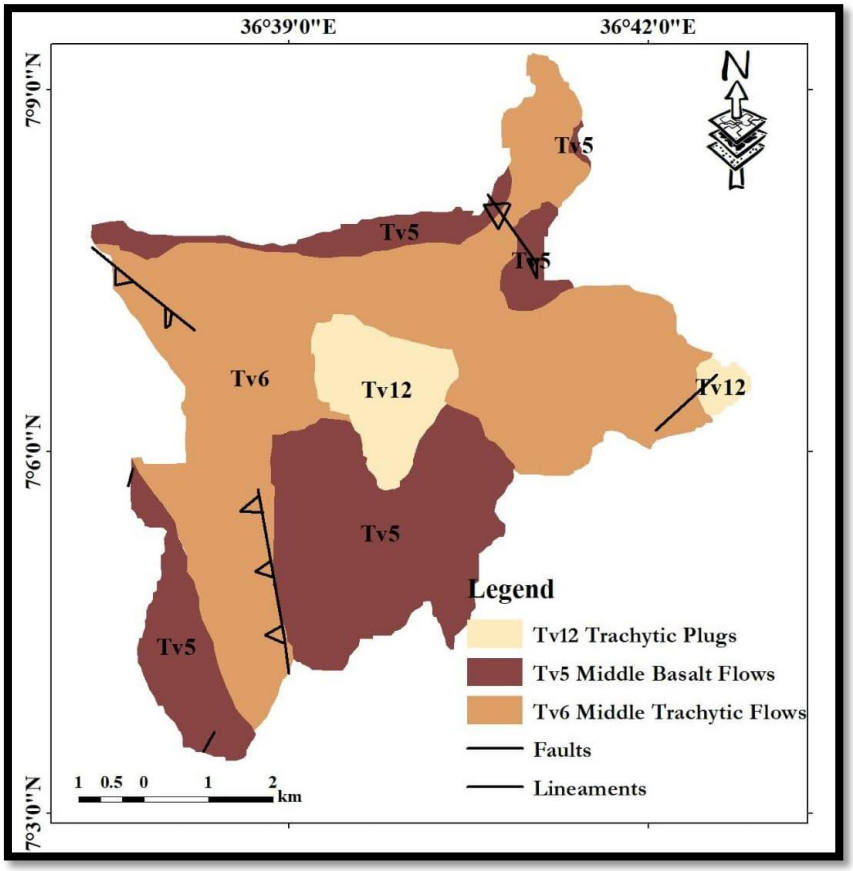


Figure 3. 2 Geological map of the study area

3.3.4 Trachyte plug

Trachyte plugs are exposed at the center of the study area and south of Chida on the way to Ameya. These plugs are associated with trachyte. The trachyte plugs form sub-circular outline of bare rocky surfaces. Plug is massive to columnar and forms steep sided rocky surface devoid of soil and vegetation. It often rises above the ground for 50 to 70 meter. The rock is fine to medium grained and contains sanidine crystals. The rock is light grey to greenish grey.

3.3.5 Unconsolidated deposit

These units are result of weathering and the result of rivers, gravity and residual deposits from different parent rocks. The unconsolidated deposits in the study area include alluvial and coluvial deposits and also residual soils (plate 3.3 & 3.4).

3.3.5.1 Alluvial deposit

These deposits in the study area are deposited on gentle low lying flat alluvial planes, close to the river course and on the gully formations. It consists of gravel, sand, silt, and clay and often contains organic matter that makes it a fertile soil (plate 3.1)

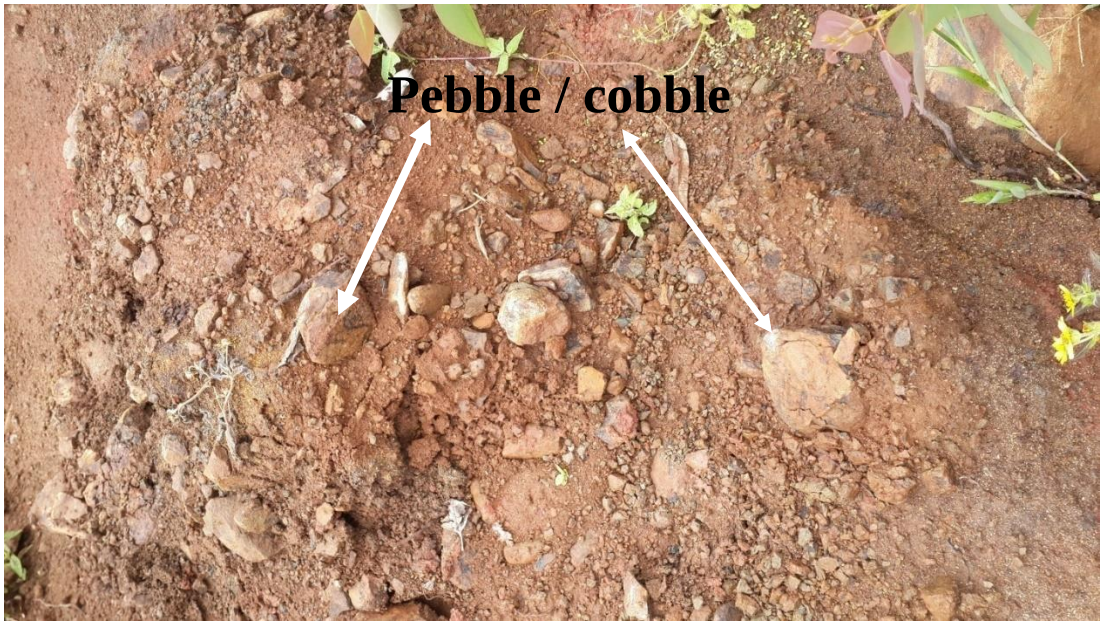


Plate 3. 1 Alluvial deposit at Dukazale kebele.

3.3.5.2 Coluvial deposit

These deposits are found at the bottom of a cliff or slope, along the road cut in the study area which form fan shaped deposit. They are poorly sorted and its fragments range greatly in size. In the study area these deposits include accumulations of rock fragments called talus which is angular. It comprises of blocks of basalt and also soil that came from the steep cliffs.



Plate 3. 2 Colluvial deposits at Dukazale kebele

3.3.5.3 Residual soil

The residual soil deposit in the study area varies in color from black-reddish-yellowish. It is loose mix of granular material comprising sand and silt. It ranges in thickness from 5- 10 m. Tension cracks are observed in most part of the study area in this unit.



Plate 3. 3 Residual soil in Dukazale kebele A&B, Reddish brown residual soils which are mainly at Sime Dukazale kebele C&D Reddish residual soils at Dukazale Kebele



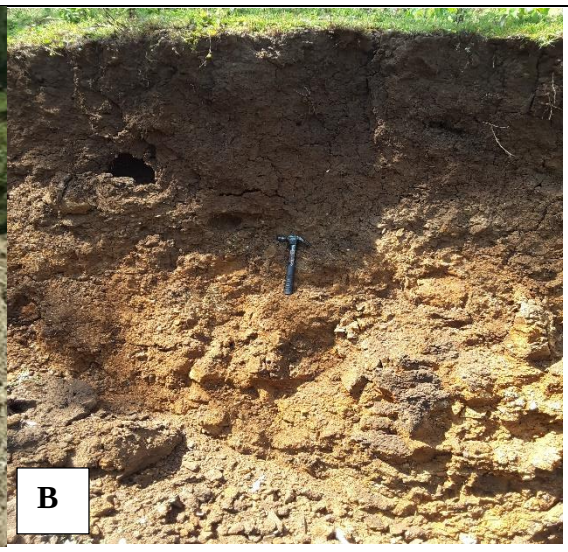


Plate 3. 4 Residual soil deposit. E), Reddish residual soils at Bubadamota Kebele and F) residual soil at Dukazale Kebele

3.3.6 Unwelded tuff

This lithologic unit consists of volcanic pyroclastic materials and thin layers of volcanic ash. They are exposed well along river and road cuts and most parts of the study area. It is characterized as yellow to light gray in color, very weak and, friable by hand (plate 3.5)





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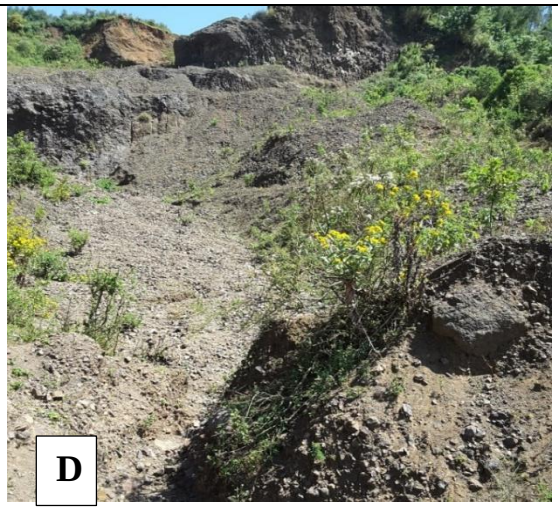


Plate 3. 5 unwelded tuff A), Very weak highly weathered tuff in Bubadamota Kebele B) Very weak highly weathered yellow color unwelded tuff in Bocha kebele . C)& D) Brownish unwelded tuff at Bubadamota Kebele

3.4 Geological Structures

The structural setting of southwestern Ethiopia is a manifestation of the regional Neogene to recent volcano-tectonic processes (Beleke Abebe et al., 2010). Geological lineaments are important of geological structure on the surface, and control the distribution of regional groundwater, geo-hazards, geothermal and earthquakes (Ning Y et al., 2018)

The Main Ethiopian Rift (MER) is a volcanically active rift that marks the transition from continental rifting in the East African rift to incipient seafloor spreading in Afar as stated in Birhanu ermias (Kier et al., 2006). The structural setting of southwestern Ethiopia is a manifestation of the regional Neogene to recent volcano-tectonic processes (Beleke Abebe et al., 2010). Numerous prominent lineaments forming long ridges and escarpments, longitudinal drainage patterns, and exposed faults and joints in the study region are major contributing factors to the large scale mass movements in the area.

3.4.1 Lineament

Lineaments of different orientation are common in the mapped area. These regional lineaments manifest themselves in the form of joint sets and fractures. Three major fault systems can be seen in structural data collected in the field (N = 30) and lineaments traced from a hill shade relief map: NNW-SSE, (Figs.

3.3). The Young fault systems which show nonconformity along the NW-SE axis. They are very frequently observed along with major landslides.

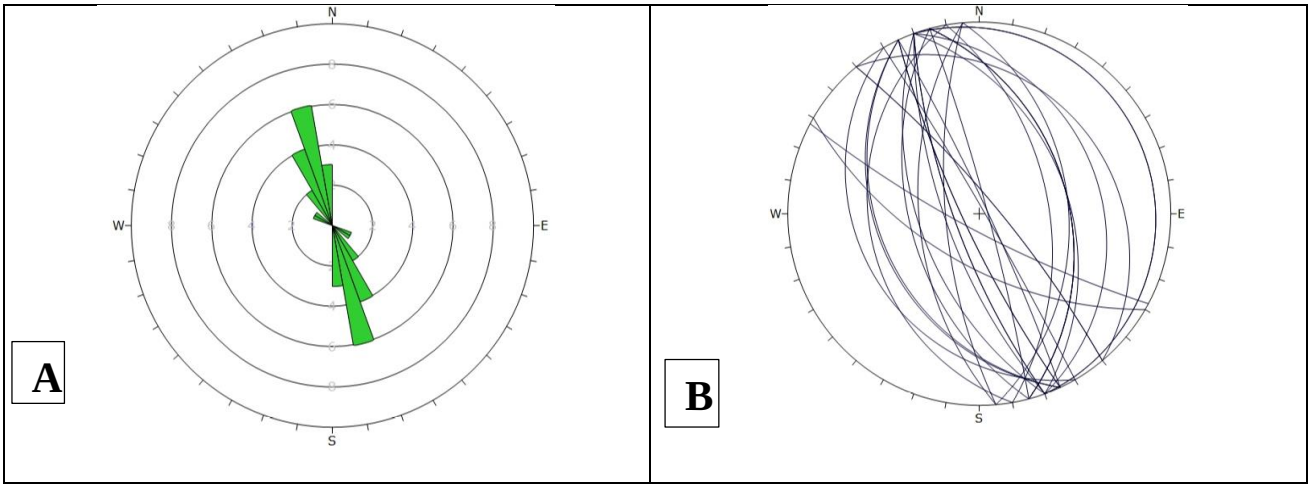


Figure 3. 3 Structural plots of normal faults in the study area: (A) rose di1`agram of fault planes; and (B) fault planes

CHAPTER 4 - METHODOLOGY

4.1 Introduction

In order to assess landslide susceptibility and hazard zonation several approaches and techniques have been proposed. These include landslide inventories, expert evaluation (heuristic terrain), statistical methods, deterministic methods,(probabilistic) methods etc. (Shano et al., 2020) The Landslide Hazard Zonation (LHZ) mapping technique is a macro zonation approach showing the probabilities of landslide hazards. It involves prediction of a certain areas where a potentially damaging, landslide may occur without any reference to the time, or the intensity of associated damage. It expresses the spatial correlation between predisposing terrain factors and the distribution of past landslide (Van Westen et al., 2006). Various researchers used different methods in determining landslide hazard zone or potentially unstable areas.

4.2 Methodology adopted for the present study area

Raghuvanshi et al. (2014) developed a new Slope Stability Susceptibility Evaluation Parameter (SSEP) rating scheme – a method for determining landslide hazard zonation. The SSEP rating scheme was created by taking into account both intrinsic and external triggering parameters that induce slope instability. Slope geometry, slope material (lithology or soil type), structural discontinuities, land use and land cover, and groundwater were all taken into account. External triggering factors such as seismicity, rainfall, and mane made activities were also taken into account. First of all the area of slopes to be covered has to be divided into individual slope facets. As a general methodology for slope stability susceptibility evaluation parameter (SSEP) technique has used, these can be divided in to different class of order. First the area of the slopes covered has to be divided into individual slope facets (Slope facet is delineation slope characterized by more or less uniform slope inclination and slope direction, and Slope facet boundaries are delineated by major or minor hill ridges, primary and secondary streams and other topographical undulations.) for the preparation of facet topographical map at the scale of 1:50,000 and or Aerial photographs are utilized. The delineated facet map was used as a base map for the other causative factor map. Secondly, the data on intrinsic and external causative parameters is collected and rating for each causative parameter is assigned for each facet. Thirdly, the ratings values of all causative parameters for individual facet have to be summed up to obtain Evaluated landslide hazard (ELH) which

show as the net probability of instability. Lastly, the area divided into different hazard zone based on the obtained (ELH) value.

ELH=sum of rating of intrinsic parameter (Relative relief + slope morphometry + Slope material + land use land cover + Aspect + Elevation + Ground water) +Sum of rating of external parameter (Rain fall + Seismicity + Mane made activity).

Table 4. 1 Distribution of maximum SSEP ratings assigned to different intrinsic and external triggering factors (Adopted from Raghuvanshi et al., 2014).

Triggering Parameter		Maximum Rating
Intrinsic parameter		
1, Slope geometry	Relative relief	1.0
	Slope morphometry	2.0
2, slope Material		1.0
3, structural discontinuity		2.5
4, Land use Land cover		1.5
5, Ground Water		2.0
External Parameter		
1, seismicity		2.0
2, Rain fall		1.5
3, Manmade activity		1.5
Total		15.0

The considered governing parameters of the adopted (SSEP) technique, tools and procedures in developing the landslide hazard zonation mapping proved the rationality (Raghuvanshi et al., 2014). The advantage of using this technique for landslide hazard evaluation and zonation is utilizing detailed facet

wise field-based data as input, and relatively it is simple in its application. However, it dis-advantage is subjectivity of the result in landslide hazard evaluation and zonation (Leroi, 1997).

4.3 Data Procurement

There were two sections to the data collection procedures used in this research. The first part involved desk study, and the second involved field work.

4.3.1 Desk study

During the desk study, all available secondary data pertaining to the current study was collected, and thematic and pre-field maps were developed. The thematic maps prepared in the present study include: Facet (base) map (1:50,000), relative relief map (1:50,000) and slope morphometry maps (1:50,000).

Slope content map (pre-field), Landuse - landcover map (pre-field), and Landslide event map are some of the pre-field maps generated during the desk study (pre - field).

Relative relief map is prepared with the help of topographical map, and digital elevation map (DEM). Slope morphometry map is prepared along gentle slope direction with in individual facet is prepared and slope angle is measured.

4.3.2 Field Data Collection

During field work primary data collection for various slope instability factors were conducted and the pre - field maps prepared under desk study were verified and modified final maps were prepared.

4.3.2.1 Slope material map

Pre-field slope material map was created during desk analysis by extracting pre-existing lithological and soil maps over the slope facet map. The different rock forms were later graded in terms of intact rock strength and degree of weathering during field work. Visual observations were used to classify the soil type, and soil depth was determined based on slope cuts along the road side, stream cuts, and any other surface indications.

4.3.2.2 Structural discontinuity data

During field work, the orientations of the various discontinuity sets present within a slope facet were measured in terms of dip direction and dip amount. Furthermore, observations were made for the general

state of the rock mass as well as discontinuity characteristics such as spacing, continuity, surface characteristics, discontinuity surface separation and thickness, and the nature of the filling material inside the discontinuity surfaces. Parallelism between discontinuities and slope face strike was later determined. In addition, the relationship between the dip of the discontinuity and the inclination of the slope was established.

4.3.2.3 Landuse - landcover map (final)

During field work the various Landuse and land cover units observed were classified and the pre - field map prepared during desk study was modified and finalized.

4.3.2.4 Ground Water data

During field work the indirect measures on surface indications of groundwater such as; damp, wet, dripping and flowing were observed and recorded slope facet wise.

4.3.2.5 Rain induced manifestation data

During the field work, data on rain-induced manifestations on slopes such as gully formation, toe erosion, stream bank erosion, and so on were gathered. Rainfall's effect on slope instability factors such as slope content, discontinuity orientation relative to slope, and slope morphometry were also taken into account.

4.3.2.6 Manmade activities data

Road or building construction, as well as cultivation practices, are the most common manmade activities in hilly regions. During field work, facet-by-facet observations were made for such developmental activities as understanding how slopes were cut, what kind of slope stabilization and drainage measures were used. Beside, for cultivation, type of irrigation being practiced was considered.

Table 4. 2 Evaluated landslide hazard Classes (adopted from Raghuvanshi et al.,2014)

Landside Hazard Zone		Landside Hazard class	Evaluated landslide Hazard
Very High Hazard zone	(VHHZ)	V	>12
High Hazard zone	(HHZ)	IV	12-8
Moderate Hazard zone	(MHZ)	III	7.9-5
Low Hazard zone	(LHZ)	II	4.9-2
Very Low Hazard zone	(VLHZ)	I	<2

4.2.3 Post field data process

Following the completion of field work, every attempt was made to combine and process all of the data gathered (both primary and secondary data), and to translate it into manageable formats for study. The data collected in pre-field and field investigation were organized, interpreted and presented. Since the current analysis used the SSEP technique, numerical ratings were assigned to each of the intrinsic and triggering parameters based on their contribution to slope instability. The SSEP technique assigns numerical ratings based on logical judgments derived from analyses of internal and external triggering factors and their relative effect on slope instability. The maximum SSEP ratings used in intrinsic and external triggering factors are assigned depending on their relative significance in causing slope instability as table 3.1.

After evaluation The Landslide Hazard Zonation of the study area was carried out through ELH which indicates the net probability of instability and was determined facet wise. The ELH for an individual facet was obtained by adding the ratings of individual intrinsic factors and external triggering parameter obtained from the SSEP rating scheme. The study area was divided into groups of hazard zones according to the SSEP rating scheme and a Landslide hazard zonation map of the study area was generated after collecting primary data for the rating values facet wise and analyzing them. Finally, the validity of the generated LHZ map was evaluated by overlaying the area's landslide inventory map on the LHZ map that was already prepared.

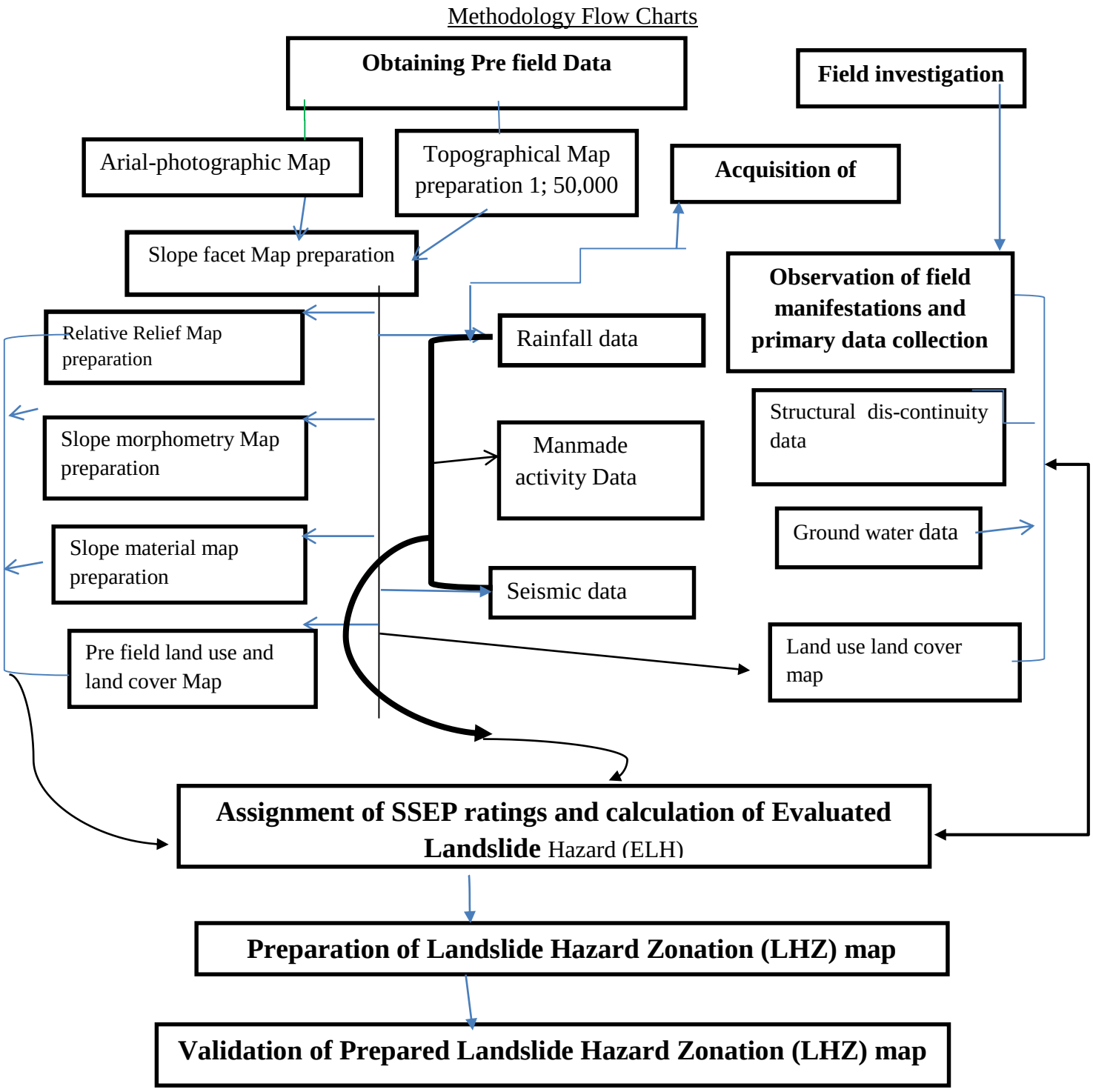


Figure 4. 1 Summary of the general methodology followed during the present study

CHAPTER 5-LANDSLIDES AND SLOPE INSTABILITY IN THE STUDY AREA

5.1 Landslide Inventory

In many studies, different techniques have been used to prepare landslide hazard evaluation and zonation. Landslide inventory is used as a starting point for many landslide hazard zonation and evaluation studies. (Sendu Demise and Raghuvanshi et al., 2019,) Landslide inventories are easy to use and delineate areas affected by landslide processes based on their location and dimensions, as well as the type and material characteristics (Tenalem Ayenew &Barbieri, 2005; fall et al 2004) The landslide inventory is used to indicate only the landslide susceptibility for areas where landslide have been observed. However, it may, not allow us to see the potential landslide area. Despite these limitations, landslide inventory represents the most basic and simple method of landslide hazard assessment because it serves as the basic data source for knowing conditions contributing to landslide occurrence and it is used as a base map with a facet map during field terrain assessment (Casagli et al., 2004). In the present study a detailed inventory of slope instability processes in the study area was carried out based on the secondary data procured during desk study, information obtained from satellite image interpretation, and also from primary data collected during the field work.

The delineated map was checked and confirmed during field work finally, final map of landslide inventory of the study area was produced in Arc-GIS 10.5 (Table 5.2 and Fig 5.1).

Generally, in the present study, a total of 25 landslide inventory processes (Table 5.1) were identified and mapped in (Fig 5.1). The total area damaged by these landslide events is about 0.5 Km^2 (Table 5.1 and Fig 5.1) and this amounts is 1.5 % of the study area (the study area being about 48 Km^2 areal coverage). From this figure it can easily be understood that landslide hazards are one of the serious geo-hazard problems in the study area.

Table 5. 1 Inventory data of Past Landslide activities in the study area.

No	Location			Description
	Northing	Easting	Elivation	
1	7.012034	36.64289	2465	A 60 m by 45 m size slide observed alluvial soil deposite
2	7.113279	36.647657	2420	A 12 m by 60 m size flowing material
3	7.113896	36.647950	2408	A 50 m by 12 m sized debris flowing material
4	7.125177	36.632139	2537	A 50 m by 45 m sized rotational slide
5	7.122248	36.637544	2481	A 25 m by 30 m sized debris flow
6	7.106645	36.688824	2050	A 15 m by 20 m sezed translational slide
7	7.104981	36.681080	2070	A 40 by 80 m sized rotational slide
8	7.106436	36.689911	2047	A 250 m by 80 m sized translational slide
9	7.105034	36.679253	2096	A 20 m by 30 m sized road sided translational slide
10	7.131179	36.626524	2003	A 50 m by 15 m sized earth flow
11	7.120405	36.690251	1899	A 150 m by 50 m sized rotation slides of residual soil.
12	7.117288	36.690275	1885	A 300 m by 100 m sized highly weatherd alluvial soil deposits of translational slide
13	7.108142	36.670903	2039	A 20 by 75 m sized translational slide
14	7.106437	36.674889	2086	A 9 m by 32 m sized rotational slide
15	7.106954	36.669327	2106	A 30 m by 150 m sized well sorted alluvial soil deposite translational slide
16	7.108461	36.669057	2063	A 20 by 80 m sized earth flow (flood formeds slide).
17	7.130331	36.682667	2145	A 150 m by 30 m sized earth flow of residual soil.
18	7.131251	36.682587	2153	A 60 m by 25 m sized earth flow of residual soil.
18	7.114698	36.671216	1943	A 50 m by 80 m sized aluvial soil deposites of rotational slide
20	7.105904	36.674031	2114	A 8 m by 45 m rotational slide
21	7.0862573	36.651078	2013	A 4m by 8 m sized residual soil slide
22	7.092498	36.641744	2283	A 20 m by 30 m sized coluvium soil rotational slide
23	7.096801	36.6494424	2193	A 120 m by 50 m sized redish color residual soil depositand it shows a (spoon shaped) and the slide movement is more or less rotational
24	7.131251	36.682587	2153	A 60 m by 15 m sized expansive residual translational slide.
25	7.097616	36.691688	1894	A15 m by 20 m sized coluvium soil deposite and rotational slide

The 25 landslide inventory data are categorised in to the following landsllide hazard, debris flow (3) facet, rotational slide (9) facet, translational slide (7) facet and earth flow (4) facet. From the total facet rotational slide cover the magor portion.

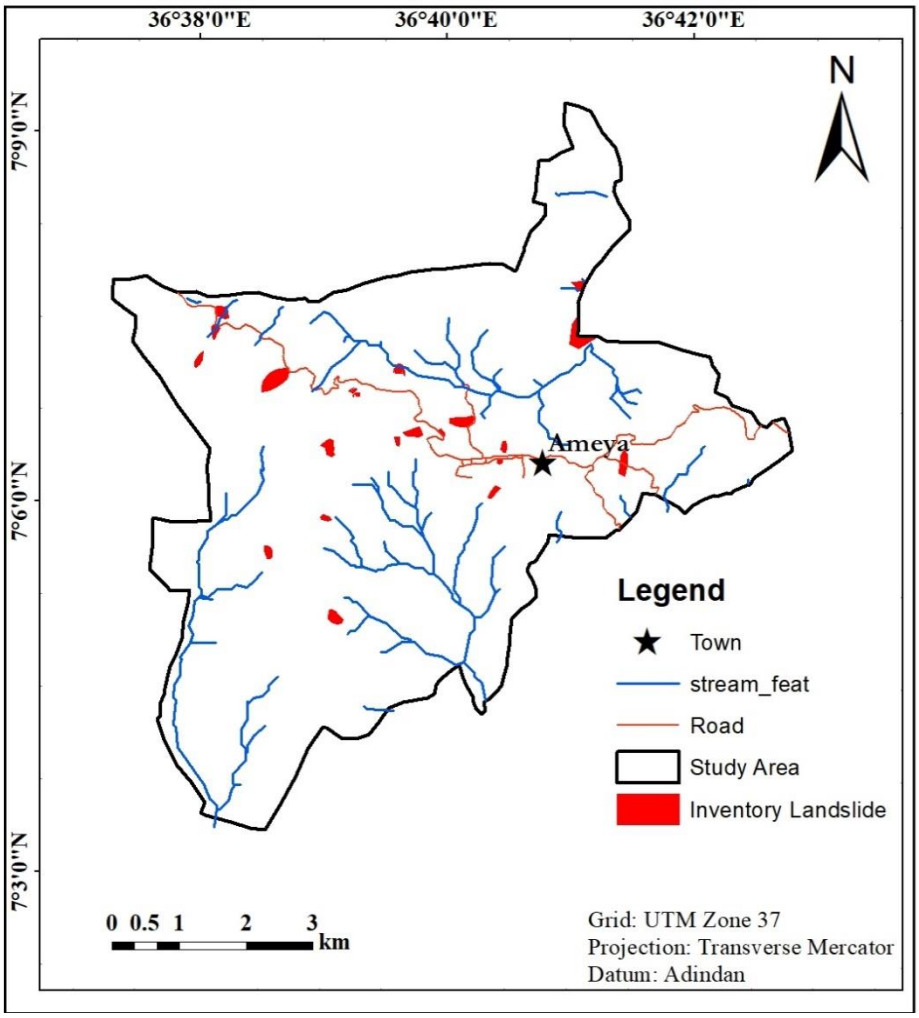


Figure 5. 1 landslide Inventory *Map of the study area*

5.1.2 Landslide Distribution

Among the total number of slope instability processes identified and mapped in the study area (i.e. 25), of 12 are found in the eastern and central, part of the study area (Ameya town and Dukazale kebele). (Table 2, Fig 5.1). About 4 landslides area coverage or identified in northeastern parts of the study area that is in ChareMalaye kebele. In the northwestern part of the study area, about 5 landslides events were mapped i,e in Bubadamota kebele area. The remaining 3 landslide events mapped in the southeastern

part of the study area i,e in Cheka Bocha kebele. The landslide distribution map of the study area (Fig 5.1) clearly indicate that there have been more landslides in the eastern, central and southern part of the study area; whereas, landslides observed in southeastern part of the study area are less.

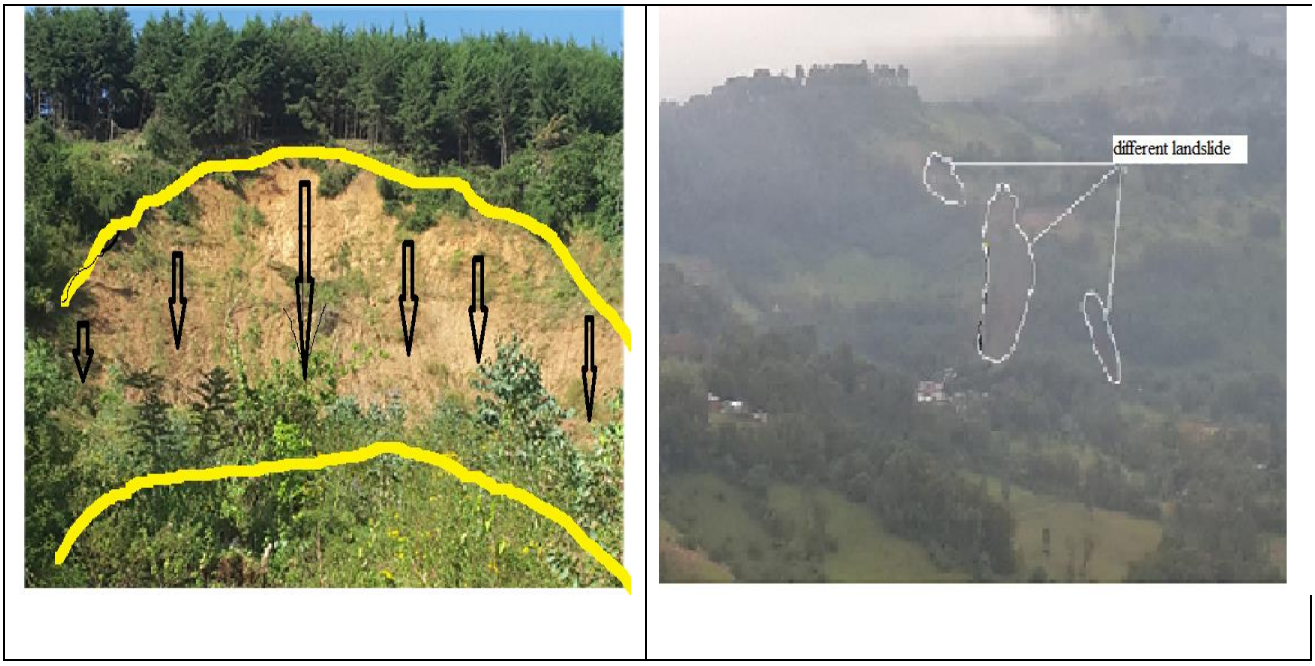


Plate 5. 1: Illustrating Debris flow observed in Dukazale kebele of the study area

5.1.3 Manifestations of Landslides and related instabilities in the area

During the landslide susceptibility zoning process, major considerations are given to evidence of recent landslide features such as: cracks in soils and engineering structures, slope and geomorphological setting, lithology and structure, geotechnical characteristics of soils and rocks, water flux during rainy season and groundwater levels, and distance from active sites that may generate landslides (Ayenew & Barbieri, 2005).

The current study focused on the manifestations of landslides and related instabilities in the study area. Vertical tension cracks, stream bank erosion, road channel displacement, vertical to sub-vertical open

joints on very steep slopes, flows on gentler areas, gabion protections along streams, inclination of tree and traces of major and minor scarps of rock slides are among the observed field manifestations.



Plate 5. 2: Photo showing Stream bank erosion



Plate 5. 3: Bending of trees manifesting slope instability erosion process in study the area

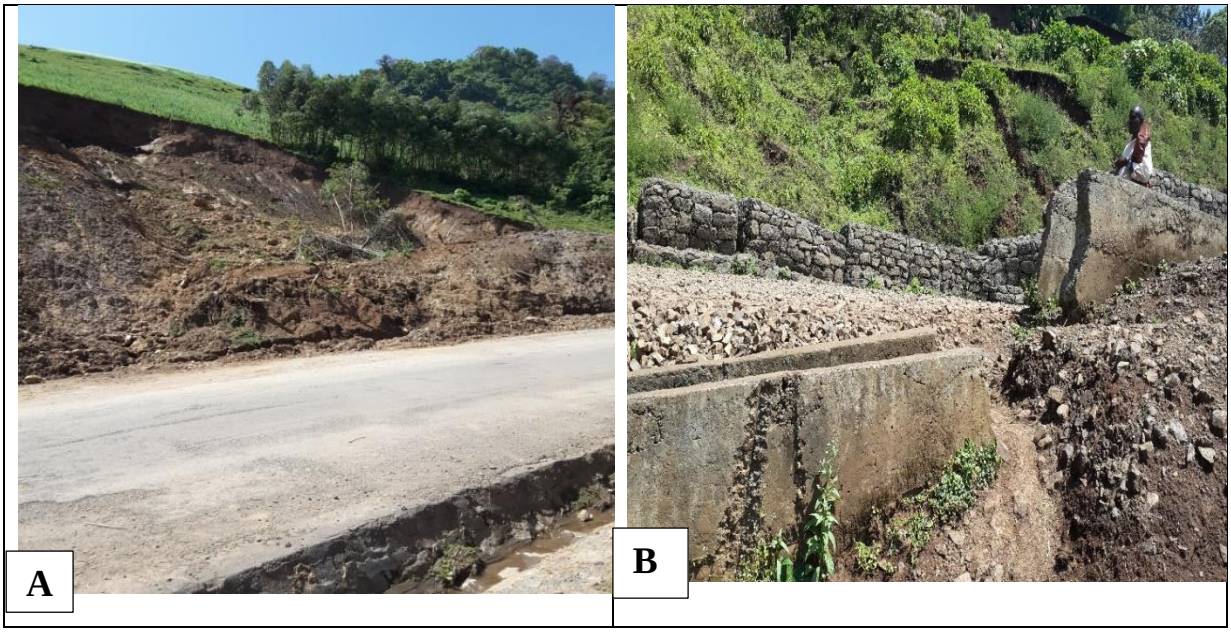


Plate 5. 4: A) disposal material placed at lower side of the road cut slope, B) and the slide One of the gabion protections observed as manifestations of presence of slope instability in the area

Furthermore, there was tree bending, dumping of road cut material (disposal) on the down slope side, and vertical deep tension cracks. After road cut material was disposed of on the down slope side of the cut road slope section, these vertical deep cracks appeared. Plates 5.1–5.3 show illustrations of observed landslides and slope instability in the current study area.



Plate 5. 5: one of the gabion protections observed as manifestations of presence of slope instability in the area

5.2 Possible Causes and Mechanism

Some of the fundamental causes of slope instability are inherent in the rock or soil, in its composition or structure; some, such as the inclination of undisturbed slopes, are relatively constant, while others, such as groundwater levels, are variable; some are transient (seismic vibration), while others are imposed by new events, such as construction activity (Varnes, 1984). Internal causative factors and external triggering factors are the two types of major causes and mechanisms for landslides and slope instability problems found in the current study field. Slope geometry, slope content (lithology or soil type), structural discontinuities, land use and land cover, and groundwater are among the main intrinsic factors; external triggering parameters include seismicity, rainfall, and man-made activities.



Plate 5. 6: Showing contribution of ground water increasingon causing slope instability

5.3 Potential Slope Instabilities

The landslide hazard prediction are not currently prone to landslides is based on the assumption. That hazardous events in the past can provide useful information data that can be used to forecast future events, as a significance, recording these phenomena and in hazard zonation, the factors supposed to be of influence are very important (Soeters and VanWesten, 1996). As a result, a landslide inventory map of the study area was developed, as shown in Fig 5.1. Such mass movement inventory maps are the basis

for most other landslide hazard zonation techniques. However, they can also be used as an elementary form of hazard map because they display the location of a particular type of slope movement.

Slope instability development as a result of the cumulative effects of several topography variables, which must be occupied into interpretation when determining slope instability. As a result, in addition to a complete inventory of slope instability processes and the study of these processes in relation to their environmental setting, the analysis of conditioning and triggering factors, as well as the representation of the spatial distributions of these factors, is extremely important when using landslide hazard zonation techniques.

In the present study, the analysis of potential slope instabilities in the area was conducted by utilizing Slope Stability Susceptibility Evaluation Parameter rating scheme (SSEP) proposed by Raghuvanshi *et al.* (2014) considering both intrinsic slope instability causative factors and external triggering factors. The details of the analysis carried out and the results obtained are discussed in Chapter - 6.

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CHAPTER 6- LANDSLIDE EVALUATION AND ZONATION

6.1 Introduction

Landslides are among the most common natural hazards and are the most damaging, leading to a variety of human and environmental impacts (Chingkhai*et al.,* 2013). The planning, design and execution of developmental schemes, such as road and building construction, are often carried out too quickly due to financial, time and other constraints. Due to this reason, the incidence of landslide is increasing greatly because many projects may not incorporate adequate details of geological and geotechnical considerations. This indicates that preparation of multipurpose terrain evaluation maps, based on the geo-environment of the mountainous terrain is crucial because this map can be used as the basis for planning future development schemes (Ambalagan, 1992).

The intrinsic parameters and external triggering factors are considered in the slope stability susceptibility evaluation parameter (SSEP). The SSEP causative factors are what characterize the slopes favorable and unfavorable stability conditions. The following intrinsic factors were used in this study: slope geometry, slop material, land use and land cover, structural discontinuity, ground water Condition, and external factors; rainfall, seismicity, and manmade activity. (Raghuvanshi et al., 2014; Anbalagan, 1992).

For the purpose of landslide hazard mapping (LHZ) the area of slopes to be covered was divided into individual slope facets. First of all, topographic maps (1:50,000) of the study area was procured from the Ethiopian Mapping Agency. On the topographic maps, delineation of the boundary for the present study area was done. Then, the area of slopes to be covered was divided into individual slope facets. Slope facet is characterized by more or less uniform slope inclination and slope direction. For this purpose topographical map at a scale of 1:50,000 was utilized to demarcate the slope facets. Slope facet boundaries were delineated by major or minor hill ridges, primary and secondary streams and other topographical undulations. Later, this slope facet map was used as a base map for various intrinsic causative and external triggering factor maps. Facet map of the study area prepared during the present study is shown in Fig 6.1.

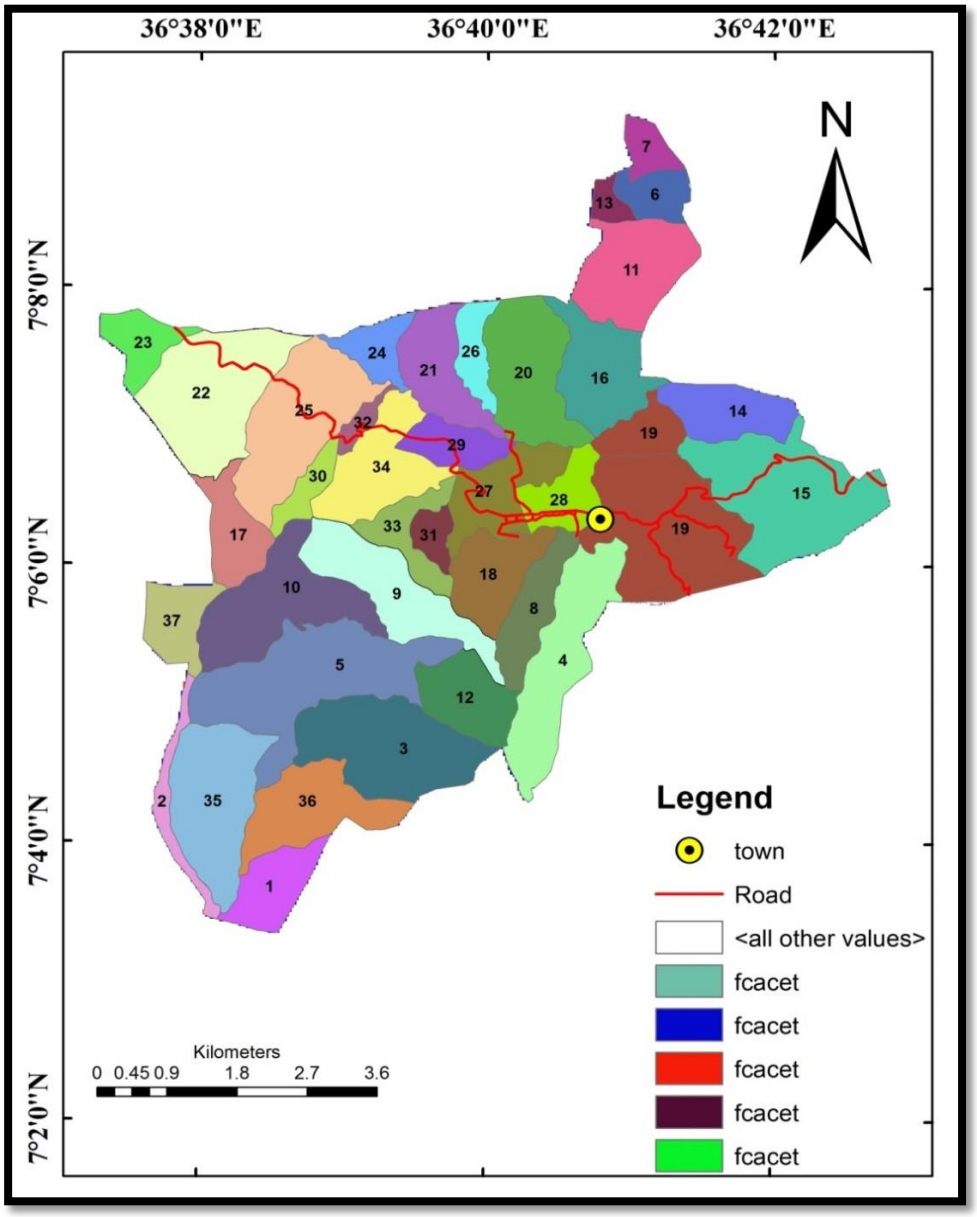


Figure 6. 1 Facet map of the study area

6.2 Intrinsic Causative Factors Evaluation

Intrinsic parameters are the governing factors that decide whether a condition is favorable or unfavorable. Inside the slope, there are stability requirements. The intrinsic causative factors taken into account in this study area Relative Relief, Slope Morphometry, Slope Material, Structural Discontinuity, Groundwater, as well as landuse and landcover.

6.2.1 Slope Geometry

In landslide hazard zonation, the area's slope geometry is also an important factor to consider. Slope geometry describes the height and the angle of the face and includes Relative relief and slope morphometry of the slope.

6.2.1.1 Relative relief

The present study area was prepared by using Topographic Map. Relief is the difference between the highest and lowest elevations, or the height of a single facet. (Raghuvanshi et al., 2014). Landslides are most likely to occur in regions with high relief. Gravity slide and debris drift have become more common in areas with higher relief. By contrasting low relative relief areas with higher relative relief areas have more instability.

Relative relief of the study area was categorized into five classes based on SSEP; Low (less than 50 meters), moderate (51–100 meters), medium (101–200 meters), high (201–300 meters), and very high (more than 301 meters) (Table 6.1). The relative relief slopes were chosen for hazard evaluation as can be observed in Fig, 6.2; 1.17 km^2 (2.41%) of the study area has Low relief, 0.97km^2. (2%) is Moderate relief, 8.64km^2 (17.82%) is High relief, and 37.69km^2 (77.77%) is Very High relief zones. Based on this we can understand that majority of the area lies with in Very High relief zone and this leads to there is higher slope instability in the area. Because, this slope will be more prone for instability if the relative relief of the area is more (Hoek and Bray, 1981); hence, Slope Stability Susceptibility Parametr (SSEP) ratings were given for each facet (Table 6.1). Summary of SSEP ratings assigned for each facet the relative relief is presented in Annexure I.

Table 6. 1 Slope stability susceptibility evaluation parameter rating for Relative relief.

Class	Value range(m)	rating
Very high	>300	1.0
High	201-300	0.8
Medium	101-200	0.6
Moderate	51-100	0.2
Low	< 50	0.1

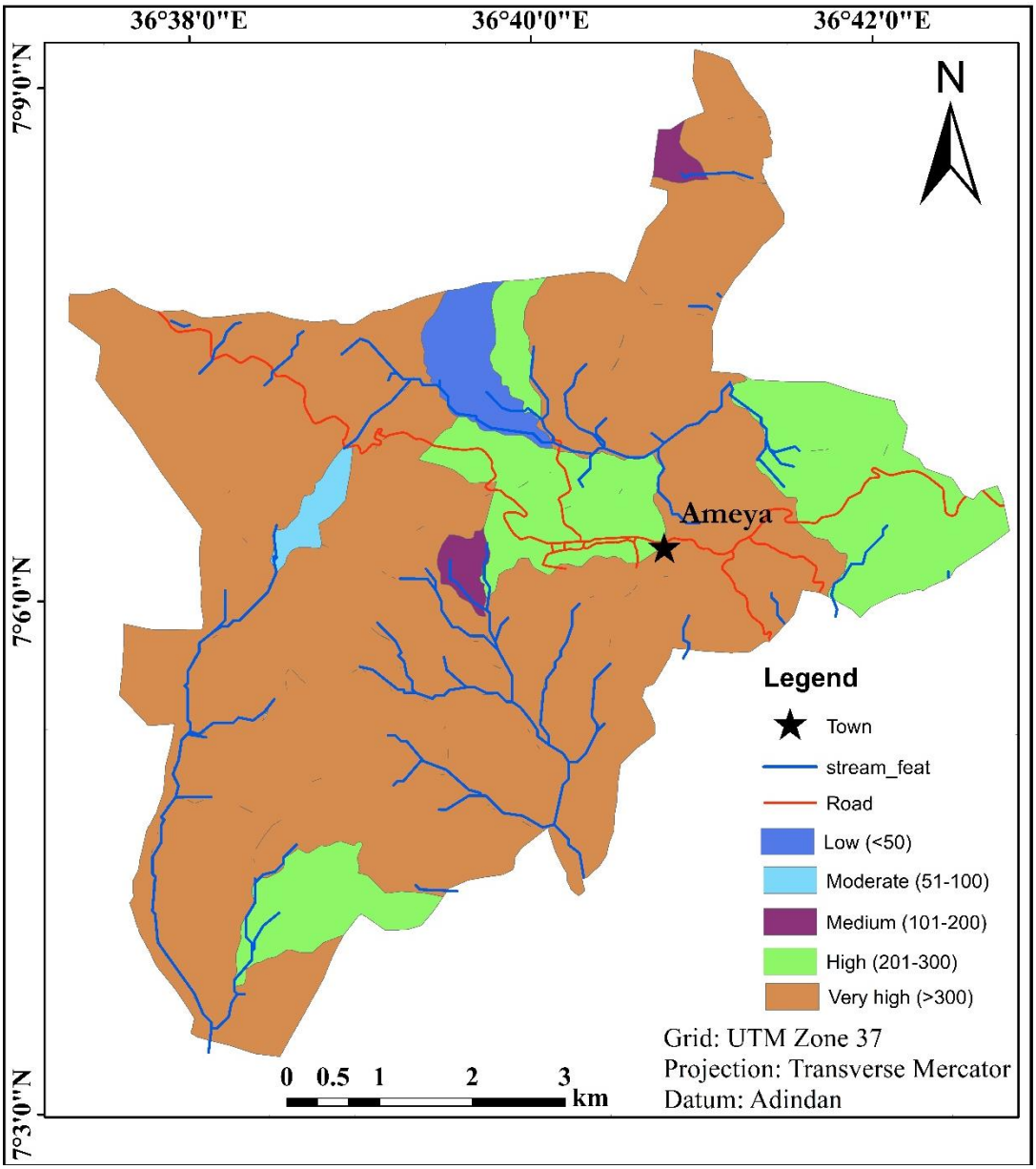


Figure 6. 2 Relative relief map of the study area

6.2.1.2 Slope morphometry

Slope morphometry maps define slope categories on the basis of the frequency of occurrence of particular angles of slope. The geomorphological history of the area determines distribution of the slope categories as the angle of slope of each unit reveals a series of localized processes and controls which has been imposed on the facet (Raghuvanshi *et al.*, 2014).The slope morphometry indicates the steepness

of the slope. This 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 landslide (Asmelash Abay and Barbieri, 2012). The slope morphometric classes are proposed by Anbalagan's (1992) LHEF rating scheme. To prepare the slope morphometry map slope sections along general slope direction within the individual slope facet is prepared and slope angle is measured. With this consideration, slope map of the study area was prepared by dividing the larger topographical map into smaller units (Fig 6.3). The ratings for each sub class of Slope morphometry are given in Table 6.2

Table 6. 2 Slope stability susceptibility evaluation parameter ratings for Slope morphometry classes.

Class	Value range (^{0})	rating
Escarpment/cliff	>45	2.0
Steep slope	36-45	1.7
Moderately steep slope	26-35	1.0
Gentle slope	16-25	0.6
Very Gentle slope	< 15	0.3

In the present study area as shown in Fig 6.3, very gentle slope covers about 6.88 km^2, Gentle slope is 17.64km^2, moderately steep is 21.81km^2, Steep and Escarpment cliff cover 2.13km^2 areas, respectively. This indicates that about 43.75 % of the study area is moderately steep and only about 4.43% of the area falls under steep to Escarpment cliff. Depending up on the slope class, ratings were assigned to individual facets on the basis of SSEP technique. Summary of the ratings assigned to individual facets is given in Annexure I.

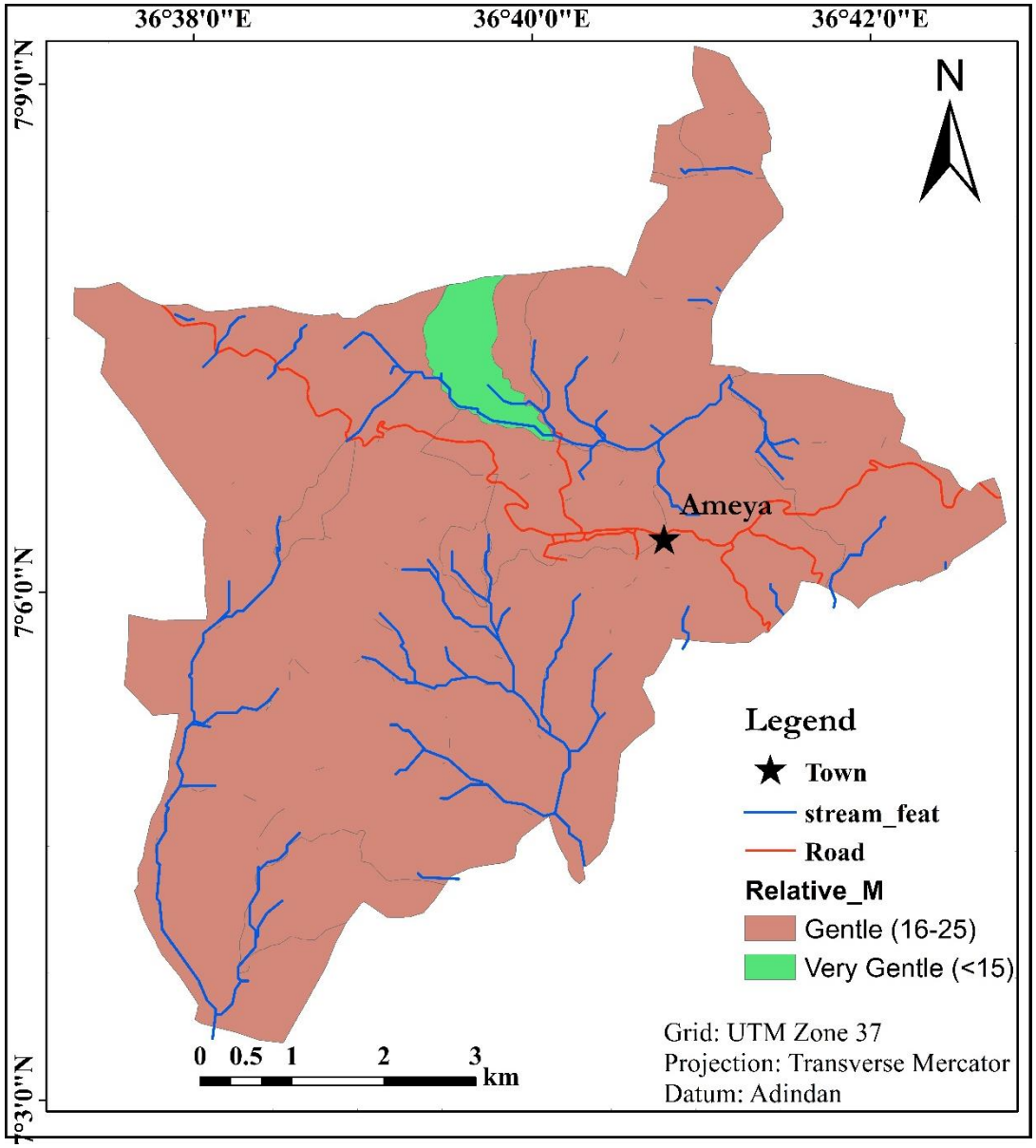


Figure 6. 3 Slope morphometry map of the study area

6.2.2 Slope Material

Slope material may compose of the rock mass, soil, and both rock and soil, the criteria for assigning to sub class of rock type are based on intact rock strength and degree of weathering. Slope material of the present study area was prepared with a scale of 1:50,000 through combining lithological and soil maps of the study area. Lithological map was extracted from the map prepared by Geological survey of

Ethiopia (GSE, 2010) and the soil map was extracted from Soil map of Ethiopia, prepared by Food and Agriculture organization (FAO, 1986). Further, through field survey these maps were verified. Generally, the area is classified into soil mass residual, alluvial and coluvial deposits (lower trachyte flow, trachyte plug, middle basalt flow, middle trachyte flows). Rock with lower trachyte flow soils are mostly present in the south western tip part of the study area and it constitute 0.2% of the total study area; rock with trachyte plug are present at the center and the eastern tip part it covers 7.53% of the study area, rock with middle basalt flow are present small portion at the top of the study area little at the north eastern part and large portion at the south east and south west part it covers 35.41% of the study area; rock with middle trachyte flow are present in all direction and it covers 57.6% of the study area, as shown fig 6.4.

When slopes are covered by soils the rating criteria is based on the genetic class and depth of the soil cover (Raghuvanshi *et al.,* 2014). The various soil types considered and their relative ratings are presented in Table 6.3. Thus, depth of soil cover was also considered while assigning ratings to various soil types. Thus, depending upon weathering class rock type rating and depth of soil cover adjusted (Annexure IV).



Plate 6. 1: Alluvial material found in Ameya town

Table 6. 3 Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme forSlope Material (Raghuvanshi et al., *2014)*

(c) Slope Material			
(i) Rock Type			
	Class *	Description*	Rating
Grade I	Very weak rock	**Strength**: 1-5 MPa ; **Field Estimate of Strength**: Crumbles under firm blows with pointof a geological hammer, can be peeled by a pocket knife. **Examples**: Highly weathered or altered rock.	1
	Weak rock	**Strength**: 5-25 MPa ; **Field Estimate of Strength**: Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer. **Examples**: Chalk, rocksalt, potash.	0.8
Grade II	Medium strong rock	**Strength**: 25-50 MPa; **Field Estimate of Strength**: Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer. **Examples**: Claystone, coal, concrete, schist, shale, siltstone.	0.5
	Strong rock	**Strength**: 50-100 MPa ;**Field Estimate of Strength**: Specimen requires more than one blow of geological hammer to fracture. **Examples**: Limestone, marble, phyllite, sandstone, schist, shale.	0.4
Grade III	Very strong rock	**Strength**:100-250MPa;**FieldEstimateofStrength**:Specimenrequiresmanyblows of a geological hammer to fracture it. **Examples**: Amphibolite, sandstone, basalt, gabbro,gneiss,granodiorite,limestone,marble,rhyolite,tuff.	0.3
	Extremely strong rock	**Strength**: >250 MPa; **Field Estimate of Strength**: Specimen can only be chipped with a geological hammer. **Examples**: Fresh basalt, chert, diabase, gneiss, granite, quartzite.	0.1

Adjustment Factor for Weathering grade for rock mass		
Weathering Grade**	**Description****	**Adjustment Factor**
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces	1
Slightly weathered	Discoloration indicates weathering of the rock material and discontinuity surfaces	1.2
Moderately weathered	Less than 35% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework as core stone	1.5
Highly weathered	More than 35% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework as core stone	1.65
Extremely weathered	All the rock material is decomposed and/or disintegrated to a soil. The original mass structure is still largely intact	1.8
Residual soil	All the rock material is converted to soils, the mass structure and material fabrics are destroyed	2
Note: The adjustment factor for weathering of rock has to be multiplied to the respective rating of fresh rock type of Grade II and Grade III rocks.		

* Rock mass classification and description adopted from Hoek 1997
** Weathering class and description adopted from Irfan and Dearman, 1978

(ii) Soil Type

Class	**Description**	**Ratings**
Collapsible soil	Loose mix of granular material comprising mainly sand and silt. Mainly cohesion-less material which may undergo suffusion.	1
Alluvial Deposits	Well graded material comprising mix of cobble/ pebbles, sand and silt in a matrix of clay.	0.8
Residual Expansive Soils	Mainly comprising clay. Exhibits swelling when saturated and typical shrinkage cracks when dry.	0.6
Poorly Graded Colluvial Material	Poorly graded rounded to sub-rounded rock fragments/ cobble/pebbles mixed in a matrix of fine grained sand or silt.	0.5
Fluvio-glacial Deposits	Well graded angular rock fragments mixed in a matrix of clayey material. Partial interlocking of angular rock fragments.	0.4
Well Graded Colluvial Material	Well graded angular to sub-angular rock fragments mixed in a matrix of clayey material. Partial or well interlocking of angular rock fragments.	0.3
Residual Soils	Well compacted residual deposits of soil mainly comprising silt and clay.	0.2

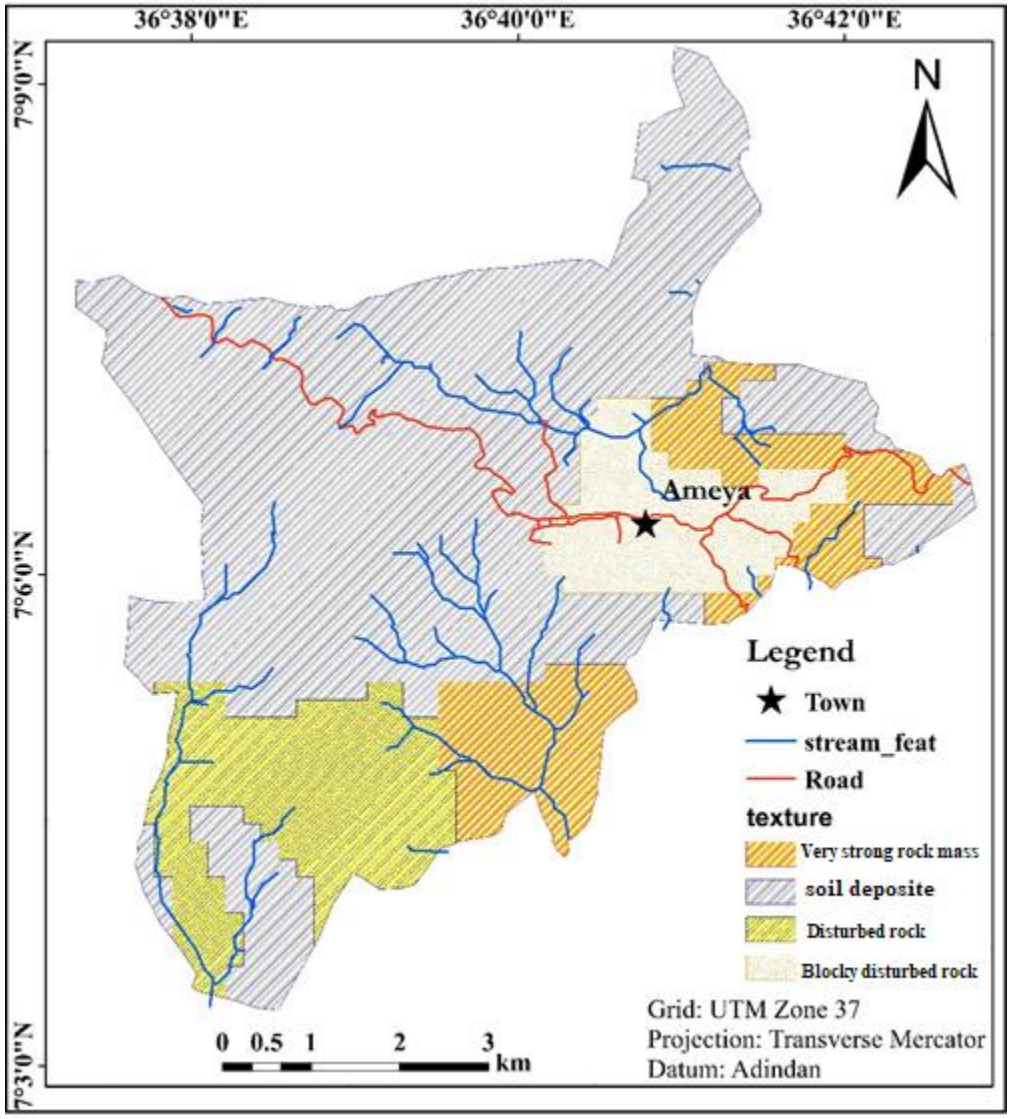


Figure 6. 4 Slope material map of the study area

Slope materials which is found within the study area are alluvial deposits, residual expansive soils, poorly graded and well graded colluvial materials. Recent materials such as slide debris are loose and have low shearing resistance (Anbalagan, 1992). Degree of weathering may affect the relative strength of the rocks therefore it has to be considered while assigning ratings to the rock type. The degree of weathering has been considered as; fresh, slightly weathered, moderately weathered, highly weathered, extremely weathered and rock as soil (Irfan and Dearman, 1978). The soil sub classes are adopted

fromconsolidated and possess better shearing strength than the alluvial or recent deposited soils (Anbalagan, 1992). Depth of soil cover is also considered while assigning ratings to various soil types. Slope material map of the study area has been prepared from field observation using 1:50,000 scale topographic map as base map fig 6.4 classification of soils based on field observation which is proposed by genetic class and depth of the soil cover. A perusal of Fig. 6.4 indicates that very weak rocks, poorly graded and well graded materials are exposed in the study area. Very week rocks covers 24.34% of the total area, 40.54% is covered by alluvial deposits whereas 29.72% and 5.4% is covered by poorly graded colluvial material and well graded colluvial material, respectively. While assigning ratings for soils soil depth was also considered.

6.2.3 Structural Discontinuity

Structures in rock mass refers to primary and secondary discontinuities such as; beddings, foliations, joints and faults. These structural discontinuities play an important role in defining stability condition of the rock slopes (Hoek and Bray, 1997). The important factors of structural discontinuity planes which influence the stability of the rock mass and considered in the present study were; orientation, spacing, continuity, surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces. Orientation of the discontinuity planes plays an important role in stability condition of the rock mass. The rock mass may fail along one or more discontinuity planes.

For the stability condition of rock mass following points are important;

a) The extent of parallelism between the directions of the discontinuity, or the line of intersection of two discontinuities and the slope,

b) Discontinuity plane or plunge of line of intersection of two wedges forming planes day light into the slope at less than the slope angle.

The continuity of discontinuity planes influence the stability of the rock mass provided the orientation of the discontinuity is kinematically critical. If the continuity of the discontinuity planes is more the rock mass will show more unstable condition in comparison to the case when continuity is less and there are intact rock bridges in between.

Three factors are involved when the surface characteristics of discontinuities are considered.

(a) The waviness or undulation of the surface.

(b) The smaller scale roughness of the surface.

(c) The physical properties of the in-filled material between the two surfaces of discontinuity plane.

These surface characteristics of discontinuities are also important in defining stability condition of rock mass (Johnson and Degraff, 1991 as cited in Raghuvanshi *et al.*, 2014).

Therefore, in the present study, data pertaining to structural discontinuities orientation has been observed facet wise from the exposed rock mass and soil deposit and its relation to slope inclinations was determined. The rock mass condition with respect to structural discontinuities was also observed. Besides, data on characteristics of structural discontinuities with respect to spacing, continuity, and surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces has also been collected. Accordingly, while assigning ratings characteristics of structural discontinuities, their interrelationship, and their extent of parallelism to slope has been considered (Table 6.4). SSEP ratings assigned to each parameters of structural discontinuities facet wise are shown in Annexure III.

Table 6. 4Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme for Structural discontinuity

(d) Structural Discontinuities					
(i) Parallelism between discontinuities dip direction and slopes			**(ii) Relationship between dip of discontinuity and inclination of slope**		
$(a_j - a_s)$ or $(a_i - a_s)$	Rating	Planer Mode of Failure $(a_j - a_s)$ Wedge Mode of Failure (ai - as)	$(\beta_j - \beta_s)$ or $(\beta_i - \beta_s)$	Rating	Planer Mode of Failure $(\beta_j - \beta_s)$ Wedge Mode of Failure $(\beta_i - \beta_s)$
0 0	0.5		< (-10^0)	0.5	
1^0 - 5^0	0.4	a_j - Discontinuity dip direction	0^0 - (- 10^0)	0.4	β_j - Dip of Discontinuity plane
6^0 - 10^0	0.3	a_i - Direction of line of intersection of two wedge forming discontinuities	0 0	0.2	β - Plunge of line of intersection of two wedge forming is continuities
11^0 - 15^0	0.25		10^0 - 0^0	0.15	
16^0 - 20^0	0.2	a_s - Direction of Slope inclination	> 10^0	0.1	β_s - Direction of Slope inclination
> 20^0	0.1		**(iii) Dip of discontinuity or plunge of line of**		

			Intersection of wedge forming planes		
(iv) Soil cover depth			**(β_i) or (β_s)**	**Rating**	
Depth	**Rating**		> 45^0	0.5	
> 20m	2.5		45^0 - 35^0	0.4	
20 - 15m	1.8		34^0 - 30^0	0.25	
14 - 10m	1.4		29^0 - 20^0	0.15	
9 - 5m	1		< 20^0	0.1	
< 5m	0.5				

(v) Structural discontinuities and rock mass condition* **	
Condition	**Rating**
Disintegrated – poorly interlocked, heavily broken rock mass with a mixture or angular and rounded rock pieces.	0.25
Blocky/ Disturbed – folded and/or faulted with angular blocks formed by many intersecting discontinuity sets.	0.2
Very Blocky – interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets.	0.1
Blocky – very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets.	0.05

(vi) Characteristics of structural discontinuity

Continuity	**Rating**	**Separation**	**Rating**	**Roughness**	**Rating**	**Infilling**	**Rating**
< 1m	0.02	None	0.02	Very rough	0.02	None	0.02
1 - 2m	0.04	< 0.1mm	0.05	Rough	0.03	Hard filling <5mm	0.04
3 - 9m	0.07	0.1 - 0.9mm	0.07	Slightly rough	0.07	Hard filling >5mm	0.07
10 - 20m	0.1	1 - 5mm	0.12	Smooth	0.1	Soft filling < 5mm	0.12
> 20m	0.15	> 5mm	0.15	Slickensides	0.15	Soft filling > 5mm	0.15

Weathering	**Rating**
Un weathered	0.02
Slightly weathered	0.05
Moderately weathered	0.07
Highly weathered	0.1
Decomposed	0.15

**** Hoek& Bray 1997

6.2.4 Landuse and Landcover

One of the most important factors influencing landslide activity is land use and land cover. (Sendu Demessie and Raghuvanshi et al., 2019). Barren and sparsely vegetated lands are more vulnerable to soil erosion and slope failures, according to (Raghuvanshi et al., 2014). The presence of dense vegetation on a slope indicates that the slope is in good shape, as the vegetation prevents excessive water seepage (Arora, 1997 as cited in Raghuvanshi et al., 2013). Aside from that, the roots of the plants anchor the soil mass, adding to the soil mass's shear strength (Turrini and Visintainer, 1998). In this analysis, a land use-land cover map of the study area was created using secondary data and the interpretation of satellite image sentinel 2A. The map was then adjusted and updated during field work based on visual field observations, and the final map was created in ArcGIS 10.5 as shown in (Fig 6.4). Crop land, forest, Grass land, urban/built-up area, were all used to classify the study area.

Later, in order to assign SSEP ratings to individual facets, geo-processing in a GIS environment was used to produce facet wise percentage area coverage of land use - land cover**.** The classes are sparsely distributed where cultivated land covers majority of the study area around 58.49 % followed by 39.81% is forest cover. 1.07%, of the total area is covered by grassland and about 0.63% of the total area is built up area. The SSEP rating is given in (Table 6.5) and (Annexure III).

Table 6. 5: Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme for land use land cover

(e) Land-use and Land-cover	
Class / Description	**Rating**
Barren land - No vegitation, land not used for any activity	1.5
Sparsely vegetated - Very thin scattered vegetation in the form of wild grass, bushes, scrub and random	1.2
Moderately vegitated area - Moderately covered vegitation land in the form of wild grass, scrub and trees.	0.75
Thickly vegitated forest area - Dense forest area with thick vegetation cover.	0.4
Cutivated land with populated area	0.4

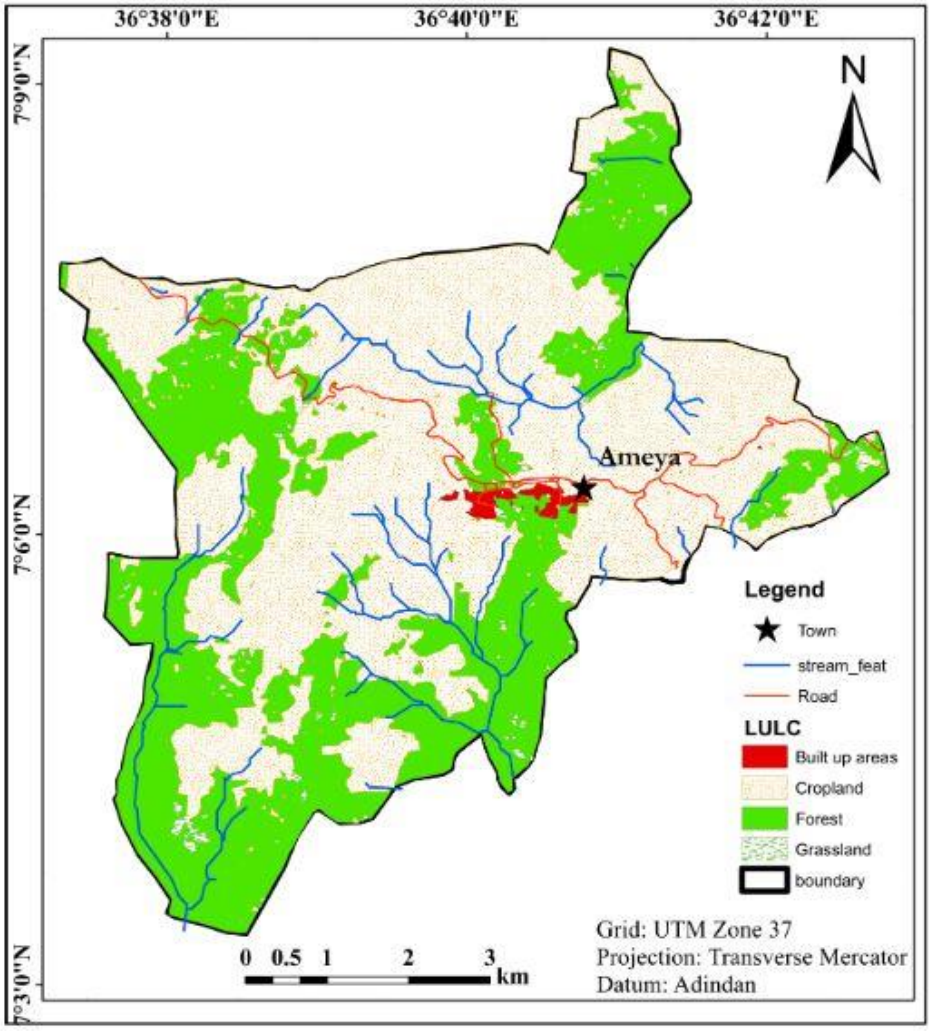


Figure 6. 5 Land use and land cover map of the study area

Table 6. 6 Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme for Land use Land cover

LULC	Area(Km^2)	Area coverage (%)
Forest	19.26	39.81
Grass land	0.52	1.07
Crop land	28.29	58.49
Built up area	0.30	0.63

6.2.5 Groundwater

Groundwater plays an important role in inducing instability to the slopes (Raghuvanshi et al., 2014) study condition for slope stability hazard mapping over relatively large areas the fluctuation of the ground water doesn't indicated directly, for this reason to make a quake up resale on the present study area we have to used indirect surface indication. (Plate 6.2) indicate that the ground water level as a flowing. Therefore, while assigning ratings to ground water in the present study as suggested in SSEP technique and other surface traces such as algal growth, water marks etc. was considered (Table 6.7) such as flowing dripping wet and dump as a rating purpose (Anbalagan, 1992). During field work, spring locations were documented as a facet wise (plate 6.3).

Table 6. 7 Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme for Ground Water

Ground water	
surface trace ground water	Ratings
Flowing-presence of spring on slope facet	2
Dripping-dripping of water on structural discontinuity	1.5
Wet -water marks on rock surface, moss and algal growth in shadow areas	1
Dump-moist condition on rock face surface, moss and algal growth in shadow areas	0.6
Dry-rock face surface is dray, no water along structural discontinuity surface	0



Plate 6. 2 a photo show that increasing of the ground water level

Thus, in assigning ratings for individual facets, the presence of these springs and hand pumps were also considered and ratings were given based on their location and density within individual facet. For instance, the presence of springs around the top part of the slope of the facet is assigned higher rating than those located around toe of the slope. Accordingly, ratings were assigned for ground water and the details are shown in Annexure V.

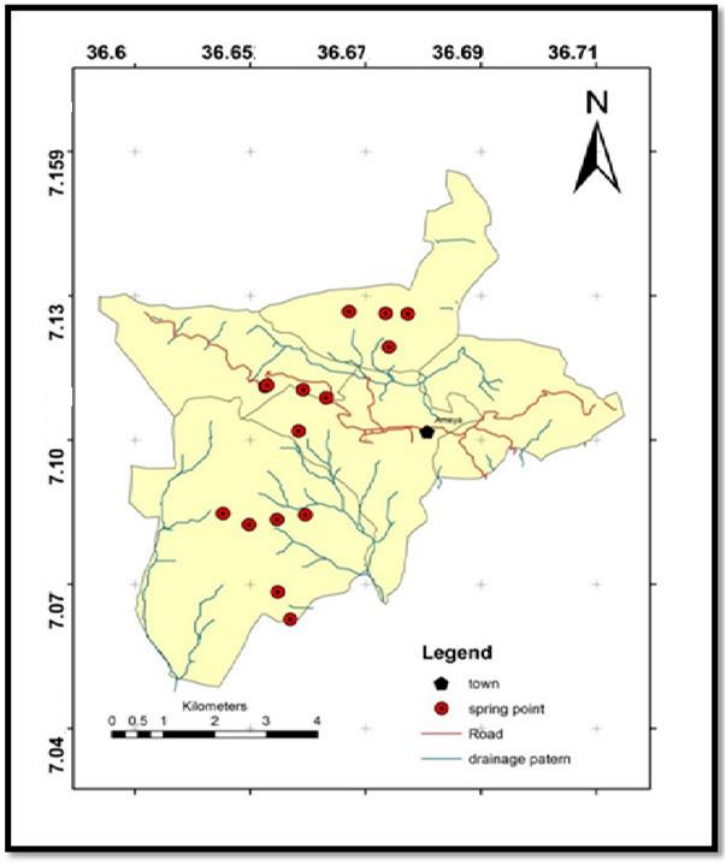


Figure 6. 6 Ground water surface trace map of the study area



Plate 6. 3: Photo showing spring Water

6.3 External Triggering Factors Evaluation

According to Varnes (1984), Dai and Lee (2001) and Raghuvanshi et al. (2014), the external causative factors are relatively variable or dynamic , temporary and imposed by new events which include rainfall, volcanic activity, seismic vibration and manmade activities. In this study, rainfall, seismicity and manmade developmental activities were considered as external causative parameters in landslide hazard zonation of study area by using Slope stability Susceptibility Evaluation Parameter expert method whereas in Landslide hazard evaluation of the study area by using integrated Slope stability Susceptibility Evaluation Parameter.

6.3.1 Seismicity

Landslides or slope failures are caused by ground acceleration caused by seismicity (Keefer, 2000; Parise and Jibson, 2000 as cited in Raghuvanshi et al., 201 4; Bommer and Rodriguez, 2002). Hill slopes that are stable under a motionless load of overlying material will fail when subjected to dynamic loads caused by seismic activity (Hoek and Bray, 1981). Ground acceleration causes a significant slope discontinuity made up of rock mas that can enlarge or open the structural discontinuity. Under seismic loading, slopes consisting of unconsolidated soft sediments or surficial deposits with steep slopes, high seasonal groundwater levels, and shallow rooted or sparse vegetation are also vulnerable to failure.

The frequency of the seismic activity can be compared to ground acceleration. Hays (1980, as cited in Raghuvanshi et al., 2014) established a relationship between earthquake intensity and ground acceleration using the Modified Mercalli intensity scale. This gives g – values, or ground motion expressed in gravitational accelerations, which can be used in engineering calculations (Johnson and DeGraff, 1991 as cited in Raghuvanshi et al., 2014). The current study area has an Updated Modified Mercalli intensity scale of VIII with an average horizontal earthquake acceleration of 0.2 – 0.4g, with an average value 0.3g. Hence, based on Table 6.8, corresponding rating was assigned for seismicity as given in Annexure I.

Table 6. 8 Relationship between intensity of earthquake, based on Modified Mercalli intensity scale, and the ground acceleration.

No	b) Seismicity	
	Ground acceleration	Rating
1	1 – 0.5g	2.0
2	0.5 – 0.1g	1.5
3	0.1 – 0.05g	1
4	0.05 – 0.01g	0.8
5	0.01 – 0.005g	0.4
6	<0.005	0.4

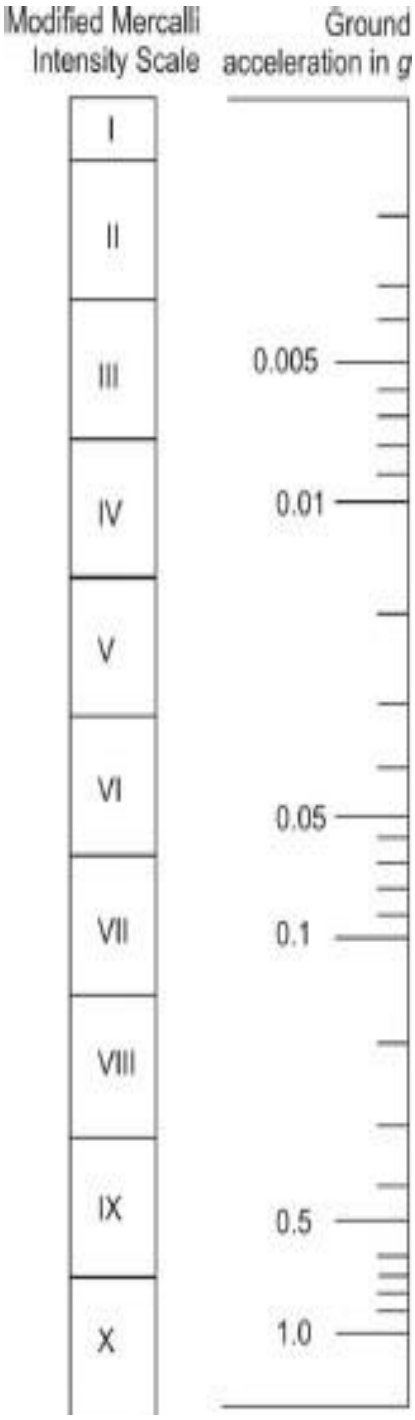


Figure 6. 7 Relationship between intensity of earthquake, based on Modified Mercalli intensity scale, and the ground acceleration.

6.3.2 Rainfall

The rainfall can be considered as an important slope instability triggering parameter in the study area. This is the reason why slope failure increases during the rainy season in the study area.

The rainfall recharges the groundwater and in general saturates the slope. The rock slope developed by the ground water and the ground water increase the pressure and decrease the shear strength (Hoek and Bray, 1981). In soil slopes after saturation from rain water the weight of soil mass increases and thus it adds to the instability of the soil mass.

In order to integrate the impact of rainfall into the SSEP rating system, the mean annual rainfall was used to allocate the ratings. The study area's long-term average annual precipitation, as collected from Ethiopia's metrological agency. Chida meteorology station is 1521mm/year; As the SSEP rating scheme the area fall in within very high class as indicated in (Table 6.9) and **Annexure** I.

As a result, the SSEP rating for mean annual rainfall has been given. Rain-induced manifestations on the slope, such as gully formation, toe erosion, stream bank erosion, and so on, were also taken into account when awarding rainfall ratings. Factors such as rainfall have also been considered to determine the effect of rainfall on slope instability plate 6.3 (Table 6.9).

Table 6. 9 Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme for Eternal Parameters

(a) Rain Fall			**(b) Seismicity**	
(i) Mean annual rainfall (mm)			**Ground acceleration***	**Rating**
Class	**Mean annual rainfall (mm)**	**Rating**	1 - 0.5g	2.0
Very High	> 1500	0.75	0.5 - 0.1g	1.5
High	1101 - 1500	0.60	0.1 - 0.05g	1.0
Moderate	701 -1100	0.30	0.05 - 0.01g	0.8
Low	300 - 700	0.20	0.01 - 0.005g	0.4
Very low	< 300	0.10	< 0.005	0.4
(ii) Rainfall induced manifestation on slope				
Surface Traces				**Rating**
Slope Toe erosion – Toe of the slope is eroded by stream flow, Surface material overhangs and prone for failure.				0.25
Stream bank erosion – Stream water has undercut the banks and made the sides of the slope hang.				0.15
Gully erosion over the slope face				0.10

No Rain induced manifestation on slope	0.00
(iii) Slope Material	
Description	**Rating**
Soil mass – Rainfall will saturate soil mass and pore water pressures will develop.	0.25
Disintegrated – heavily broken rock mass. Much of the rain water will seep into the rock mass and will recharge Groundwater considerably.	0.2
Blocky/ Disturbed – folded and/or faulted with angular blocks formed by many intersecting discontinuity sets.	0.15
Very Blocky – Partially disturbed rock mass having four or more discontinuity sets.	0.1
Blocky – Undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets.	0.05
(iv) Discontinuity Orientation with respect to slope	
Soil Mass	**0.25**
More than one discontinuity dipping into the hill or the bedding joint/discontinuity dipping into the hill.	**0.25**
At least one discontinuity dipping into the hill. Which may or may not be a bedding joint.	**0.12**
None of the discontinuities dips into the hill.	**0.00**

Rainfall adjustment factor for slope morphometry

Class	**Value Range**	**Adjustment factor**
Escarpment/cliff	$> 45^0$	0.1
Steep slope	35^0 - 45^0	0.3
Moderately steep slope	25^0 - 35^0	0.5
Gentle slope	15^0 - 25^0	0.8
Very gentle slope	$< 15^0$	1.0

Rainfall adjustment factor for slope morphometry has to be multiplied with Rainfall rating after summing up (i, ii, iii and iv).



Plate 6. 4 A photo showing contribution of slope toe erosion

6.3.3 Manmade Activities

In addition to the natural triggering parameter, the man-made activities are triggering activity; which increases the possible instability of the slopes (Wang and Niu, 2009 as cited in(Raghuvanshi et al., 2014)). Developmental activities such as road or building construction, as well as cultivation activities, have an effect on slope stability. All of these activities cause an increase in moisture in the soil or rock mass, as well as a shift in slope shape. Cutting or blasting of slope material is often performed in an unplanned manner during road or building construction. Typically, slopes are cut steeply and toe support is withdrawn, resulting in soil or rock mass overhangs that can easily collapse. Furthermore, excavated slope material is often deposited because of steep road cut on down slopes and this deposited material is unconsolidated material so it can be fast for slope movement at the time of intense rain fall (Plate 6.5). The cultivation activities in the study area have visited as densely cultivated, and sparsely cultivated. Some of the main man made activities that are observed in the present study area are shown in Plate 6.5 and the details are illustrated in Fig 6.8

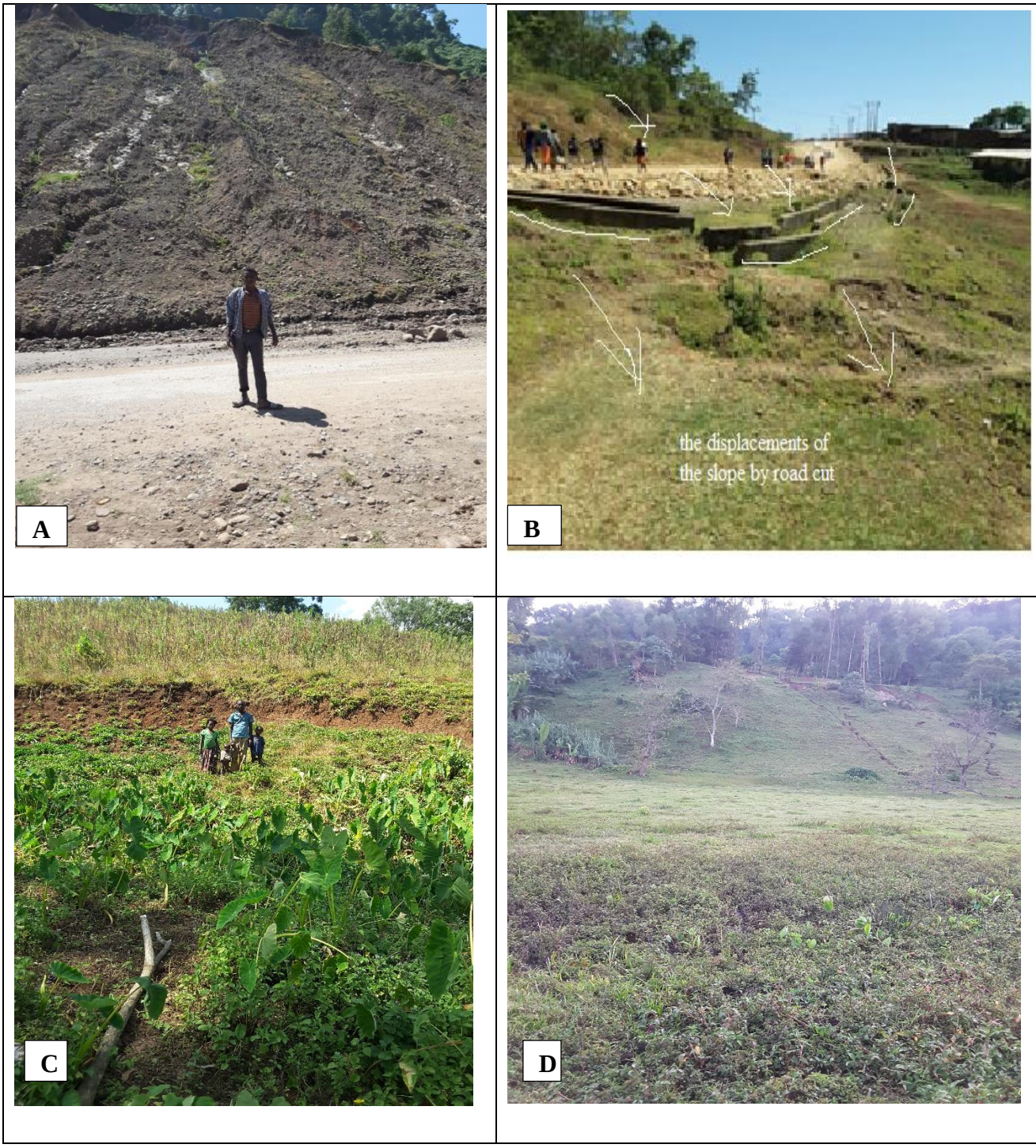


Plate 6. 5: Photo showing road cut effect. A) showing that the steep road cut effect, B) the displacement of the channel C) &D) show that an intensive agricultural practice in in duka zale and Ameya townr respectively

As a result, when awarding SSEP scores, the above considerations were taken into account. For such manmade activities, facets wise were observed to determine how slopes were cut, how excavated slope material was disposed of, and what form and how slope stabilization and drainage measures were implemented. A side from that, the form of irrigation used for agriculture was taken into account. Man-made activities were given SSEP ratings in accordance. Developmental activities (such as excavations for road construction) and cultivation activities are the two key manmade activities in the current study field (such as intensive farming and setting cutting of vegetation to prepare land for farming).

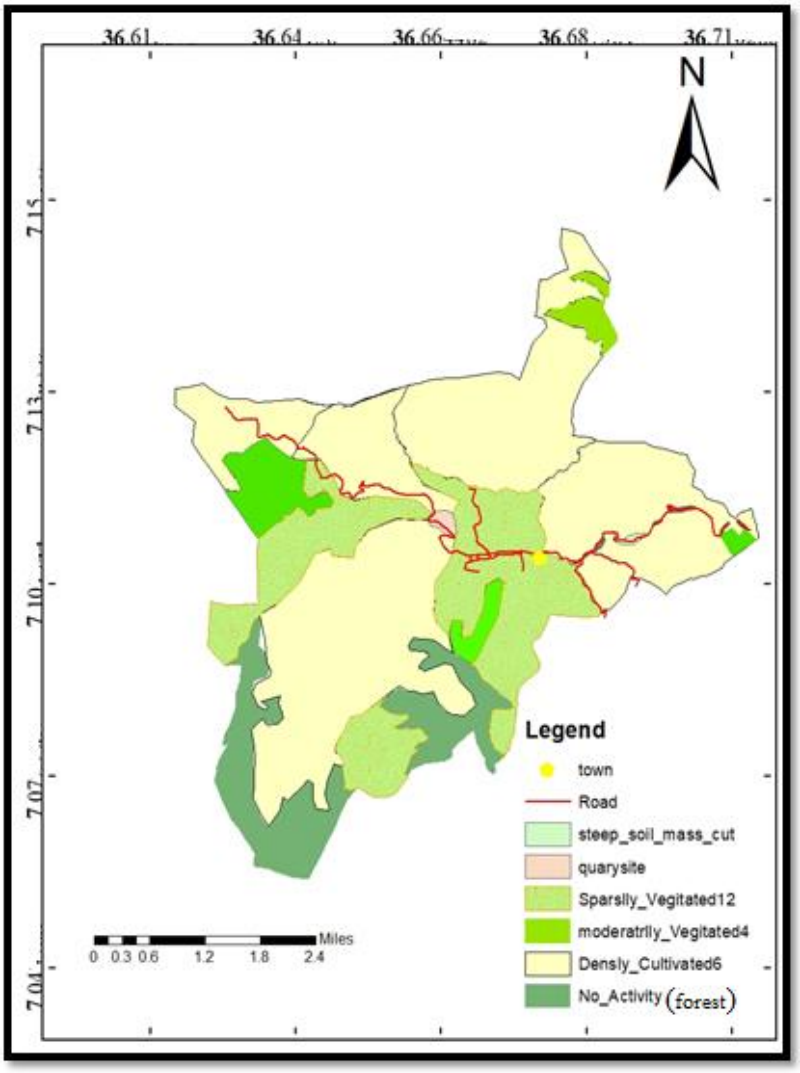


Figure 6. 8 Man-made developmental activities map of the study area.

6.4 Landslide Hazard Evaluation

In order to evaluate landslide hazard zonation of an area individual facet wise ratings for causative intrinsic parameters and external triggering parameter ratings were summed up. The sum total of all ratings for causative intrinsic parameters and external triggering parameter are represented as Evaluated landslide hazard (ELH) (eq.6.2)

ELH = Sum of Ratings of intrinsic parameters (relative relief + slope morphometry + slope Material + structural discontinuity + Landuse and landcover + Groundwater + Sum of Ratings of External parameters (Rainfall + Seismicity + Manmade activities) … …….....eq. 6.1.

The ELH was categorized into five classes as presented in Table 6.8. The SSEP rating scheme facilitates to evaluate an area for landslide hazard zonation under existing and/ or anticipated adverse conditions. The anticipated adverse conditions to which the given area can be subjected may be represented when there will be heavy rains or when the slopes will be subjected to dynamic loading due to seismic activities or both.

Table 6. 10 Evaluated landslide hazard

Landslide Hazard Zone	Landslide Hazard Class	Evaluated Landslide hazard
Very high hazard zone(VHHZ)	V	> 12
High hazard zone(HHZ)	IV	12 - 8
Moderate hazard zone(MHZ)	III	7.9 - 5
Low hazard zone(LHZ)	III	4.9 - 2
Very low hazard zone(VLHZ)	I	< 2

As a result, the current study area was assessed, and the results show that the entire study area falls into two landslide hazard classes, landslide hazard classes III and IV. From the outcome the minimum Evaluated Landslide Hazard is 5.27 which shows Landslide Hazard Class of III and Moderated Hazard

Zone, whereas, and the maximum Evaluated Landslide Hazard value obtained is 9.4, this indicating Landslide Hazard Class fall on IV and High Hazard Zone, (Annexure I).

6.5 Landslide Zonation

The ELH for an individual facet was calculated using the SSEP rating scheme and the ratings of individual intrinsic factors and external triggering parameters. The study area was divided into sections of three hazard zones according to the SSEP rating system, and a Landslide hazard zonation map of the study area was generated in a GIS setting after collecting primary data for the rating values facet wise and analyzing them. Figure 6.9 shows the Landslide Hazard Zonation (LHZ) map that was created.

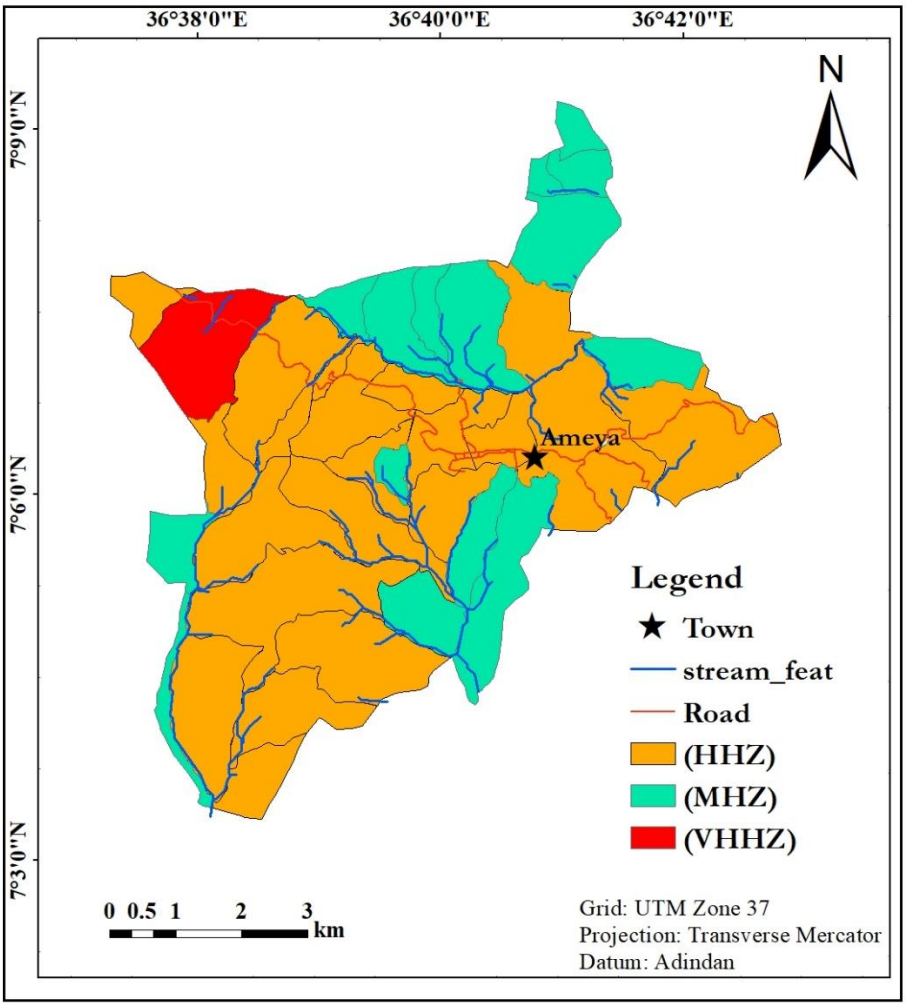


Figure 6. 9 Landslide Hazard Zonation map of the study area

Figure 6.9 shows that approximately 35.14% of the study area is located in the High Hazard Zone, while the remaining 64.86 % is located in the Moderate Hazard Zone. This means that slope instability is a serious issue in the study area, as no area is completely free of the risk of landslides or no low hazard zone.

Very High Hazard zine

5.12 % of the study area and 2.48 km^2 is covered by Very high hazard zone, the area is characterized by very gentle slope, high cultivation, and high soil slope deposit up to 70m, highly weathered disintegrated rock mass, high ground water flow and structural discontinuity. Based on field observation the zone is highly vulnerable to the landslide, there is different indication those are tilted tree, skewed and bog-down house. This zone is high attention area for developmental activities.

High Hazard Zone

The total area of the current study is approximately 48km2. The High Hazard Zone, which covers about 32.35 km2, accounts for about 66.73% of the total area. Moderately steep to steep slopes and major groundwater surface traces such as flowing and dripping define the high hazard zones in the study area. In this zone, the slope material is mostly soil slope deposits and disintegrated weathered rock mass. Field observations, data analysis, and the findings of this study suggest that this zone is highly vulnerable to landslide hazards, requiring extra attention and consideration in the design and preparation of future construction activities and irrigation practices.

Moderate Hazard Zone

Approximately 28.15% of the current study area or 13.64 km2, is in the Moderate Hazard Zone. The study area's Moderate Hazard Zones are distinguished by gentler slopes, moderately cultivation, and moderate planted area. The slope content in this zone is alluvial soil deposit and blocky disrupted (mainly) and disintegrated rock mass; however, weathering is moderate (i.e. slightly weathered to weathered) and the impact of structural discontinuities is relatively moderate.

6.6 Validation of LHZ Map

In the present study area a total of around 25 past landslide events is collected (Table 5.2 in Chapter five). As shown in Fig. 5.1, a landslide inventory map of the study area was also produced at (Chapter

five). Landslide hazards in the study area were evaluated using both intrinsic and extrinsic landslide triggering factors, and a landslide hazard zonation map was developed, as shown in Fig 6.10.

Landslide Inventory map of the study area (Fig 5.1) was overlaid on Landslide Hazard Zonation map (Fig 6.10) of the study area to verify the validity of the created map, as shown in Fig 6.11.

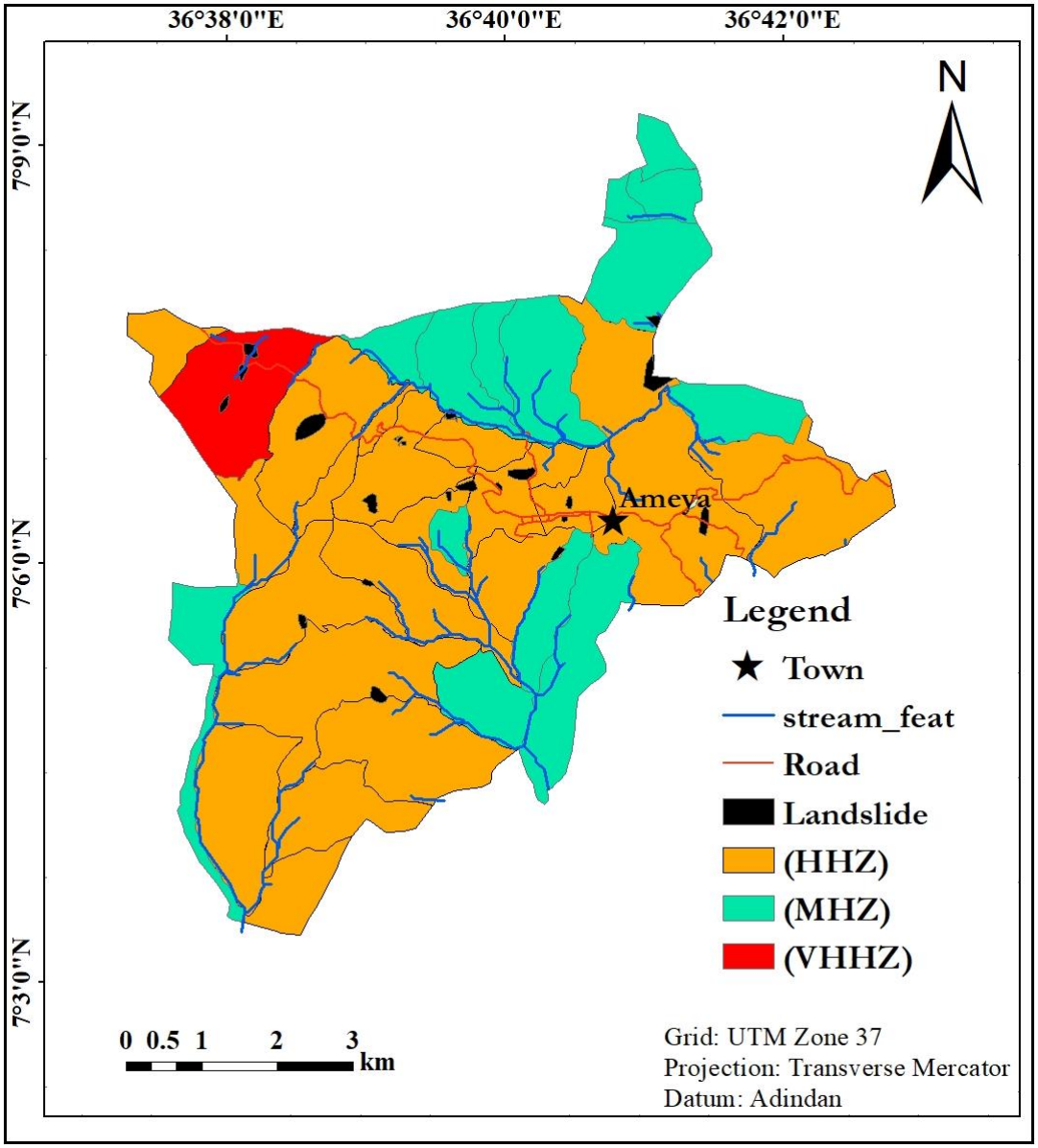


Figure 6. 10 Map showing past landslide events overlaid on LHZ map of the study area

Fig 6.11 shows that among the total number of past landslide events identified in the study area, 3 past landslide events 12% have fallen in very High hazard zone whereas 18 past landslide events 72% have been identified in High Hazard and 4 past landslide events 16% have fallen in moderate hazard zone. This shows that 84 % of the total past landslide events identified are found within very high hazard and High hazard zone.

However, around 14 % of the past landslide activities has not fallen in to Very High Hazard and High Hazard Zone. Rather, it falls into Moderate Hazard Zone. It is clear that the technique used in this study (SSEP) is the quickest technique for covering a wide area in a short period of time.

6.7 Remedial Measures

Natural disasters such as landslides, rock falls, and flooding are common in Ethiopia. Both slow-onset and rapid-onset disasters should be considered, as well as large-scale and localized but frequently occurring disasters like landslides, flash floods, fires, and storms, keeping in mind that they may require different approaches (Jiri Sima et al., 2009)

Since the causes of slope instability in the current study area are multiple and multi-directional, an adaptive approach to remedial measures may be more effective for mitigating the area's potential landslide danger. However, about 84% of previous landslides is occurred in the very High and High Hazard Zone. The other, it is classified as a Moderate Hazard Zone. Retaining walls can be built to stop land from slipping (these walls are commonly seen along roads in hill stations). Therefore, consideration has better be given to all these factors in the area while designing future developmental activities.

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CHAPTER 7-CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The present study area is located at about 458 km south west of Addis Ababa which is situated in the south western part of Omo River basin of Ethiopia. Specifically, it is located in the Northern part of Jimma Zone, Oromia Regional state, in the west part of Kefa zone and eastern part of Dawro Zonae in south Nation National Regional State. Geographically the study area is located between 7°3'N to 7°9'N latitude and36°37' E to 37°43' E longitude.

The area is characterized by deeply dissected gorges, plateau and high altitude continuous chain of mountains and ridges. The rainfall in the study area is above 1500 but the major rainfall is during the summer season mainly from June to September. The local people interviewee in the area indicates that, it is during this peak rain fall time that landslide and flood hazards create damages to the land, houses and property in the study area.

It has been reported by various researchers that the hilly and mountainous terrains of the highlands of Ethiopia are characterized by variable topographical, geological, hydrological (surface and groundwater) and land-use conditions, and are frequently being affected by rainfall-triggered slope failures. However, much has not been reported on earthquake triggered landslides in the country. Thus, the present study was conceived with the idea of incorporating the effect of both rainfall and soil material.

The major objectives of the present study was to prepare Landslide Hazard Zonation (LHZ) map of the study area, by considering both inherent causative and external triggering factors and then, to check the validity of the produced LHZ map. To achieve these objectives a thorough literature review was conducted to develop a conceptual framework of the problem and to identify the appropriate technique required to achieve the goal within the given time. Accordingly, Slope Stability Susceptibility Evaluation Parameter (SSEP) rating scheme was adopted to prepare LHZ map in the present study.

Desk study, field study, data compilation, analysis, and interpretation were used as a general methodology. Preparation of thematic maps (such as facet, relative relief, and slope morphometry) and pre-field maps (such as slope material, Landuse/ landcover, and landslide inventory) were carried out as

part of the desk study. Various primary data was collected during the field survey, as well as the finalization of the pre-field maps. In addition, field observations and data were collected to determine the form of landslides that occurred in the study region. Soil slides and Flows are two types of landslides that have been identified in the current study area. Following the fieldwork, data was analyzed, interpreted, and a report was compiled.

The relative contribution of each intrinsic slope instability causative factor and the influence of each extrinsic triggering factor were evaluated and ratings were given facet wise for each factor using the SSEP rating scheme. Evaluated Landslide Hazard was calculated as the number of all ratings for causative intrinsic and external triggering parameters (ELH). The study area is divided into two Landslide Hazard areas, according to the results of the ELH: "High Hazard" and "Moderately Hazard."

The study's over all findings show that 35.14 % of the current study area is in the High Hazard Zone, while the remaining 64.86 % is in the Moderate Hazard Zone. To effectively mitigate landslide hazards in such terrain, such as the current study location, an LHZ map of the area must be prepared by considering various slope instability causative and triggering factors and applying various LHZ techniques. This LHZ map may be used as a starting point for potential land-use planning and construction projects.

7.2 Recommendation

Following are the suggestions made after evaluating the slide in various locations and evaluating the results of this study as well as actual field observation.

The current study's LHZ map indicates that the entire study area is classified as High Hazard (35.14%) and Moderate Hazard (64.86%). Since the majority of the region is in a moderate danger zone, it is impossible to prevent all construction activities in this area; instead, strategic efforts must be made to analyze and mitigate disaster causes, minimize social and economic vulnerability to hazards, and increase disaster preparedness.

- During the current study's fieldwork, it was also discovered that there is intensive cultivation, on gentle to moderately steep slopes. Developmental practices such as road building and agriculture have been found to have a negative impact on the slope's stability. As a result, it is recommended that extensive work be done to raise local residents' awareness of the role of deforestation in causing slope instability in the region, and that afforestation and reforestation activities be revitalized in the area.

- Infrastructure development in such mountainous, high rainfall area with active landslides should be well studied and design criteria should consider full package of triggering factors.

- The research showed that landslides vary in severity and magnitude at different locations, necessitating different and site-specific Engineering remediation activities for different locations that are appropriate for the defined slope segment, material type, depth to groundwater, soil property, and other factors. As a result, light gabions, retaining walls, and strong drainage systems, as well as networking systems with one another, appear to be needed in some areas.

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Annexure I Ratings assigned to individual facets for internal and external parameters

Facet Id and Area		**SSEP Ratings for Internal Causative Factors**						**SSEP Ratings for External triggering Factors**			**Evaluated Landslide Hazard (ELH)**	**Landslide Hazard Class**	**Landslide Hazard Zone**
Facet ID	**Facet Area (m^2)**	**Relative Relief**	**Slope Morphometry**	**Slope Material**	**Structural Discontinuity**	**Landuse Land cover**	**Ground Water**	**Seismicity**	**Rain Fall**	**Man Made Activity**			
1	6627559.6	1	1	0.8	2.3	0.41	0.93	1.5	0.75	0.075	8.77	IV	(HHZ)
2	554908.5	1	0.3	0.56	1.2	0.43	1.41	1.5	0.75	0.075	7.23	III	(MHZ)
3	1538655.2	1	1	0.75	2.17	0.6	0.8	1.5	0.75	0.25	8.82	IV	(HHZ)
4	10018818.7	1	1	0.6	1.4	0.86	0.55	1.5	0.75	0.25	7.91	III	(MHZ)
5	1524444.2	1	1	0.75	1.99	0.6	0.54	1.5	0.75	0.25	8.38	IV	(HHZ)
6	347149.6	1	0.3	0.37	1.99	0.47	0.50	1.5	0.75	0.15	7.03	III	(MHZ)
7	494925.7	1	0.3	0.52	1.15	0.96	0.50	1.5	0.75	0.25	6.93	III	(MHZ)
8	522796.6	1	0.6	0.6	1.73	0.47	0.55	1.5	0.75	0.11	7.31	III	(MHZ)
9	100504.5	1	1	0.82	2.16	0.4	0.50	1.5	0.75	0.12	8.25	IV	(HHZ)
10	285117.7	1	1	0.75	2.19	0.52	1.06	1.5	0.75	0.18	8.95	IV	(HHZ)
11	167219.8	1	0.3	0.37	2.08	0.87	0.60	1.5	0.75	0.15	7.92	III	(MHZ)
12	81323.5	1	0.6	0.6	1.66	0.56	0.80	1.5	0.75	0.25	7.72	III	(MHZ)
13	209654.2	0.6	0.6	0.37	1.54	0.9	0.60	1.5	0.75	0.075	6.94	III	(MHZ)
14	48502.6	0.8	0.6	0.93	2.11	0.6	0.30	1.5	0.75	0.25	7.84	III	(MHZ)
15	343271.9	1	0.6	0.63	2.1	0.71	0.30	1.5	0.75	0.65	8.24	IV	(HHZ)
16	282839.8	1	1	0.92	2.16	0.75	0.20	1.5	0.75	0.65	8.93	IV	(HHZ)
17	1378893.4	1	1	0.75	1.66	0.43	1.06	1.5	0.75	0.75	8.90	IV	(HHZ)
18	241349.9	1	0.6	0.87	1.86	0.4	0.55	1.5	0.75	0.5	8.03	IV	(HHZ)
19	459341.8	1	0.6	0.95	2.14	0.48	0.70	1.5	0.75	0.6	8.72	IV	(HHZ)
20	314939.5	1	0.3	0.38	2.38	0.47	1	1.5	0.75	0.12	7.90	III	(MHZ)
21	305705.8	0.1	0.3	0.68	1.8	1.03	0.60	1.5	0.75	0.12	6.88	III	(MHZ)
22	368155.5	1	1.3	0.97	2.45	1.10	1.60	1.5	0.75	0.65	12.05	V	(VHHZ)
23	689713.9	1	0.6	0.82	2.44	0.68	1.6	1.5	0.75	0.65	10.04	IV	(HHZ)
24	139884.4	1	0.6	0.68	1.58	0.78	0.8	1.5	0.75	0.12	7.81	III	(MHZ)
25	99059.5	1	0.6	0.93	1.88	0.67	1.9	1.5	0.75	0.5	9.73	IV	(HHZ)
26	1021523.4	0.8	0.3	0.38	1.01	0.56	0.5	1.5	0.75	0.12	5.92	III	(MHZ)
27	808634.0	0.8	0.6	0.87	2.12	0.74	1.45	1.5	0.75	0.65	9.48	IV	(HHZ)
28	373523.1	0.8	0.6	0.57	2.50	0.65	0.95	1.5	0.75	0.65	8.97	IV	(HHZ)
29	277522.0	0.8	1	0.56	1.79	1	0.3	1.5	0.75	0.65	8.35	IV	(HHZ)
30	455165.9	0.2	0.6	0.84	2.09	0.84	0.6	1.5	0.75	0.65	8.07	IV	(HHZ)
31	865506.3	0.6	0.3	0.55	2.13	0.66	0.9	1.5	0.75	0.5	7.89	III	(MHZ)
32	678021.0	1	0.6	0.8	2.45	0.77	0.9	1.5	0.75	0.65	9.42	IV	(HHZ)
33	805929.1	1	0.6	0.82	2.23	0.46	1.15	1.5	0.75	0.5	9.01	IV	(HHZ)
34	827332.8	1	1	0.96	0.75	0.82	0.65	1.5	0.75	0.65	8.08	IV	(HHZ)
35	855917.4	1	1.7	0.32	1.5	0.56	1.41	1.5	0.75	0.1	8.84	IV	(HHZ)
36	1218618.2	0.8	1	0.56	2.48	0.44	0.93	1.5	0.75	0.1	8.56	IV	(HHZ)
37	3206491.2	1	1	0.75	1.81	0.67	0.4	1.5	0.75	0.11	7.99	III	(MHZ)

Annexure II SSEP Ratings assigned to each parameters of Structural Discontinuity.

Code	Type of Structural Discontinuity	Max. SSEP Rating value
A	Relationship between dip of discontinuities and inclination of the slope	0.5
B	Parallelism between discontinuities dip direction and slope inclination	0.5
C	Dip of discontinuities	0.5
D	Soil cover depth	2.5
E	Structural discontinuities and rock mass condition	0.25
F	Continuity	0.15
G	Separation	0.15
H	Roughness	0.15
I	Infilling	0.15
J	Weathering	0.15

Facet	A	B	C	D	E	F	G	H	I	J	Total
1	0.1	0.1	0.1	1.8	0.05	0.02	0.02	0.02	0.02	0.07	2.3
2	0.1	0.1	0.1	0.5	0.2	0.02	0.02	0.07	0.02	0.07	1.2
3	0.2	0.2	0.4	1	0.05	0.04	0.07	0.07	0.12	0.02	2.17
4	0.1	0.1	0.1	0.5	0.2	0.02	0.07	0.07	0.12	0.02	1.4
5	0.1	0.1	0.1	1.4	0.1	0.2	0.02	0.03	0.02	0.1	1.99
6	0.4	0.1	0.25	0.5	0.25	0.02	0.15	0.1	0.12	0.1	1.99
7	0.15	0.15	0.25	0	0.1	0.1	0.12	0.1	0.12	0.06	1.15
8	0.1	0.1	0.1	1	0.25	0.02	0.02	0.07	0.02	0.05	1.73
9	0.1	0.1	0.1	0.5	0.2	002	0.02	0.03	0.02	0.07	2.16
10	0.4	0.4	0.5	0.5	0.1	0.2	0.01	0.07	0.12	0.07	2.19
11	0.1	0.1	0.1	1.4	0.2	0.02	0.02	0.07	0.02	0.07	2.08
12	0.15	0.5	0.4	0	0.1	0.1	0.12	0.1	0.12	0.07	1.66
13	0.15	0.4	0.4	0	0.1	0.1	0.12	0.1	0.12	0.05	1.54
14	0.1	0.4	0.5	0.5	0.25	0.02	0.05	0.1	0.04	0.15	2.11
15	0.4	0.4	0.5	0.5	0.05	0.02	0.12	0.02	0.04	0.05	2.1
16	0.1	0.1	0.1	1.4	0.2	0.02	0.02	0.1	0.02	0.1	2.16
17	0.15	0.1	0.5	0	0.1	0.5	0.12	0.1	0.04	0.05	1.66
18	0.1	0.2	0.1	1	0.25	0.02	0.05	0.07	0.02	0.05	1.86
19	0.2	0.4	0.5	0.5	0.25	0.02	0.05	0.03	0.04	0.15	2.14
20	0.1	0.1	0.1	1.8	0.1	0.02	0.02	0.02	0.02	0.1	2.38
21	0.5	0.1	0.5	0.5	0.04	0.02	0.03	0.02	0.02	0.07	1.8
22	0.5	0.2	0.5	0.5	0.25	0.04	0.15	0.17	0.04	0.1	2.45
23	0.3	0.25	0.4	0.5	0.5	0.05	0.15	0.12	0.12	0.05	2.44
24	0.5	0.1	0.5	0.5	0.125	0.02	0.03	0.02	0.02	0.07	1.58
25	0.15	0.2	0.1	1	0.2	0.04	0.05	0.02	0.02	0.1	1.88
26	0.1	0.1	0.1	0.5	0.05	0.02	0.02	0.03	0.04	0.05	1.01
27	0.1	0.1	0.1	1.4	0.25	0.02	0.05	0.07	0.02	0.1	2.12
28	0.1	0.1	0.1	1.8	0.2	0.02	0.02	0.07	0.02	0.07	2.5
29	0.2	0.3	0.15	0.5	0.2	0.2	0.05	0.07	0.02	0.1	1.79
30	0.1	0.3	0.5	0.5	0.05	0.2	0.07	0.15	0.15	0.07	2.09
31	0.1	0.1	0.1	1.4	0.25	0.02	0.02	0.02	0.02	0.1	2.13
32	0.1	0.1	0.1	1.8	0.25	0.02	0.02	0.03	0.02	0.01	2.45
33	0.1	0.1	0.15	1.4	0.25	0.02	0.02	0.07	0.02	0.1	2.23
34	0.1	0.1	0.1	0	0.05	0.02	0.05	0.15	0.15	0.035	0.75
35	0.1	0.1	0.4	0.5	0.2	0.02	0.02	0.07	0.02	0.07	1.5
36	0.3	0.15	0.4	1	0.25	0.04	0.12	0.1	0.02	0.1	2.48
37	0.3	0.2	0.4	0.5	0.05	0.2	0.02	0.03	0.04	0.07	1.81

Annexure III SSEP Ratings assigned to each parameters of Land use - Land cover

Facet ID	Grass Land (0.75)		Bare Land (1.5)		Cultivated Land(0.4)		Shrub Land (1.2)		Forest Land (0.4)		Total SSEP Rating
	%	Rating	%	Rating	%	Rating	%	Rating	%	Rating	
1	5	0.03	0.0	0.0	0.0	0.0	0.0	0.0	95	0.38	0.41
2	10	0.07	0.0	0.0	0.0	0.0	0.0	0.0	90	0.36	0.43
3	0.0	0.0	0.0	0.0	50	0.2	25	0.3	25	0.1	0.6
4	0.0	0.0	0.0	0.0	55	0.4	35	0.42	10	0.04	0.86
5	25	0.18	0.0	0.0	45	0.18	15	0.18	15	0.06	0.6
6	10	0.07	0.0	0.0	15	0.06	5	0.06	70	0.28	0.47
7	25	0.18	0.0	0.0	55	0.4	15	0.18	5	0.02	0.96
8	20	0.15	0.0	0.0	0.0	0.0	0.0	0.0	80	0.32	0.47
9	0.0	0.0	0.0	0.0	75	0.3	0.0	0.0	25	0.1	0.4
10	35	0.26	0.0	0.0	45	0.18	0.0	0.0	20	0.08	0.52
11	50	0.37	0.0	0.0.	25	0.2	25	0.3	0.0	0.0	0.87
12	45	0.3	0.0	0.0	10	0.04	5	0.06	40	0.16	0.56
13	45	0.33	25	0.37	20	0.08	10	0.12	0.0	0.0	0.9
14	0.0	0.0	0.0	0.0	65	0.26	25	0.3	10	0.04	0.6
15	10	0.07	0.0	0.0	40	0.16	40	0.48	0.0	0.0	0.71
16	15	0.11	0.0	0.0	65	0.56	0.0	0.0	20	0.08	0.56
17	20	0.15	0.0	0.0	30	0.12	0.0	0.0	40	0.16	0.43
18	30	0.22	0.0	0.0	45	0.18	10	0.12	15	0.06	0.4
19	25	0.18	0.0	0.0	50	0.2	0.0	0.0	25	0.1	0.48
20	20	0.15	0.0	0.0	65	0.26	0.0	0.0	15	0.06	0.47
21	10	0.07	0.0	0.0	0.0	0.0	75	0.9	15	0.06	1.03
22	15	0.21	0.0	0.0	65	0.46	10	0.29	10	0.04	1.1
23	0.0	0.0	0.0	0.0	40	0.16	35	0.42	25	0.1	0.68
24	25	0.18	0.0	0.0	55	0.4	15	0.18	5	0.02	0.78
25	10	0.07	0.0	0.0	45	0.18	30	0.36	15	0.06	0.67
26	0.0	0.0	0.0	0.0	70	0.28	20	0.24	10	0.04	0.56
27	25	0.18	0.0	0.0	25	0.1	45	0.54	5	0.02	0.74
28	50	0.37	0.0	0.0	15	0.06	10	0.12	25	0.1	0.65
29	25	0.18	0.0	0.0	0.0	0.0	65	0.78	10	0.04	1
30	0.0	0.0	0.0	0.0	35	0.14	55	0.66	10	0.04	0.84
31	25	0.18	0.0	0.0	55	0.4	0.0	0.0	20	0.08	0.66
32	50	0.37	0.0	0.0	25	0.1	25	0.3	0.0	0.0	0.77
33	25	0.18	0.0	0.0	25	0.1	10	0.12	40	0.16	0.46
34	25	0.18	0.0	0.0	55	0.4	20	0.24	0.0	0.0	0.82
35	25	0.18	0.0	0.0	25	0.1	10	0.12	40	0.16	0.56
36	0.0	0.0	0.0	0.0	0.0	0.0	5	0.06	95	0.38	0.44
37	20	0.15	0.0	0.0	30	0.12	25	0.3	25	0.1	0.67

Annexure IV Ratings assigned to Slope material for individual facets

ID	Collapsible soil (1)		Alluvial deposits (0.8)		Residual Expansive soil (0.6)		Poorly Graded Expansive soil (0.5)		Fluvial glacial deposits (0.4)		Well graded colluvial Material (0.3)		Residual Soil (0.2)		SSEP Rating
	Adju. fact.	Rating	Adju. fact	Rating	Adju. fact	Rating	Adju. fact	Rating	Adju. fact	Rating	Adj.fact	Reting	Adj.fact	Rating	
1	1	0.0	1.2	0.5	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.1	0.8
2	1	0.0	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.1	0.56
3	1	0.0	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.1	2	0.1	0.75
4	1	0.0	1.2	0.5	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.6
5	1	0.0	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.1	2	0.1	0.75
6	1	0.2	1.2	0.0	1.5	0.1	1.65	0.0	1.8	0.0	1.9	0.0	2	0.01	0.37
7	1	0.02	1.2	0.0	1.5	0.2	1.65	0.0	1.8	0.0	1.9	0.0	2	0.1	0.52
8	1	0.0	1.2	0.5	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.6
9	1	0.7	1.2	0.1	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.82
10	1	0.5	1.2	0.0	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.03	2	0.1	0.75
11	1	0.02	1.2	0.0	1.5	0.1	1.65	0.0	1.8	0.0	1.9	0.0	2	0.1	0.37
12	1	0.0	1.2	0.5	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.6
13	1	0.2	1.2	0.0	1.5	0.1	1.65	0.0	1.8	0.0	1.9	0.0	2	0.01	0.37
14	1	0.0	1.2	0.0	1.5	0.4	1.65	0.2	1.8	0.0	1.9	0.0	2	0.0	0.93
15	1	0.3	1.2	0.0	1.5	0.0	1.65	0.2	1.8	0.0	1.9	0.0	2	0.0	0.63
16	1	0.2	1.2	0.6	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.92
17	1	0.5	1.2	0.0	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.03	2	0.1	0.75
18	1	0.0	1.2	0.3	1.5	0.0	1.65	0.2	1.8	0.0	1.9	0.0	2	0.0	0.87
19	1	0.2	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.1	2	0.1	0.95
20	1	0.0	1.2	0.0	1.5	0.0	1.65	0.2	1.8	0.0	1.9	0.0	2	0.2	0.38
21	1	0.0	1.2	0.4	1.5	0.0	1.65	0.8	1.8	0.0	1.9	0.0	2	0.1	0.68
22	1	0.0	1.2	0.0	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.3	2	0.2	0.97
23	1	0.0	1.2	0.0	1.5	0.0	1.65	0.5	1.8	0.0	1.9	0.0	2	0.0	0.82
24	1	0.0	1.2	0.4	1.5	0.0	1.65	0.8	1.8	0.0	1.9	0.0	2	0.1	0.68
25	1	0.45	1.2	0.4	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.93
26	1	0.0	1.2	0.0	1.5	0.0	1.65	0.2	1.8	0.0	1.9	0.0	2	0.2	0.38
27	1	0.0	1.2	0.3	1.5	0.0	1.65	0.2	1.8	0.0	1.9	0.0	2	0.0	0.87
28	1	0.0	1.2	0.0	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.3	2	0.0	0.57
29	1	0.2	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.2	1.9	0.0	2	0.0	0.56
30	1	0.2	1.2	0.2	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.2	0.84
31	1	0.0	1.2	0.0	1.5	0.1	1.65	0.0	1.8	0.0	1.9	0.0	2	0.2	0.55
32	1	0.4	1.2	0.0	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.2	0.8
33	1	0.7	1.2	0.1	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.82
34	1	0.6	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.0	0.96
35	1	0.0	1.2	0.1	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.1	0.32
36	1	0.0	1.2	0.3	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.0	2	0.1	0.56
37	1	0.5	1.2	0.0	1.5	0.0	1.65	0.0	1.8	0.0	1.9	0.03	2	0.1	0.75

Annexure V Percentage area coverage of Ground water for individual facets

Percentage Area coverage of Ground water for individual facets.						
Facets	Flowing	Dripping	Wet	Damp	Dry	Total
Max SSEP	2	1.5	1	0.6	0	2
1		10%=0.150	60%=0.60	30%=0.18		0.93
2	30%=0.6	30%=0.450	30%=0.30	10%=0.06		1.41
3	50=0.5			50%=0.3		0.8
4		50%=0.150	40%=0.40		10%=0.0	0.55
5	50=0.5				70%=0.0	0.54
6	50= 0.5				50%=0.0	0.5
7	50= 0.5				50%=0.0	0.5
8		50%=0.150	40%=0.40		10%=0.0	0.55
9	50%=0.5				25%=0.0	0.5
10	25=0.5		25%=0.30	25%=0.24	25%=0.0	1.064
11			75%=0.60		25%=0.0	0.6
12	50=0.5			50%=0.3	50%=0.5	0.8
13			75%=0.60		25%=0.0	0.6
14				50%=0.3	50%=0.0	0.3
15				70%=0.3	30%=0.0	0.3
16				20%=0.2	80%=0.0	0.2
17	25=0.5		25%=0.30	25%=0.24	25%=0.0	1.064
18		50%=0.15	40%=0.40		10%=0.0	0.55
19		15%=0.40		40%=0.3	30%=0.0	0.7
20	60%=1				40%=0.0	1
21		50%=0.60			50%=0.0	0.6
22	70=0.9	30%=0.80				1.7
23	40%=1.1	60%=0.50				1.6
24			50%=0.50	50%=0.3		0.8
25	70% =1.6		30%=0.30			1.9
26	50= 0.5				50%=0.0	0.5
27	40%=0.9	20%=0.15	20%=0.40		20%=0.0	1.45
28	50%=0.4	25%=0.15	25%=0.40			0.95
29	50=03				50%=0.0	0.3
30	40%=0.3	30%=0.30			30%=0.0	0.6
31	50%=0.4				50%=0.5	0.9
32	60%=0.75	40%=0.15				0.9
33	50%=0.75	50%=0.40			50%=0	1.15
34	50%=0.20	10%=0.15	30%=0.30	30%=0.18	20%=0	0.65
35	30%=0.6	30%=0.45	30%=0.30	10%=0.06		1.41
36		10%=0.15	60%=0.60	30%=0.18		0.93
37			50%=0.40		50%=0	0.4

Annexure VI Monthly temperature [0C] at Chida

Name	Element	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chira	TMPMAX	2003	26,4	27,4	25,7	25,5	26,4	24,4	21,2	21,1	22,5	23,8	24,9	24,5
Chira	TMPMAX	2004	24,6	24,9	25,7	24,6	25,4	21,4	21,1	21,7	22,4	23,5	24,2	24,6
Chira	TMPMAX	2005	25,4	28,7	27,1	25,4	24,1	22,9	21,3	22,5	22,9	24	24,5	26
Chira	TMPMAX	2006	26,6	27,6	26,2	24,8	23,9	23,1	21,6	21,2	22,4	23,9	24,1	24,1
Chira	TMPMAX	2007	24,5	25,2	26,6	25,2	24,5	22,2	21,2	21,5	22,7	24	24,8	25,3
Chira	TMPMAX	2008	26	26,6	27,5	24,5	23,6	22,5	20,7	21,6	22,6	23,5	23,9	24,7
Chira	TMPMAX	2009	25,1	25,7	25,9	25,6	25,1	24	22	21,9	22,9	23,6	25	24
Chira	TMPMAX	2010	25,2	24,9	25,2	25,5	24	22,8	21,1	21,5	22,4	24,2	24,4	24
Chira	TMPMAX	2011	24,6	27,3	25,7	25,9	24,5	22,9	22,2	21,6	22,7		24,3	25,2
Chira	TMPMAX	2012	26,5	28,3	28	25,6		25,1	21,2	21,7	22,2	25,2	24,9	25,3
Chira	TMPMAX	2013	25,8	27,1	27,4	28	24,3	22,6	21	21,1	23,3	23,9		
Chira	TMPMAX	2014	25,2	26	25,5	24,3	23,6	23,1	21,2	20,7		23,1	24,5	24,4
Chira	TMPMAX	2015	26,7	27,8	27,7	25,4	24,2	22,9	22,6	22,4		24,5	23,6	
Chira	TMPMAX	2016	24,3	26,5	27,2	24,7	23,4	22,8	21,3	22	23,2	24	24,6	25,3
Chira	TMPMAX	2017	27,4	26,2	26,6	25,8	24,2	23,3	21,4	21,7	22,6	23,7	24,3	26
Chira	TMPMAX	2018	25,9							21,7	23,3	25,3		
Chira	TMPMIN	TEMPMIN Average	24,13	25,01	24,88	23,80	22,75	21,63	20,07	20,35	21,21	22,51	22,80	23,10
Name	Element	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chira	TMPMIN	1985	13,6	14,6	13,6	11,6	11,7	10,9	10,6	10	10,8	10,6	10,6	10,6
Chira	TMPMIN	1986	11,3	12	11,7	12,4	12,6	12,1	11,5	11,6				
Chira	TMPMIN	1987	11,1	11,7	12,9	11,5	11	12,6	11,8	12,5	11,9	12,2	11,6	11,8
Chira	TMPMIN	1988	11,7	12,9	12,9	12,8	13,1	12,6	12,5	12,1	12,2	12,3	11,1	10
Chira	TMPMIN	1989	10,9	11,6	12,2	12	12,1	12,2	11,8	12	11,9	12,1	11,4	11,5
Chira	TMPMIN	1990	10,9	12		12,9	12,6	12	11,3	11,3	11,4	11	11,4	11
Chira	TMPMIN	1991	11,8	11,7	12,5	12,4	12,9	12,5	12,3	12	11,7	11	11,1	10,9
Chira	TMPMIN	1992	11,5	11,8	12,8	13	12,2	11,8	12,2	12,4	11	11,6	11,5	8,3
Chira	TMPMIN	1993	9,4	9,1		10,3	9,4	10,7	9,6	8,8	10,6			
Chira	TMPMIN	1994			10,9	11,4	10,3	11,2	11,9	12	11,1	10,6	10,6	10,7
Chira	TMPMIN	1995	10,8	11,1	11,9	12,3	12,5	12,6	12,6	12,5	12,5	12,2	11,4	11,8
Chira	TMPMIN	1996	11,8	11,8	12,1	12,4	12,5	12,5	12,5	12,2	11,8	11,5	11,4	11,6
Chira	TMPMIN	1997	11,1	10,6	11,2	11,8	11,9	12,2	12,1	11,6	12,3	12,2	12,1	11,7
Chira	TMPMIN	1998	11,5	11,4	11,4	11,8	11,9	12,2	12					
Tercha	TMPMIN	2002	16,8	18,4	17,5	17,2	17,6	17	17	16,4	16,5	16,5	16	16,8
Tercha	TMPMIN	2003	16,3	17,6	17,6	17,7	18	16,6	16,7	17	16,5	16	16,6	15,9
Chira	TMPMIN	2004		12	12,8	12,9	12,6	12,6	12,1	12,2	12,2	11,8	11,9	12,3
Chira	TMPMIN	2005	11,8	13,8	13,5	14	13	12,8	12,7	12,6	12,8	12,1	11,2	10,8
Chira	TMPMIN	2006	12,5	13,1	13	13,1	12,9	11,8	12,7	12,5	12,6	12,5	12,4	12
Chira	TMPMIN	2007	12,5	12,4	13	13	13,2	12,7	12,8	12,7	12,4	11,6	11,4	11,1
Chira	TMPMIN	2008	12,3	12,8	13,2	12,9	12,6	12,6	11,9	12,4	12,4	12,1	11,9	11,7
Chira	TMPMIN	2009	12,2	13	13	13,2	12,9	12,4	12,6	12,6	12,7	12,5	11,6	12,4
Chira	TMPMIN	2010	12	13,4	13	13,8	14	12,9	12,8	12,9	12,9	12,6	12,1	11,8
Chira	TMPMIN	2011	12	12,1	12,6	12,8	12,4	12,3	12,3	12,4	12,5		12,3	12,3
Chira	TMPMIN	2012	12,4	11,9	13	13,2		12,9	12,2	12,3	12,1	12,2	12,3	11,9
Chira	TMPMIN	2013	12,5	13,4	13,7	13,5	12,9	10,4	10,1	9,9	10	9,7		
Chira	TMPMIN	2014	12,3	11,9	12,6	12,6	12,6	12,7	12,3	12,1		12,5	12,3	11,6
Chira	TMPMIN	2015	11,7	13,3	13,4	13,1	13,2	13	12,7	12,6		12,8	12,4	
Chira	TMPMIN	2016	12,8	13,7	14,6	14,2	13,2	12,5	12,9	11,9	11,3		10,9	10,5
Chira	TMPMIN	2017	9	12,9	13,2	13,2	13,1	12,7	12,7	12,9	13,1	12,9	11,8	11,2
Chira	TMPMIN	2018	11,6							12,7	12,3	13,1		
Chira	TMPMIN	TempMAX average	12,00	12,69	13,06	12,97	12,79	12,53	12,37	12,30	12,28	12,24	11,97	11,69
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Chida MAX	24,13	25,01	24,88	23,80	22,75	21,63	20,07	20,35	21,21	22,51	22,80	23,10
		Chida MIN	12,00	12,69	13,06	12,97	12,79	12,53	12,37	12,30	12,28	12,24	11,97	11,69
		Chida MEAN	18,06643	18,85108	18,96964	18,38333	17,76816	17,07917	16,22104	16,3252	16,74222	17,37548	17,38654	17,394

Annexure VII Monthly rainfalls at Chida [mm]

Name	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chira	1986	1,2	79,5	140,4	206,5	153,6	198,8	238	170,3	231,9	70,3	59,4	52,2
Chira	1987	41,5	89,8	120,8	110,7	194	258,4	297,6	207,5	267,3	259,1	16,5	37,9
Chira	1988	212		83,5	74,6	326,4	232,9	295,1	402,3	305,9	196,8	3,8	30,1
Chira	1989	35,1	66,3	129,9	144,6	202,4	167	225,9	158,6	189,9	141,1	62,4	136,7
Chira	1990		81,4		132,2	112,7	263,8	255,5	355,6				
Chira	1991	92,3	58,8	77,4	151	286,5	220,2	299,6	356,2	140,8	74,3	24	42,2
Chira	1992	57,1	113,8	115,1	150,2	199,6	328,4	187,2	169,4	175,8	196,8	47,2	39,7
Chira	1993	81,7	96		192,5	255	304	233	185,6	232,3	213,9	20,4	0,1
Chira	1994	33,9	38,7	84	90,4	146,7	239,6	224,5	238,6	226,4	121,6	28,2	27,3
Chira	1995	7,5	79,5	74,6	182,8	163,7	227,8	246,8	201,8	249,6	120,5	68,1	154,4
Chira	1996	53,9	46,3	244,8	201,6	252,3	238	286,8	176,3	260,1	111,4	124,3	42,2
Chira	1997	73,1	0,5	144,6	185	267,9	255,5	235,7	200,8	207,6	262,5	188,3	99,2
Chira	1998	54,3	33,9	183	122,7	206,1	237,8	234,8	208,7	195,8	32,9	67,2	0
Chira	1999	20,7	20,9	34	118,8		241,5	262,8	133,1	103,4	221,4	21,1	32,1
Chira	2000	17,3	0,6	59,3	137,7	247,2	275,9	230	249,4	192,1			32,6
Chira	2001	19,3	94,3	120,4	185,5	268,9	276,3	243,8	236,6	280,5	210,8	97,5	30
Chira	2002	44,2	11,4	143,2	112,7	187,1	243,6	213,3	239,2	182,2	137	29,3	53,2
Chira	2003	30,6	64,8	94,5	212,3	80,5	229,7	261,9	212,3	217,4	50,5	66,9	48
Chira	2004	106,2	39,2	40,1	183,8	198,6	184,7	298,2	290	209,3	95,1	139,9	57
Chira	2005	25,5	8,5	123,5	127,6	158,1	231,3	284,4	213,5	265,7	146	69,5	0
Chira	2006	56	21,4	188,6	97,6	258,1	348,3	269,7	350	226,7	244,7	68,6	68,5
Chira	2007	105,8	63	115,4	145	264,9	160,9	209,8	196,2	241,2	81,4	109,5	0
Chira	2008	47,8		53,6	272	286	132,1	419,6	305,5	180,7	131,8	83,7	14,2
Chira	2009	104,7	44,5	192,9	155,1	151,8	205,1	201,1	250,4	259,2	206,6	58,5	75,9
Chira	2010	52,8	131,4	68,6	105,7	275	276,5	255	276,6	204,6	169,3	52,5	67,3
Chira	2011	55,4	12,2	72,6	147,1	255,3	293,1	298,4	253,2	287,6		143,2	82,7
Chira	2012	5,4	6,1	66,3	174,5		257,5	278,3	175,6	294,1	52,1	42,4	113
Chira	2013	58,1	33,2	55,9	58,3	298,2	295,2	193,3	200,5	288,1	162,3	42,7	2,5
Chira	2014	60,1	29,8	114,7	269,1	260,5	159,3	131,4	301		213,1	76,4	41,3
Chira	2015	0	8,9	149,2	0	296,9	223,7	178,8	186,4		116	148	
Chira	2016	41,1	31	118	224,4	272,3	230,7	221	201,9	238,9	164	16,5	23,5
Chira	2017	0	138,4	88,5	234,9	299,7	267	229,5	214,3	272,1	271,6	57,7	1,4