Landslide hazard Evaluation and Zonation in Dilbe and its Surrounding area Northwestern Central Ethiopia; An Integrated GIS based Grid Overlay and Statistical Approach

Sendu Demessie

A Thesis Submitted to

School of Earth Sciences

Presented in Partial Fulfilment of the requirements for the Degree of Masters of Science (Environmental Geology)

ADDIS ABABA UNIVERSITY

Addis Ababa, Ethiopia

May, 2018

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Signature Page

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School of Graduate Studies

This is to certify that the thesis prepared by **Sendu Demessie**, entitled: *Landslide hazard evaluation and zonation in Dilbe and its surrounding area Northwestern central Ethiopia; an integrated GIS based grid overlay and statistical approach* and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Environmental Geology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Landslide hazard evaluation and zonation in Dilbe and its surrounding area Northwestern central Ethiopia; an integrated GIS based grid overlay and statistical approach

Sendu Demessie

Addis Ababa University, 2018

The present study was carried out in Dilbe and its surrounding area around Northwestern Central Ethiopian, about 576 km from the capital city Addis Ababa. Due to landslides and related slope instability problems in the Dilbe area roads and agricultural plots are damaged and also local people are displaced from their residences. The main objective of the present study was to evaluate landslide hazard in the area and to produce landslide Hazard Zonation Map of the area. To achieve these objectives integrated GIS based grid overlay and statistical approach was followed. Six causative parameters: namely; slope-material, land use land cover, groundwater surface traces, slope, aspect and elevation were considered for hazard evaluation and zonation. A total of 30 past landslides in the study area were identified and recorded through field survey. An integration of Geographic Information Systems (GIS) based grid overlay and statistical approach was followed to rate the responsible factors for the landslide occurrence. As a part of methodology, a 10 x10 m polygon grid was prepared and overlaid over prepared causative factor maps in GIS environment. This overlay analysis was done to know the presence or absence of each causative factor sub-class within each polygon grid cell. For the purpose of rating of various causative parameters quantitative prediction was established using raster calculator in Arc-GIS, density ratio was made between total pixel count for landslide occur to total pixel count for landslide did not occurred. Later, hazard index ratio was calculated which was further utilized to deduce Landslide susceptibility index (LSI). Within each grid cell depending on presence of various factor classes LSI values were assigned. The sum total of LSI values for six parameters within each grid cell provided total landslide susceptibility index (TLSI), which finally formed the basis to produce LHZ map of the study area. The LHZ map shows that 11.64% (5.774km^2) of the study area has a ‘very high landslide hazard’ (VHH) potential and 19.86% (9.91km^2) 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% (7.22km^2), 38.2% (19.1km^2) and 16% (8km^2), respectively. Validation of the prepared hazard zone map revealed that 74% of past landslides fall within very high hazard and high hazard zone of the prepared LHZ map. Thus, the LHZ map validation provided satisfactory results and the various zones delineated can safely be applied for future developmental planning in the present study area.

Keywords Landslide, Landslide hazard zonation, Hazard index, Landslide susceptibility value

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Sendu Demessie

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Table of Contents

List of Tables

List of Figures

List of Plates

List of Acronyms

DEM	Digital elevation model
FAO	Food and agricultural organization
GIS	Geographic information system
GSE	Geological Survey of Ethiopia
GPS	Global positioning system
HGZ	Homogeneous ground water zone
LHZ	Landslide hazard zonation
LSI	Landslide susceptibility index
LSV	Landslide susceptibility value
TLSI	Total landslide susceptibility index
USGS	United States of Geological Survey
VHH	Very high hazard
HH	High hazard
MH	Moderate hazard
LH	Low hazard
VLH	Very low hazard

Chapter One Introduction

1.1 Background

Many authors define landslides as a geomorphic event that possess rapid or slow downward motion of naturally forming slope material or artificial landfill materials occurring in sloppy terrain (Singhroy, 1995; Wieczorek, 2009). Landslides are one of the harsh natural processes which cause enormous damage to infrastructures and also lead to loss of life (Sarkar and Kanugo, 2004, Marraqu and Jakka, 2014). It happens due to the result of a combination of factors, primarily involving those internal factors like geology, geomorphology and hydrology or by manmade activities like improper land use planning. These factors can cause an immediate or near immediate slope failure either by increasing shears strength or by reducing the strength of slope materials (Sarkar and Kanugo, 2004).

In many of hilly and mountainous terrain of the world landslide caused ground failures are among the common geo-environmental hazards (Kifle Weldaregay, 2013). Now days, landslide occurrence is on the trend of increasing worldwide impact of which cause loss of life, destroying developmental activities, villages and damaging agricultural land (Damtew Tsigi et al., 2017). It may occur in different mechanism at a speed of quickly or in a slow rate, including rock falls, rock slides, debris flow, soil slip, rock avalanche, and mud flow (Chau et al., 2004).

Currently the study of landside hazard has attracted global attention due to having an understanding of its impact and due to increasing urbanization and other developmental activity in mountainous terrain (Aleotti and Chowdhury, 1999). Landslide hazard analysis involves mapping and identifying future hazardous zones through the analysis of controlling parameters (Arnous, 2011). Landslide Hazard Zonation is classification of land surface into areas of different degrees of actual or potential hazards (Varnes, 1984).

For the past several years, several researchers have proposed a number of approaches for the purpose of landslide hazard evaluation, prediction and zonation (Raghuvanshi et al., 2015). Among these experts, statistical and deterministic approaches are common. Each of these approaches has its own merits and demerits over others (Raghuvanshi et al., 2014a; 2014b; Fall et al., 2006; Kanungo et al., 2006; Casagli et al., 2004; Guzzetti et al., 1999; Leroi, 1997).

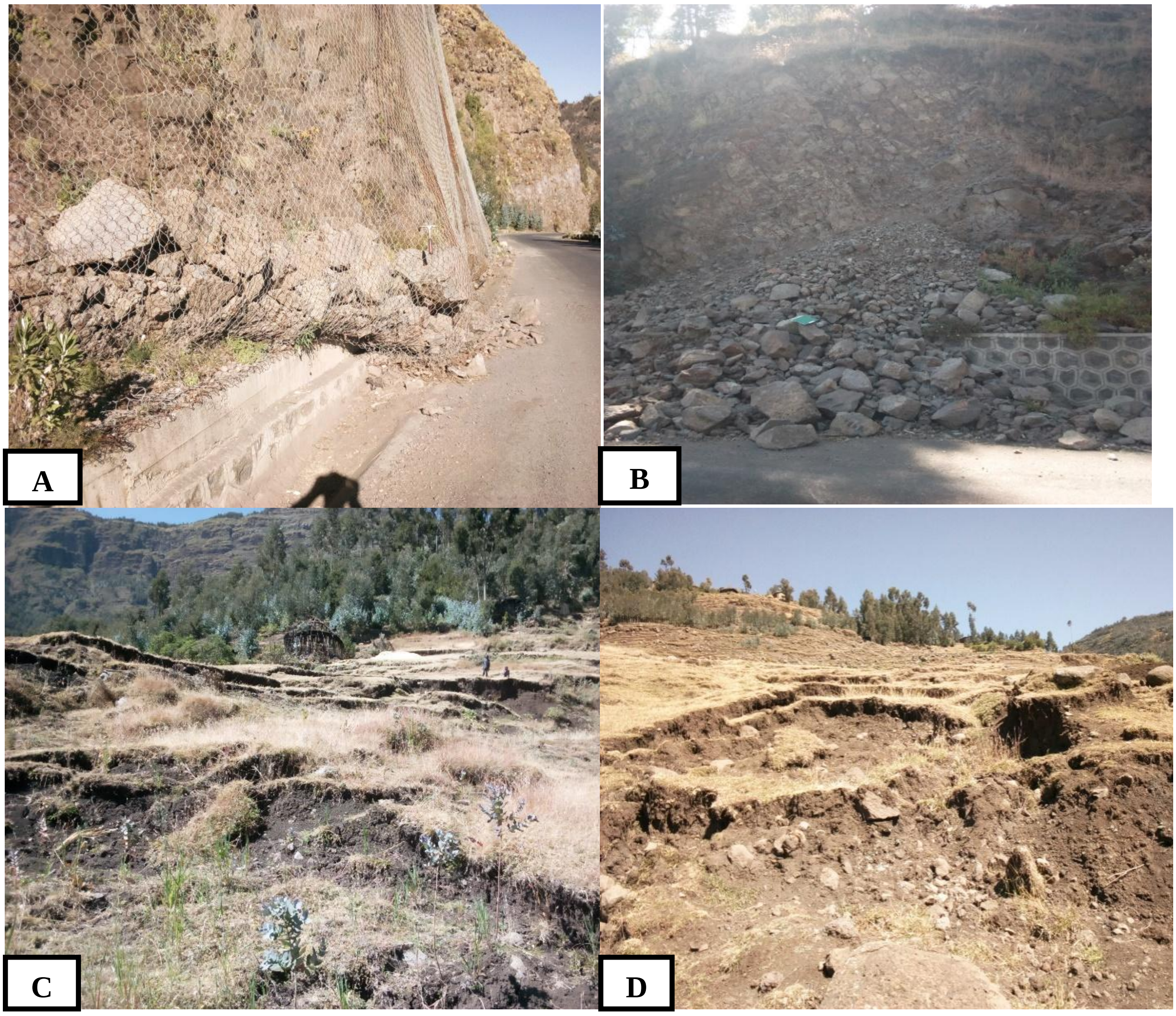
1.2 Problem statement

According to many researchers (Lulseged Ayalew and Yamagishi, 2004; Tenalem Ayenew and Barrberie, 2005; Bekele Abebe et al., 2010; Raghuvanshi 2014a; 2014b), landslide is a common geo-environmental hazard in northern, southern and western highlands of Ethiopia. From the past experience landslide hazard have resulted into damaging infrastructure as well as human life all over the world (Dai et al., 2002; Raghuvanshi et al., 2014a).

The present identified study area is located in north western central Ethiopian highland which is rugged mountainous terrain. The area is known by landslide activities which cause considerable damage on infrastructures especially on road construction and agricultural land.

In mountainous terrain developmental activity especially, road construction covers large area of slope therefore it needs detailed slope stability assessment (Raghuvanshi et al., 2014a). Due to this; LHZ mapping, forecasting, monitoring of landslide is necessary to inform government and the public about the spatial probability of landslide for safer land use planning and developmental activities and to minimize emanation impacts.

Even though the present study area is highly affected by the landslides, either published or unpublished study on landslide has not been reported from the area before the present study. Therefore, this study is focused on the evaluation of the landslide hazard and generating landslide hazard zonation mapping for the proposed study area to reform the current spatial plan and to give insight for local government in managing present and future land use practices.



A) and(B) damaged road due to slope failure; (C) People have been permanently displaced from their residences, as they lost their houses and farm plots; (D) Damaged farm land due to landslide

Plate 1.1 Field photograph showing damaged infrastructure and agricultural land

1.3 Objectives of the research study

1.3.1 General objective

The main objective of the present study is to produce the landslide Hazard Zonation Map of Dilbe and its surrounding area, Gubalaffto Wereda, and North Wello Zone, North Central Ethiopia through integrated GIS based grid overlay and statistical approach.

1.3.2 Specific objectives

(i) To identify and describe the causative factors responsible for possible landslides
(ii) to evaluate the factors influencing landslide hazard initiation and occurrence
(iii) To know the possible slope failure mechanism in the area.
(iv) To produce landslide inventory map from past and existing landslide records.
(v) To assess the relative contribution of causative factors on the landslides.
(vi) To evaluate landslide potential hazard zones in the area.
(vii) To make efficient/ appropriate recommendations.

1.4 Significance of the study

The landslide hazard zonation map of the area provides for planners with a practical and cost-effective way to zone areas susceptible to land sliding. It also helps to do safer strategic planning of future developmental activities like; selection of appropriate sites for road construction, agriculture and other development activities. Further, it may be helpful to minimize the upcoming impact in landslide prone areas by providing a better insight in to the landslide hazards for concerned bodies and local government in managing present and future land use.

1.5 Future research extension

This research was conducted within a small area of North western Ethiopian plateau. Therefore, it is necessary to conduct research work by covering large area of the plateau. In addition to this landslide in the area has damaged the major road which passes from Woldiya to Bahirdar and also local people have been permanently displaced from their residences they lost their house and farm plots. Therefore, it needs further research work on developing a cost effective remedial measures for the landslide hazard.

1.6 Overview of the study area

1.6.1 Location and Accessibility

The study area is located in Northern western central Ethiopia, Amhara regional state, N-Wello zonal administration, Gubalafto Wereda, some 576 km from Addis Ababa the capital city of Ethiopia (Fig 1.1). Geographically it is bounded by UTM co-ordinates 1318000m to 1326500m N and 543200m to 552800mE with a total coverage area of 50 km^2. The study area is accessible by Asphalt road from Addis Ababa to Woldiya which is 521 Km toward the

North and by another asphalt road that extends from Woldiya to the site about 55 Km North West and by all weathered road that extend from the site to its surrounding villages (Fig 1.1).

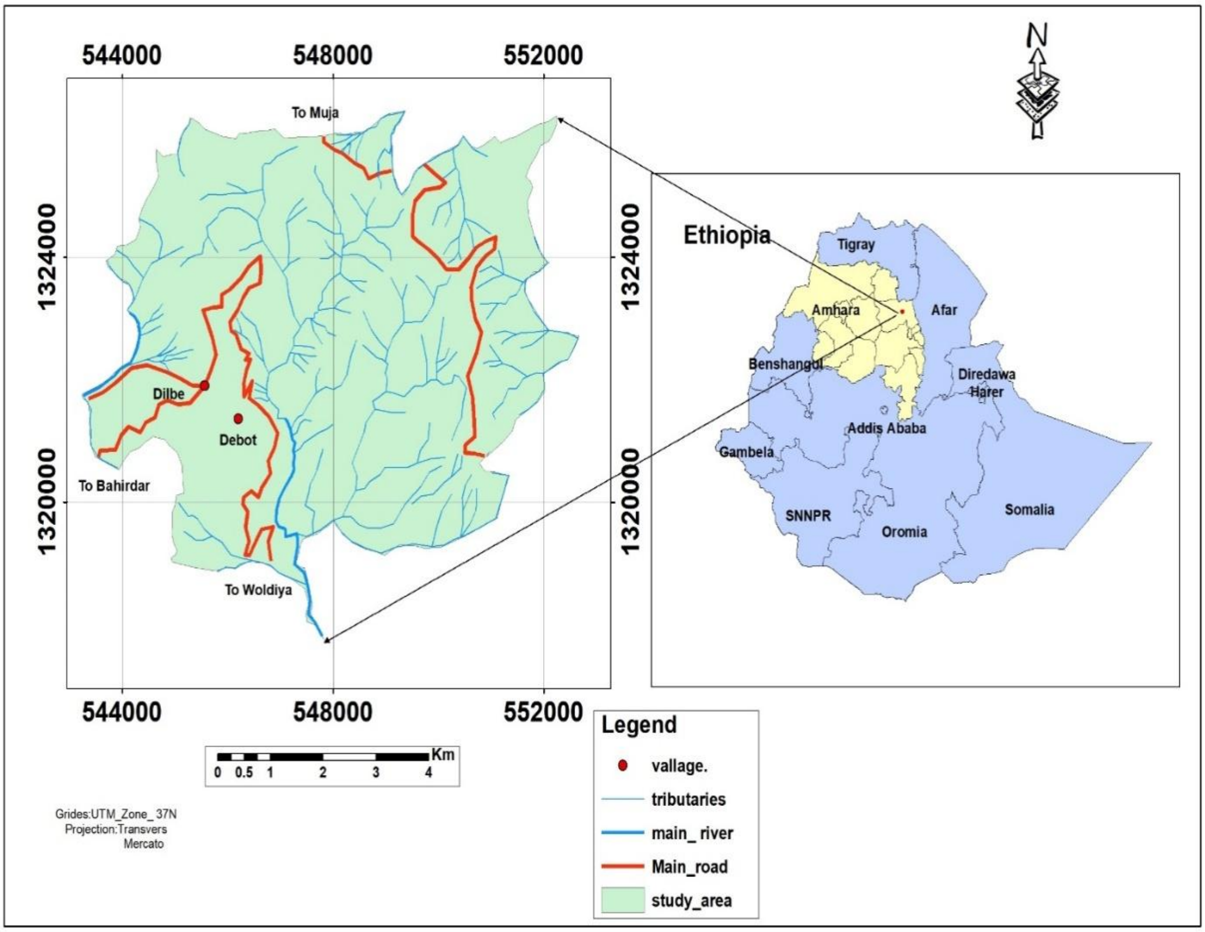


Fig 1.1 Location map of the study area

1.6.2 Climate

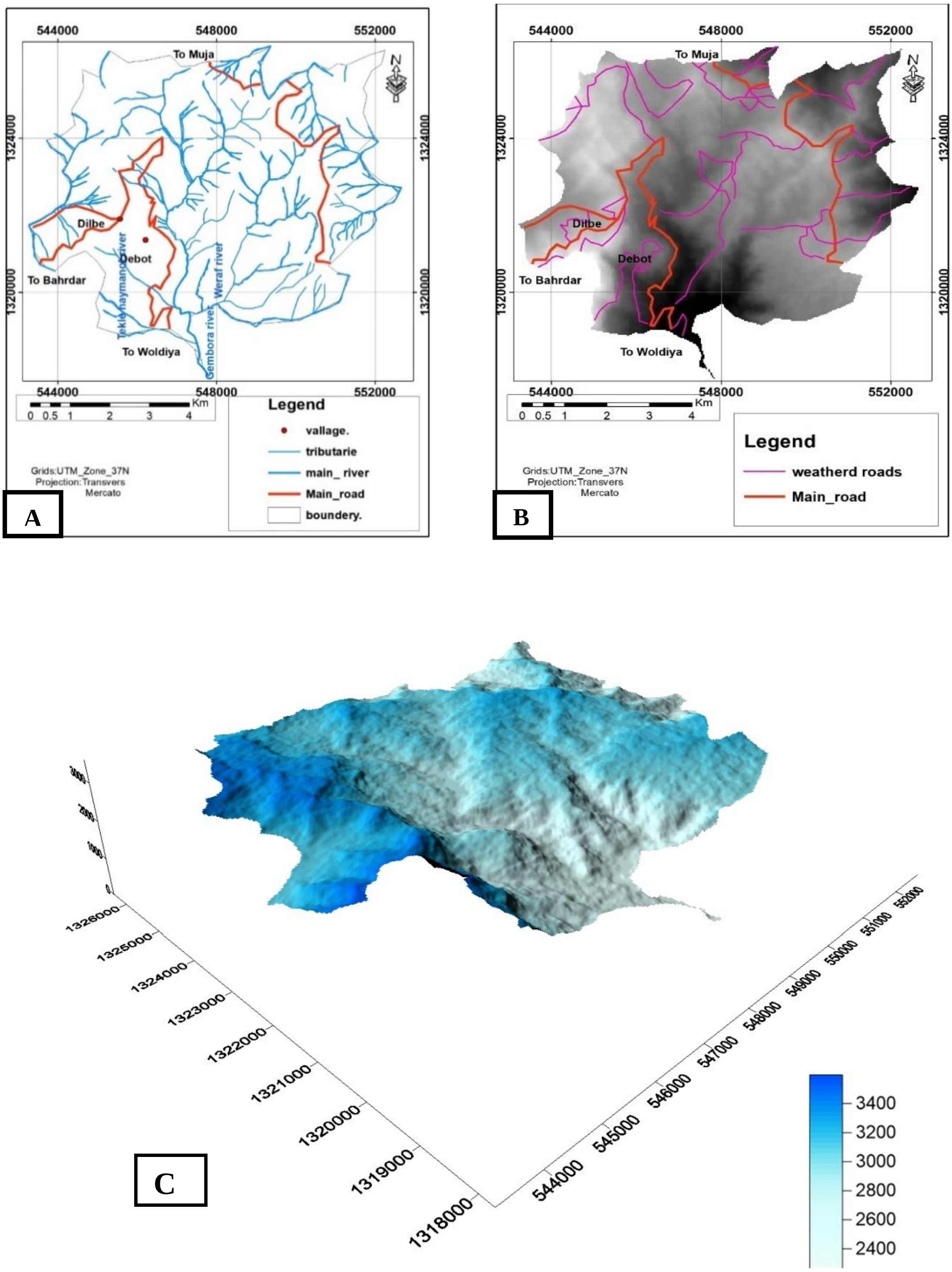
The variability in topography has an influence on the climate of the study area. The elevation of the study area ranges from 2243m to 3597m a.s.l. According to Danel Gemechu (1997) climate can be classified with respect to elevation as Desert climatic zone (Bereha), Tropical (Kola), Subtropical (Weynadega), Temprate (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 area can be categorizing as temperate (dega) since it falls within the range of 2243-3597m in elevation. According to Ethiopian Metrological station the maximum temperature recorded in the area is 24.3^{o}C and 1.2 ^{o}C as the minimum temperature.

1.6.3 Physiography and drainage pattern

The area is found in Weastern highlands, part of Northern central plateau, forms typical plateau topography, which often extensively eroded and dissected by the deep gorge. The area is highland with elevation ranging from 2243m to 3591m from mean see level (Fig 1.2 C). The elevation difference is more than 1300m. It is characterized by rugged topography. It is full of sharp valleys, hills and ridges. It ranges from the highland in northern part to erode in southern part of Gembora River valley. The areas include Agazen Kend Ridge and it is surrounded by Wiraf Ridge in the East, Alech Ber Ridge in the West and Lambo Chama Ridge in the Southern part of the area. In this area most of the rivers originates from the highlands of plateau and they are characterized by dendritic to sub parallel drainage patterns. They drain towards Gembora River (Fig 1.2 A).

1.6.4 Vegetation

Scarce eucalyptus trees are common in the area. Most of the study area is vegetated by Amhara flora enterprise. Most of the area is being used for Agricultural farming practice by the local people, which has contributed for significant vegetation cover in the study area. The most common crops cultivated in the study area are teff, barley, carrot and legume.



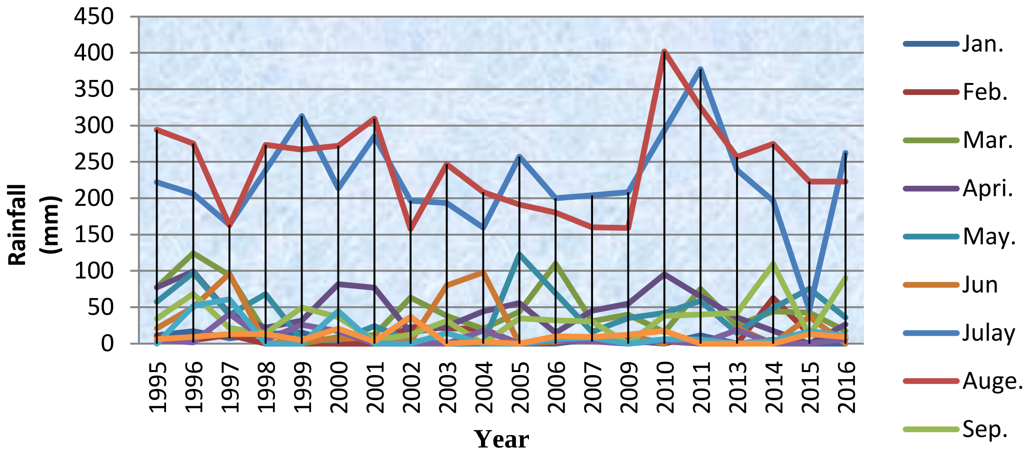
(A) *Elevation map of the study area, (B) - Drainage pattern of the study area, (C)- physiography map of the study area, (D) Accessibility map of the study area.*

Fig 1.2 General physiography of study area

1.7 Rainfall distribution in the study area

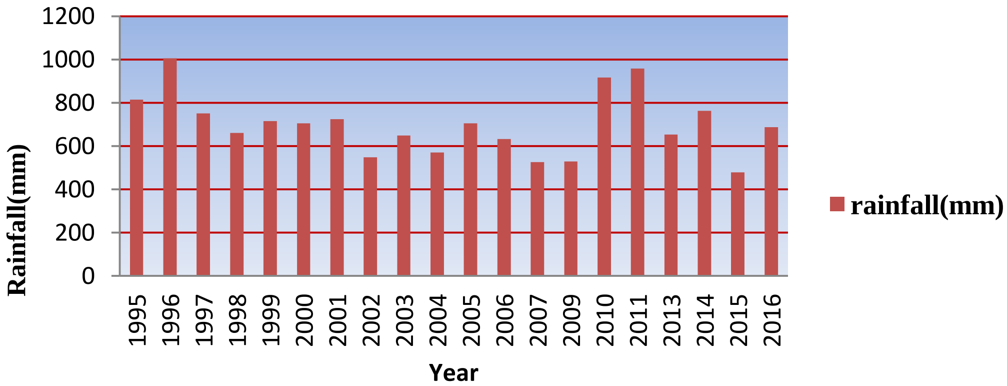
The instability of slope aggravates with rainfall (Lulseged Ayalew et al., 2004; Dai and Lee, 2001). It is the most important external triggering parameter for landslides (Raghuvanshi et al., 2014a). In the study area the mean annual rainfall recorded was 661.5 mm from the year 1995 to 2016. For the assessed 20 years the maximum monthly rainfall was 401.7 mm which was recorded in the month of August (Fig 1.3).

According to Ethiopian metrological station, the area received maximum rainfall in the summer season from July to September and from October to December minimum rainfall was recorded. In the months July and august the rainfall reaches at peak. The annual rainfall distribution of the study area ranges from 478.7 to 1005.2 mm/year in the assessed years, respectively.



(Source: Ethiopian metrological agency)

Fig 1.3 Monthly rainfall distributions



(Source: Ethiopian metrological agency)

Fig 1.4 Yearly rainfall distribution (1995-2016)

1.8 Structure of the thesis

This thesis is organized in 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 detailed descriptions of the 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: focuses on detailed descriptions of the regional and local geology.

Chapter four: provide the details of Methodology adopted in the present research work

Chapter five: provides detailed descriptions on Data collection, processing and Analysis which include Governing factors and distribution in the present study area, Landslide inventory of the study area, Landslide manifestations in the study area and the Failure mechanism of landslide in the study area. In addition, Landslide Susceptibility Index (LSI) computations and Grid overlay analysis was discussed in this chapter.

Chapter six: describes about the governing factor influence and Hazard potential, Also, landslide hazard map generated through this method is discussed. In addition, the validation of the prepared hazard map with the past landslide is also presented.

Chapter seven: conclusion and recommendations for further research works are presented.

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Chapter Two Literature Review

2.1 Background

Landslides are the most hazardous phenomena throughout the world, where they cause extensive damage for both property and human life (Lee et al., 2004). Geomorphology includes gradient of slope, steepness of the slope, aspect and elevation of the area which has an influence on the stability of the slope. The relationship between gradient of the slope to strength of slope forming material, and also slope aspect are very important and may in turn affect slope stability. Not only this but also, hydrologic (movement, amount and pressure of water) and climatic (temperature and precipitation) conditions also influences the stability of slopes (Varnes, 1984).

In Ethiopia, slope failure occurs in most of the region that possess characteristic earth materials, topographic setting and geologic structures (Lulseged Ayalew and Yamagishi, 2004). Due to the hilly nature of Ethiopia with improper planning, landslide hazard will continue to challenge road constructions, houses and other infrastructural developments of the country unless it has to be properly addressed in time (Kifle Weldaregay, 2013). From the instability point of view, hilly terrains of Ethiopian highland remain highly fragile. Natural causative factors with increasing man-made activities have resulted in increased landslide activities in Ethiopian highland (Raghuvanshi et al., 2014a). The artificial manmade activities (developmental activity) in hilly terrain, especially road constructions, cover large area of the slopes therefore it requires a raped slope stability analysis technique (Raghuvanshi et al., 2014a). Before any developmental planning and construction activity Landslide hazard assessment and risk analysis is advisable (Kifle Weldaregay, 2013).

According to several studies, many landslides prone areas have been reported in the Ethiopian highlands. Therefore, in Ethiopia, landslide hazards are becoming serious problem for both public and the government decision makers at various levels (Kifle Woldearegay, 2013). Northern Ethiopia has long history of landslide activity especially hill side and road cutting of most rugged regions (Tenalem Ayenew and Barbieri, 2004).

For safer strategic planning and proper mitigation, delineating landslide hazard prone areas is essential. Therefore, to classify lands in to different degree of susceptibility, LHZ technique can be employed (Anbalagan, 1992). In the past, different techniques of LHZ were developed. Those techniques are classified into three groups; expert evaluation, statistical methods and deterministic approach (Leroi, 1997; Guzzettiet et al., 1999).

2.2 Factor influencing landslide

2.2.1 Intrinsic factors

The intrinsic factors are mainly; slope material (lithology or soil), structural discontinuity, ground water condition, geometry of the slope and land use /land cover (Tilahun Hamza and 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).

2.2.1.1 Slope material

Land surface may have overlain by rocks, soils or both (Varnes, 1978). If the slope materials are rocks, the severity for slope failure may varies based on intact rock strength and degree of weathering of rock. The strength of rocks and degree of weathering relates with the texture (grain size/shape), composition and fabric of the rock. The physical properties of slope material like cohesion between grains may reduce the strength of the slope. The rocks which have high intact rock strength are generally high resistance for failure. Similarly, degree of weathering may affect the relative strength of the rock, since weathering can produce a thick unconsolidated material on slope (Raghuvanshi et al., 2014a). Slope materials have also an influence on the type of failure within the slope. Failure like rock fall, topple, rock slide /avalanche are common in the slope which are covered by hard bed rock like basalt, ignimbrite, limestone and sandstone (Varnes, 1978; Birhanu Temesgen et al., 1999).

On the other hand, if the slope is covered by highly weathered unconsolidated material, avalanche, earth flow, and mud flow are common types of failure (Birhanu Temesegen et al., 1999). On alluvial, and coluvial soils at the foot of steep slopes rotational slide are common (Varnes, 1978). For the slope which is covered by soil the probability for failure relates with depth of the soil and genetic origin of the soil material (Raghuvanshi et al., 2014a).

2.2.1.2 Structural discontinuity

Structures on the slope material may be primary or secondary such as bedding, fault, joint and foliation (Raghuvanshi et al., 2014a). Both the primary and secondary structural discontinuities are important for determining the stability of the slope (Hoek and Bery, 1981). Not only the presence of these structures that control the stability of the slope but also the orientation, spacing, surface characteristics and continuity of the structure have an influence on the stability of the slope (Price, 2009; Johnson and DeGraff, 1991, as sited in Rghuvanshi et al., 2014a: 2014b).

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 the 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).

2.2.1.3 Ground water conditions

For the landslide initiations ground water plays an important role by reducing shear strength of the material and by creating pore water pressure. Rainfall is a major triggering parameter for landslide. Most of the landslides in general have occurred in Ethiopian highlands during prolonged and high rainfall periods (mainly in periods from mid-July to mid-September) (Kifle Woldaregay, 2013). Ground water in hilly terrain does not have a uniform distribution and is generally channelized with structural discontinuities. The addition of water from rainfall on the slope material adds weight to the slope. This phenomenon increases the shear stress and can lead to slope failure/ mass movement.

2.2.1.4 Land use/land cover

Land use land cover has an important role for the stability of slope. If the land is covered by thick vegetation, the slope become stable because of this thick vegetation prevents more seepage of water in to the ground (Arora, 1997 as sited in, Rghuvanshi et al., 2014a).Barren and sparsely vegetated lands are more susceptible to erosion, weathering and slope failure (Anbalgan, 1992). Vegetation cover has an influence in relation to the hydrologic process (precipitation, soil moisture and hydraulic conductivity). Cultivation / agricultural practice also have an influence on the stability conditions of the slope.

2.2.1.5 Geometry of the slope

Slope geometry includes slope morphometry and relative relief (Rghuvanshi et al., 2014a; 2015b). The relative relief tells the difference between maximum and minimum elevation of individual slope facts. Normally, if the relative relief is high the slope will be more prone to failure (Hoek and Bray, 1981). On the other hand, slope morphometry describes as 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).

2.2.2 External parameters

The major external causative factors for slope failure are rainfall, seismicity, volcanism and manmade activities.

2.2.2.1 Rainfall

Rainfall is important external triggering parameters. According to (Lulseged Ayalew, 2004; Dai and lee, 2001) slope failure increases during rainy seasons. The hilly mountainous terrain of Ethiopia is frequently affected by rain fall induced landslide (Kifle Woldaregay, 2013). Rainfall intensity and duration of rainfall play an important role by decreasing shear strength of the slope material and by increasing pore water pressure. Rainfall also triggers slope failure by lubricating discontinuity surface and develop pore water pressure (Highland and Bobrowsky, 2008). According to Hoek and Bray (1981), rain water can cause slope failure by increase weight of slope material especially in area where covered by soils. The impact of rain fall relates with other controlling parameters like discontinuity orientation, slope morphometry and types of slope material. In area where covered by unconsolidated material, rainfall triggers slope failure as a result of decreasing angle of repose.

2.2.2.2 Seismicity

According to (Keefer, 2000; Bommor and Rodriguez, 2002) ground acceleration which is caused by seismic activity can produce landslides or slope failure. In mountainous regions ground shaking may trigger rapid mass-wasting events, rock and debris falls, rock and debris slides, slumps, and debris avalanches. These landslides caused by seismicity are more widespread and sudden. All types of landslide can be triggered by seismic activity (Keefer, 2002). However, rock fall, disrupted rock slide and disrupted slide of earth and debris are common. There is one type of landslide which is unique for seismic caused landslide which is liquefaction. Slope materials which are affected by many structural discontinuities when subjected to ground acceleration this cause widening or opening of structural discontinuities. Slope failure produces as a result of decreasing shear strength along the discontinuity (Highland and Bobrowsky, 2008). Seismic activity not only cause landslide but over time it also creates steep slope topography and potentially unstable slopes. According to Raghuvanshi et al., (2014a) slopes having unconsolidated material, high seasonal ground water level and shallow rooted or sparsely vegetated are more prone for seismic cause landslide.

2.2.2.3 Volcanism

Volcanic activities are the most dramatic and violent agent. Volcano can emit voluminous unconsolidated materials which become deposited on land surface. Such loose deposited are prone to failure with the help of rainfall activity. On the other hand, volcanic mountains are very steep as a result of the addition of new material from new eruptions then the mountain become unstable through time. Hot volcanic activity can melt snow or ice and this melt water picks all rocks and soils along its path by producing fast flows (Highland and Bobrowsky, 2008).

2.2.2.4 Manmade activities

The instability of the slope can be triggered by manmade activities in addition to natural parameters. The developmental activities which are performed in mountainous terrain like road construction; building and agricultural activities aggravate slope instability (Raghuvanshi et al., 2014a). Since most of Ethiopian highlands are highly populated, the areas are threatened by deforestation, desertification and other activity which aggravate slope instability (FAO, 1986; Oldeman et al., 1991). All these activities change the natural slope and trigger slope instability by increasing moisture in the soil and cutting the slope steeply.

2.3 Types of slope failure

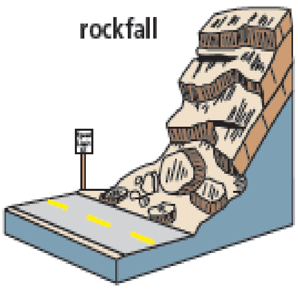
Landslide can happen as falling, flowing, toppling, sliding or as a combination of two or more slope failures (Varnes, 1978). There are various mechanisms that are used for the classification of failure but according to Varnes (1978) landslide classification is based on the material involving during the movement and the type of movement. This classification method distinguishes five types of movement namely, fall, topple, slide, spread, flow and combination of two or more type of landslide along with type of material (soils, bed rocks, mud and debris).

Table 2.1 Types of landslide according to Varnes 1978

Types of movement		Types of material		
		Bed rock	Soil	
			Fine	Coarse
Fall		Rock fall	Debris fall	Earth fall
Topple		Rock topple	Debris topple	Earth topple
Slide	Rotational	Rock slump	Debris slump	Earth slump
	Transitional	Rock block slide: rock slide	Debris block slide; debris slide	Earth block slide; earth slide
Lateral spread debris slide		Rock spread	Debris spread	Earth spread
Flow		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
Complex slope movements (combination of two or more movement type)				

2.3.1 Fall

Falls are abrupt movement of slope material (soil or rock) that is detached from steep slope or cliffs. In this type of movement, the material moves by bouncing, falling or rolling (Varnes, 1996). It is rapid down ward movement of slope material. In this type of failure there is no interaction between one failure and the next.



(Source: WGS, 2017)

Fig 2.1 Schematic representation of fall

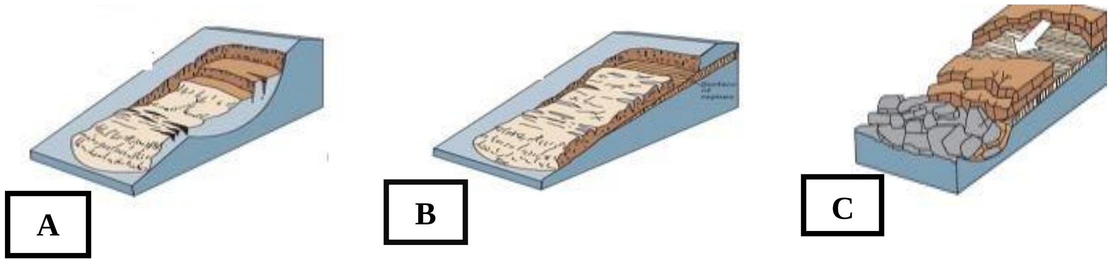
2.3.2 Slide

Slide is a down ward movement of slope material along a surface of plane. It can be deep sated or shallow sated. This type of movement has its own subdivision such as rotational, transitional failure (USGS, 2004).

Transitional slide: associated with geological discontinuities such as fault, joint bedding surfaces. This type of failure happens with small rotation or back ward tilting (USGS, 2004).

Rotational slide: This type of failure is with a surface of rapture which is curved concavely upward. It occurs when the internal strength of slope material is overcome by its own weight (USGS, 2004).

<u>A block slide</u>: is a type of translational slide which occurs when alternating layer of strong and weak rock down a slope hill.



(A) translation, (B) rotational and (C) block slide

Fig 2.2 Schematic representation of slide types

2.3.3 Topple

This type of mass movement is usually downward movement of large pieces of rocks. It is forward rotation and movement of rock out of the slope. This type of failure occurs around an axis at or near the base of rock. The triggering mechanism for this type of failure may be gravity, ice or water occurring within weak zones like cracks or joints that weaken the rock mass. This type of failure happens within the rate of extremely rapid to extremely slow movement (Highland and Bobrowsky, 2008).

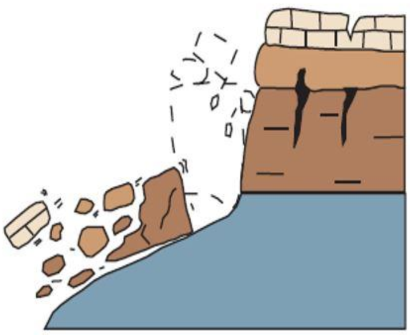
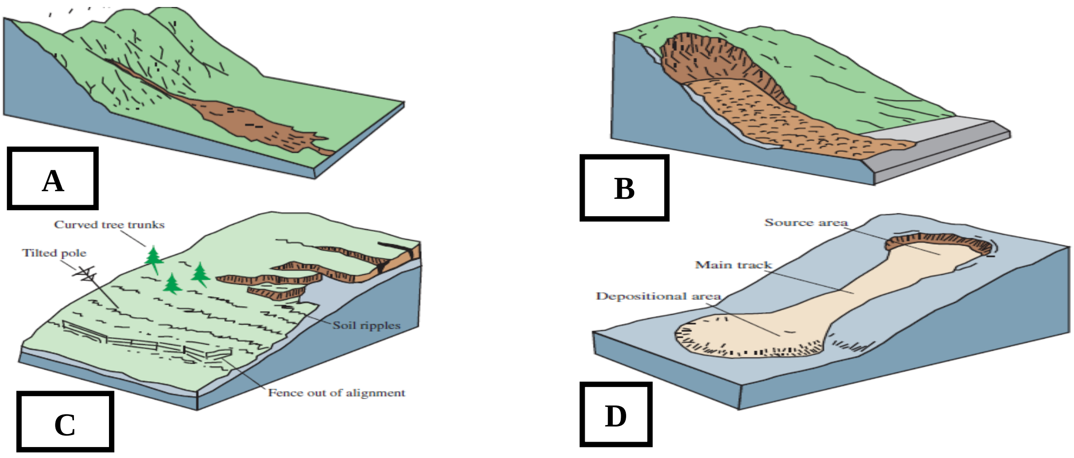


Fig 2.3 Schematic representation of topple

2.3.4 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. They are unconsolidated at the time of flow but may consist of variety type of material like rock fragments, fine material, and debris (USGS, 2004).



(A) Debris flow, (B) Debris avalanche, (C) Creep and (D) Earth flow (Source: USGS, 2004).

Fig 2.4 Schematic representation of flow

2.3.5 Complex type of movement

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

2.4 Landslide hazard mapping techniques

Landslide activities in different parts of the world require some rapid slope stability analysis technique. For the purpose of delineation of an area with different degree of susceptibility for slide different analysis techniques can be applied (Anbalabgan, 1992). These approaches can be classified as expert, statistical and deterministic approaches (Leroi, 1997; Fall et al., 2006). The detailed description of each method is discussed in the following paragraphs;

2.4.1 Expert evaluation technique

This technique classified as inventory and heuristic approach (Fall et al., 2006). Landslide inventory mapping is a method of identification of landslide affected area and record the location, dimension, causative factor, frequency of occurrence and mode of failure of landslide (Dai and Lee, 2001; Fall et al., 2006). It shows the susceptibility for those area where landslide have been observed. This method doesn't care about for areas which may have future probability for failure (Casagil et al., 2004 as sited in Raghuvanshi et al., 2014a). However, it uses as a base for most susceptibility analysis studies (Dai and Lee, 2002). 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). According to Anbalagan (1992) numerical rating are assigned based on logical judgment of geoscientists from their past experiences on the relation between those causative factors and slope instability. Even if this method has subjective, it is simple in application by utilizing much field data which are supported by experience of geoscientists (Fall et al., 2006; Raghuvanshi et al., 2014a; 2014b).

2.4.2 Statistical analysis technique

Statistical analysis techniques are based on statistical determination of combination of causative variables in a given area. These methods are indirect and the landslide hazard technique is based on rule evolved statistically with the relative contribution of each causative parameter (Carrara et al., 1992). Statistical method can be bivariate and multivariate (Dai and Lee, 2001). In this method the major problem is collection of data over large area and identification of causative factors which needs large time and more cost (Van Westen et al., 1997). The other limitation of statistical method is the result is highly depending on the quality of data (Van westen et al., 1997). Even though statistical methods have this limitation, it avoids the subjectivity nature of an expert evaluation.

2.4.2.1 Bivariate statistical method

In this method each factor map is overlaid on an active landslide map (Kanungo et al., 2009). Weights to each causative factor are assigned based on landslide density. There are many important bivariate statistical methods such as, the landslide susceptibility method of Van Westen (1993), the information value model (IVM) (Kobashi and Suzuki (1988), weight overlay method etc.

2.4.2.2 Multivariate statistical method

Multivariate statistical approach considers relative contribution of each thematic data layer to total landslide susceptibility (Kanungo et al., 2009). Percentage of landslide affected area for each pixel and landslide absence presence data layer is created followed by the purpose of multivariate statistical method for reclassification of hazard for the given area. Discriminate analysis, multiple regression models, conditional analysis and artificial neutral network are among the common method for landslide hazard zonation method.

2.4.3 Deterministic approach

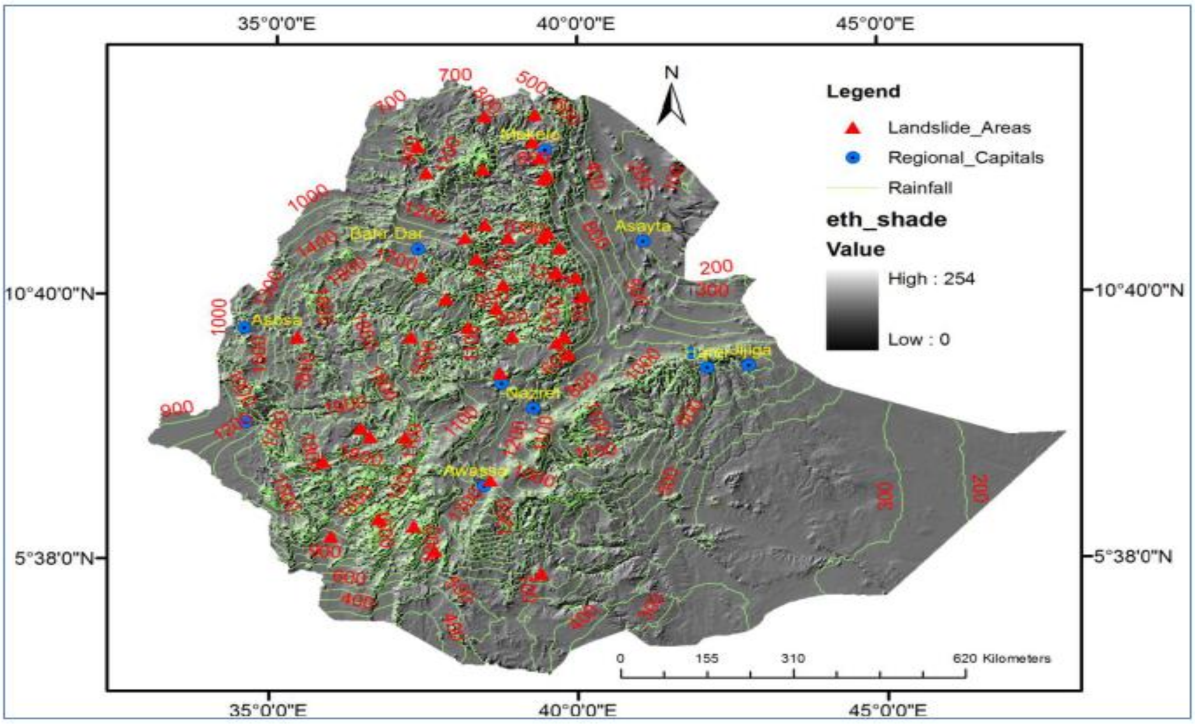
This method generate hazard in absolute value in the form of safety factor (Raghuvanshi et al., 2014a). This approach provides quantitative result which is used for direct engineering designs (Fall et al., 2006). Application of such method is more practical and simple. This technique is applied for landslide hazard zonation which is performed in small to medium size areas through large or medium scale mapping. However, this method requires the availability of detailed geotechnical and hydrological data (Raghuvanshi et al., 2014a; Van Westen et al., 2006). The main limitation of this technique is its difficulty to conduct suitability zoning in large area and unsuitability for landslide zone mapping where the areas have complex hydrological system.

2.5 Landslide overview in Ethiopia

The land mass of Ethiopia is divided as highlands and low lands. Landslides are common geo environmental hazard in Ethiopia highlands and rift margins. According to the report of FAO (1986), 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 elevation of these highlands ranges from 1500-3500m a.s.l. 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. In addition, the highlands of Ethiopia are densely populated and there is intensive agricultural practice in the area (FAO, 1986). Also, the area is threatened by deforestation and desertification (FAO, 1986; Oldeman et al., 1991). Due to this and other factors Landslide activities are common in northern, southern and western hilly regions of Ethiopia and along rift margins.

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; Fikire Girma et al., 2015; Raguvanshi et al., 2015; 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.



(Source; Kifle Woldaregay, 2014)

Fig 2.5 Landslide affected areas in different parts of Ethiopian highlands

Tilahun Hamaz and Raghuvanshi, 2017, delineated Jeldu district area in to different degree of slope susceptibility and evaluate all the causative parameters which are responsible for failure using GIS based statistical approach for LHZ. As the result revealed in this study that 12% (5.64 km^2), 27% (12.69 km^2), 32% (15.04 km^2), 21% (9.87 km^2) and rest 8% (3.76 km2) of the study area falls under no hazard, low hazard, moderate hazard, high hazard and as very high hazard, respectively. Tsion Aragaw, 2017 conduct a study around Alemketema northern Sewa zone. She uses an integrated expert evaluation and statistical approach for LHZ and evaluation of responsible causative parameters. In which the results showed that in original SSEP LHZ map and in LHZ by integrated approach 85% and 72% of area is covered by high hazard high hazard zone, respectively.

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.

Fikire Girma et al., 2015, conducted a study around Ada Berga district/ Blue NielAbay basin, central Ethiopia using GIS based statistical and probabilistic approach for LHZ with a result of 24% (36.72 km^2), 32% (48.96 km^2), 17% (26.01 km^2),25% (38.25 km^2) and2% (3.06 km^2) of the study area falls under no hazard, low hazard, moderate hazard, high hazard and as very high hazard, respectively. Further, Raguvanshi et al., 2015 conducted a study by following a comparative GIS based grid overlay analysis versus modeling approach for the evaluation of landslide controlling parameters and delineating the area in different degree of susceptibility around Meta Robi District of West Showa Zone of Ethiopia. The results revealed that 82% and 95%of past landslides fall within 'very high hazard' or 'high hazard' zones of the prepared LHZ map through 'Grid overlay' method and 'GIS modeling, respectively.

Raghuvanshi et al., 2014a, conducted a study using slope stability susceptibility parameter (SSEP) / an expert evaluation technique in the area around Wurgessa Kebelle N-wello zonal administration, Amhara national state in northern Ethiopia for landslide hazard evaluation and zonation.The LHZ map which was prepared using this method shows that 8.33%, 83.33%, 8.34% of the area fall under Moderately hazard, High hazard and Very high hazard zone, respectively. Also, Heanok Woldegeorgis et al., 2014, had made landslide hazard evaluation and zonation in the area of southern part of Blue Nile Gorge using a Land Hazard Evaluation Factor (LHEF). He also made quantitative analysis for critical slope by using the limit equilibrium method.

Birhanu Temesgen et al., 1999, studied Landslide hazard and evaluate the occurrence of landslide with the related causative parameters by applying GIS and Remote sensing technique in Wondogenet area.

Bekele Abebe et al., 2010 conducted a study on landslides in Ethiopian highlands and rift margins. This study identifies the main triggering parameters for landslide happening and identify slope failure mechanisms in the highlands of Ethiopia and rift margins.

2.6 Genesis of methodology for the present study

The methodology followed in the present study is based on the principle of past is the key for future. An integrated GIS based grid overlay and statistical approach was followed in the present study. Statistical approach is the most popular technique (Raghuvanshi et al., 2014a). Many authors agree that statistical methods are more appropriate for hazard zoning, because of having minimum degree of subjectivity. In this method result of the inventory data are compared with the causative factors which influence landslides. Statistical analysis techniques are based on statistical determination of combination of causative variables in a given area. Based on the analysis for the interrelationship of the governing factors and the invented landslide activities quantitative estimations are made. For Grid overlay analysis a grid of 10 x 10 m is prepared and overlaid over each prepared causative factor maps and geo-processing (intersection) is made to know the presence or absence of each causative factor sub-class within each polygon grid cell. Later, Landslide susceptibility Index (LSI) within each grid cell is computed for each factor class based on density ratio. Further, these LSI values for each factor class within a grid cell are summed up to get Total Landslide susceptibility Index (TLSI) values. Finally based on these TLSI value zones of different probability of landslide hazard are delineated for each grid cell. Thus, a Landslide Hazard Zonation (LHZ) map for the given study area can be produced (Raghuvanshi et al. 2015).

For the present study, statistical approach was used for rating of the causative parameters. Representative Field data on various parameters and past landslides was collected facet wise and later Grid overlay analysis was used to know the comprehensive influence of causative parameters within a single grid cell. Thus, based on this analysis finally Landslide Hazard Zonation map of the present study area was prepared.

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Chapter Three Geology

3.1 Regional Geology overview

The present study area is located in North Western Central Ethiopia. The regional geology of the area contains early Cenozoic extension/faulting accompanied by widespread volcanism. Cenozoic eruption in North Western Ethiopia has happened via eruption of Ashengi basalt for the Eocene-Oligocene period, and followed by Aiba basalts and Alajae formation extrusions for Oligocene-Miocene period. Extrusion of flood basalts, with interbeds of pyroclastic rocks of rhyolitic or less commonly trachytic compositions were the characterization of these volcanic episode, mostly in the upper stratigraphic levels. These were followed by alkaline Tarmaber- Gussa basalts of central eruption in the Middle to late Miocene (Tesfaye Demessie et al., 2010).

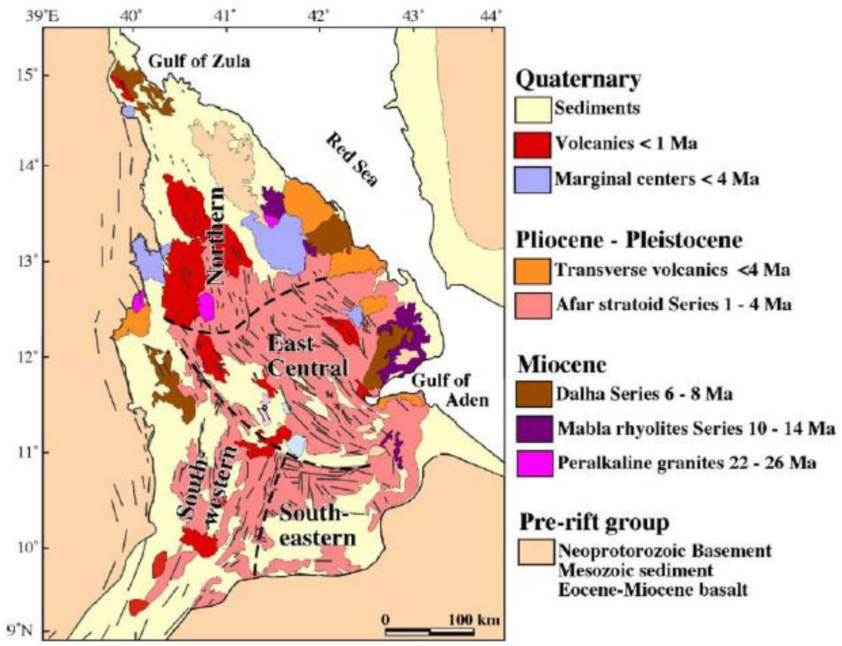
The study area is located in the South-western block of the Afar Depression, where the Main Ethiopian Rift (MER) gradually funnels towards the Afar Depression (Fig.3.1).The South-western Afar is a continuation of the northern part of MER that is interrupted by the Tendaho-Gobaad discontinuity. Those three, Northern MER, the southern Red Sea and western Gulf of Aden lie down within Afar Depression which forms a triple junction between the Nubian, Somalian and Arabian plates (Alebachew Beyene and Mohamed Abdelsalam, 2005). Geological units of the Afar Depression and marginal areas can be divided into four broad groups (Alebachew Beyene and Mohamed Abdelsalam, 2005) (i) Pre-rift sequences of Neoproterozoic, Mesozoic sedimentary rocks and Eocene-Miocene basalts; (ii) Miocene igneous rocks; (iii) Pliocene volcanic rocks and (iv) Quaternary volcanic rocks and sedimentary rocks. Previous formational names Ashangie basalt, Wegel Tena rhyolite, Dessie basalt, Tarmaber-Megezez Formation, are common from Zanettin et al. (1974); Hoffman et al.(1997); Derege Ayalew et al.(2002) and Wolfenden(2003).

3.1.1 Eocene-Oligocene volcanic rocks

This volcanic succession comprises Ashengi basalt and Wegel Tena ryolitic ignimberite.

3.1.1.1 Ashengi basalts (Tab)

These basalts are the earliest fissural volcanism in the area (Mengesha Tefera et al., 1996). This type of basalt is exposed in the western plateau and the basalt attains a maximum thickness of around 1000 m. The thickness of this unit decreases toward south. Ashangie basalts are also exposed as faulted block along NW-SE trending escarpment. It is exposed as steep slopes of undulating ridge chains and low lying flat plains along road cuts, stream beds, and gentle slopes. These units had overlain un-conformably on the Dessie basalt formation and Wegel Tena rhyolite and / or ignimbrite.



(Source: GSE, 2010 after Alebachew Beyene and Mohamed Abdelsalam, 2005)

Fig. 3.1 Geological map of the Afar Depression

The basalts are characterized as strongly weathered, tilting in different direction, jointing and fracturing (Tesfaye Demesie et al., 2010). Columnarly jointed aphanitic basalts are common in most of the Ashengi basalt exposures of the area. The unit also contains intercalated layers of agglomerate and volcanoclastic sediments on the Beshilu section. The rocks are characterized megascopically by black, dark gray and greenish gray in color with aphanatic to coarse grain in texture. On the other hand, petrographically this unit is classified in to three as; Vesicular augite-plagioclase phyric basalt,Vesicular augite phyric basalts and Aphanatic basalt (Tesfaye Demsie et al., 2010)

3.1.1.2 Wegel Tena rhyolitic ignimbrite (Twtr)

This unit is exposed in north of Wegeltena town and Gishen Mariyam and Ambasel section. The ignimberite forms hill topography like the basalt. In the Mekdela and Gishen Mariam area the unit is exposed on the hill top with steep slopes overlying the Ashangie basalts. This unit has 500m maximum thickness. It is characterized as pink, white, light gray with fine to coarse grained rock. On the other hand, its composition varies from purely Rhyolite to Rhyolitic ignimbrite (Tesfaye Demsie et al., 2010)

3.1.2 Oligo-Miocene sequences

3.1.2.1 Dessie basalt formation (Tdb)

The name for this unit as Dessie basalt formation is adopted from Wolfenden (2003). It is exposed in the western plateau area forming chain of cliff. This unit has association with different types of aphanatic and porphyritic, massive and vesicular basalts, with subordinates of pyroclasts and ash layers (Tesfaye Demsie et al., 2010). The aphanatic basalts are dominated by fine microcrystalline matrix with fine plagioclase microlites. They also contain traces of augite, olivine, plagioclase and opaque minerals with scarce vesicles. The porphyritic basalts are varying in composition (Tesfaye Demsie et al., 2010).

3.1.2.2 Ancharo rhyolitic ignimbrite (Tar)

This unit is exposed in southern part of Dessie map sheet exposed with a thickness of 50m in Kombolcha to Bati road. The name Ancharo is named after the locality called Ancharo which has white, pink, gray with medium to coarse grained rocks. The southern part of this unit is highly weathered and found as fragmental outcrop with fine alkaline feldspar, plagioclase feldspar, pumice rock fragment and opaque minerals (Tesfaye Demsie et al., 2010).

3.1.2.3 Tarmaber Megezez Formation (Ttb)

The name is adopted from Zanettin et al. (1974) and Mengesha Tefera et al.(1996). This unit is exposed along plain road sections, gentle slopes and river beds. It forms elevated plains along Woldeya-Hamusit road. It forms high ridges and chains in the south-western part like Abe Boru ridge (4247 m a. s. l.). It has a conformable contact with the Dessie basalt formation. Its thickness reaches above 1000m with a characteristic of distributed dark gray to black with coarse grained, vesicular basalt and columnarly jointed aphanatic basalt. Compositionally the coarse grained verities are porphyritic comprising augite-plagioclase phyric and augitephyric basalts, aphanatic basalt (Tesfaye Demsie et al., 2010).

3.1.3 Late-Miocene

3.1.3.1 Kemise Formation (Tk)

Previously this formation has been mapped as Kemise rhyolite formation (Wolfenden, 2003). It is exposed in the central eastern part along the western margin of the Afar rift. This formation consists of rhyolite, ignimbrite, tuff and ash with a thickness reaches around 100m. The Kemise formation contains pink and greenish gray rhyolitic ignimbrite, which is weathered to yellowish brown, light gray and reddish brown rocks. Compositionally the rhyolitic ignimbrite comprises alkaline feldspar, rock fragment, opaque minerals and traces of quartz.

3.1.3.2 Dalha Formation (Ndb)

The Dallha formation is exposed in the north eastern corner along the rift floor. The name for this formation is adopted from Mengesha Tefera et al., (1996). This formation consists of fissural flows of basalts (Mengesha Tefera et al., 1996).

3.1.4 Quaternary volcanic

3.1.4.1 Adami Basalts (Qab)

The unit forms plain and hilly topography near Chekorsa village. Admi basalts has tectonic contact with Ashangie basalt and Wederage basalt. It is characterized by greenish gray, friable, strongly weathered to reddish brown and green color rock. Compositionally the Adami basalt is composed from plagioclase, opaque minerals and traces of augite (Tesfaye Demise et al., 2010).

3.1.4.2 Wederage basalt (Qwb)

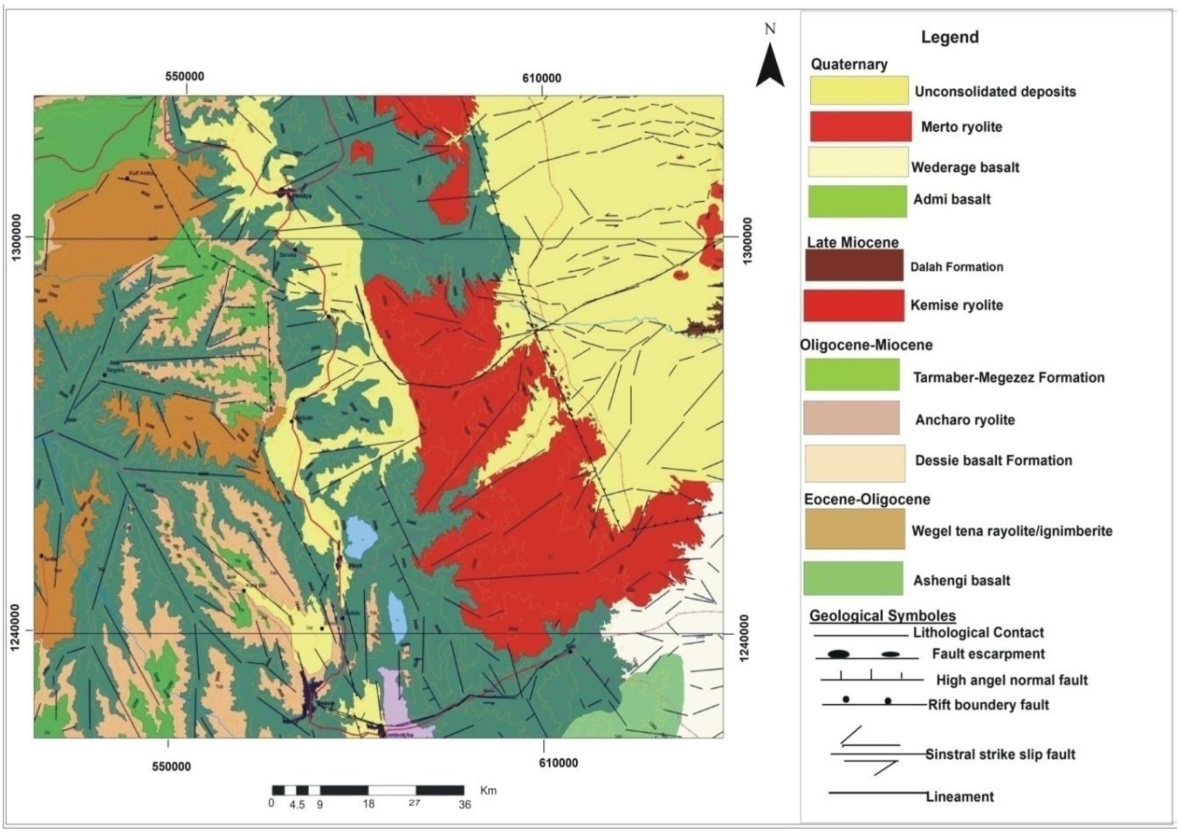
This unit is exposed along the western boundary of the rift. It is characterized by fresh greenish gray, dark gray and grayish black in color with aphanatic and fine to medium grained rock. Its characteristics are highly similar to the Quaternary basalts of the Afar rift floor. It contains plagioclase phyric and aphanitic basalts (Tesfaye Demsie et al., 2010).

3.1.4.3 Merto rhyolite (Qmr)

Merto rhyolite is patches of an isolated hill found in the Afar rift floor. It is characterized as pink, coarse grained, dome forming unit with a composition of alkaline feldspar, vesicles found within the ashy matrix (Tesfaye Demsie et al., 2010).

3.1.5 Undifferentiated alluvial, elluvial and lacustrine sediments (Qal)

These units are exposed in the eastern low land plain and in the central part along the western Afar marginal basin, they are characterized by black cotton and reddish brown silty to sandy soil with few outcrops of diatomite exposed along western marginal basins and on the top of the western plateau and eastern low land plain of the Afar rift floor, respectively (GSE, 2010).



(Source: Tesfaye Demsie et al., 2010)

Fig 3.2 Geological map of Dessie map sheet

3.2 Local Geology

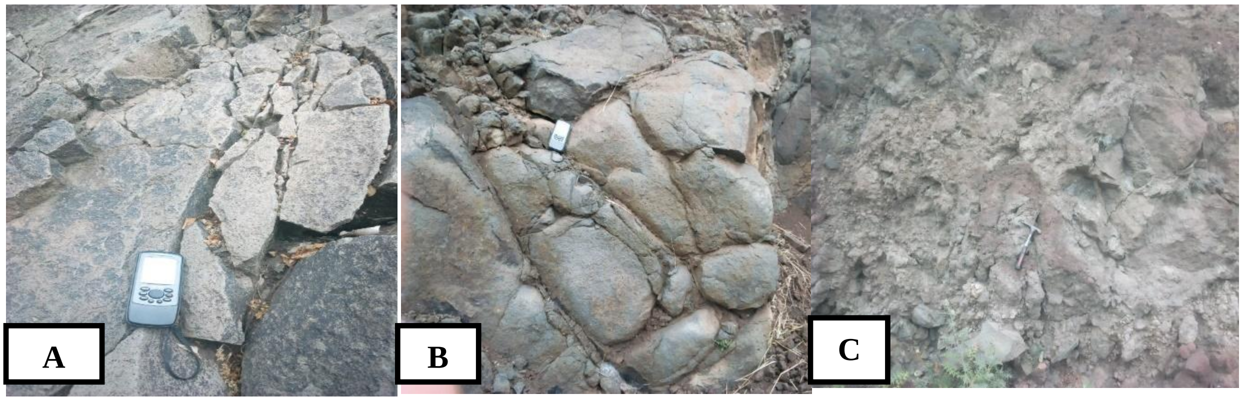
The geology of the present study area was mapped through field survey and from secondary source. It consists of basalt, unconsolidated / loose sediments alluvial, colluvial deposits and residual soils. The lithologies are exposed along the road cuts and on the natural hill sides. The detailed descriptions of each unit are presented in the following paragraphs;

3.2.1 Aphanatic Basalt

This geologic unit is exposed along the road cuts and on hill slopes which formsa chain of cliffs. It is highly fractured and weathered, dark to dark grey in color with aphanitic texture (Plate 3.1A). In some part of the area this unit is also affected by exfoliation type of weathering (Plate 3.1 B).

3.2.2 Agglomeratic Basalt

This lithologic unit is exposed along the road cut which is in south eastern part of the study area. This rock unit is brownish in color with a coarse accumulation of large block of volcanic material. It is typically poorly sorted which contain a fine matrix and vary from matrix to clast support (Plate 3.1C).



(A) Fractured aphanatic basalt (North of the area); (B) expholated weathered aphanatic basalt (East of the area); (C) Agglomeratic basalt (South east of the area)

Plate 3.1 Exposed rocks in the study area

3.2.3 Unconsolidated deposits

These units are the results of weathering activity which breaks large rocks into smaller one, and Sediments deposited by running of water along the streams and rivers. Alluvial deposits, colluvial materials and residual soils are unconsolidated deposits which are included in the study area. Each of the unconsolidated deposits is discussed below.

3.2.3.1 Alluvial deposits

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 3.2 A, B, C).

3.2.3.2 Colluvial deposits

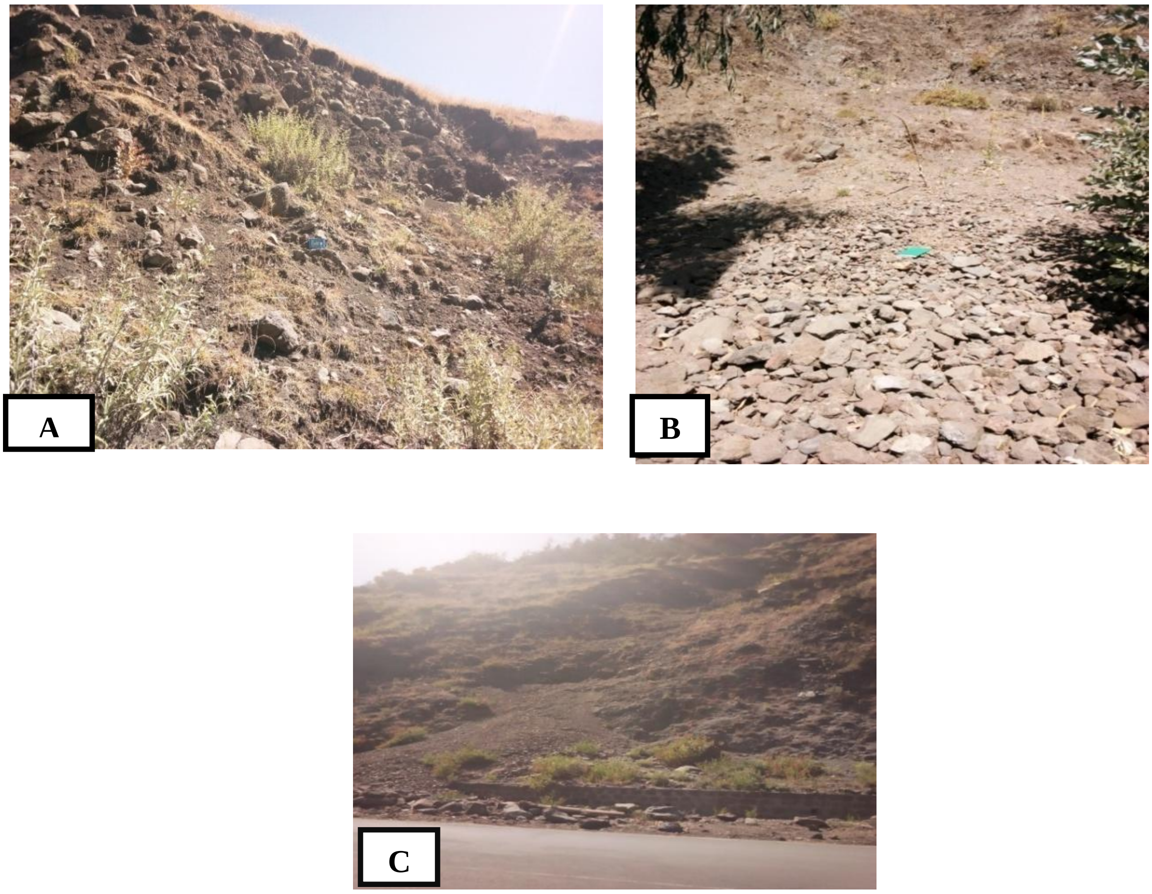
These deposits are found at the bottom of a cliff or slope, along the road cut in the study area which form fan shaped deposit (Plate 3.3A). They are poorly sorted and its fragments range greatly in size. In the study area these deposits include accumulations of rock fragments called talus which is angular, quite the reverse to round. It comprises of blocks of basalt and also soil that came from the steep cliffs (Plate 3. 3B).

3.2.3.3 Residual soils

Most of the residual soils which are deposited in the study area are black in color. They are deposited in low laying/ gentle slope. It is mostly applied for agricultural practice in the area. It consist granular material comprising sand and silt (Plate 3.4.B)

(A)alluvial deposit along stream in Dilb village; (B) alluvial deposit along the river at Imbawechkebelle;(C) alluvial deposit along river channel in Debot village

Plate 3.2 Alluvial deposits in the area

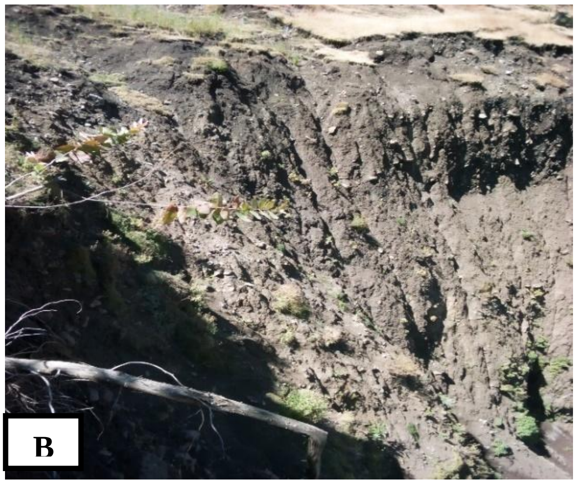


(A) Colluvial deposits that came from the steep cliffs; (B)and (C) Talus deposit along Woldiya to Dilbe road

Plate 3.3 Colluvial deposits in the area

3.2.4 Geologic structure in the area

Based on field observation joints are noted in the study area which are characterized by orientation, spacing continuity and aperture. The dip amount of most joints ranging from 25 to 68^o and have continuity up to 90 cm. They are closely spaced and the opening reaches to 3 cm. Majority of joints are observed in disintegrated rock mass. Surface cracks are also observed in the study are on soil deposit around Abayterfo area (Plate 3.5).



(A) Residual soil used for agriculture in the area;(B)Residual soil comprises sand and silt

Plate 3.4 Residual soil in the area

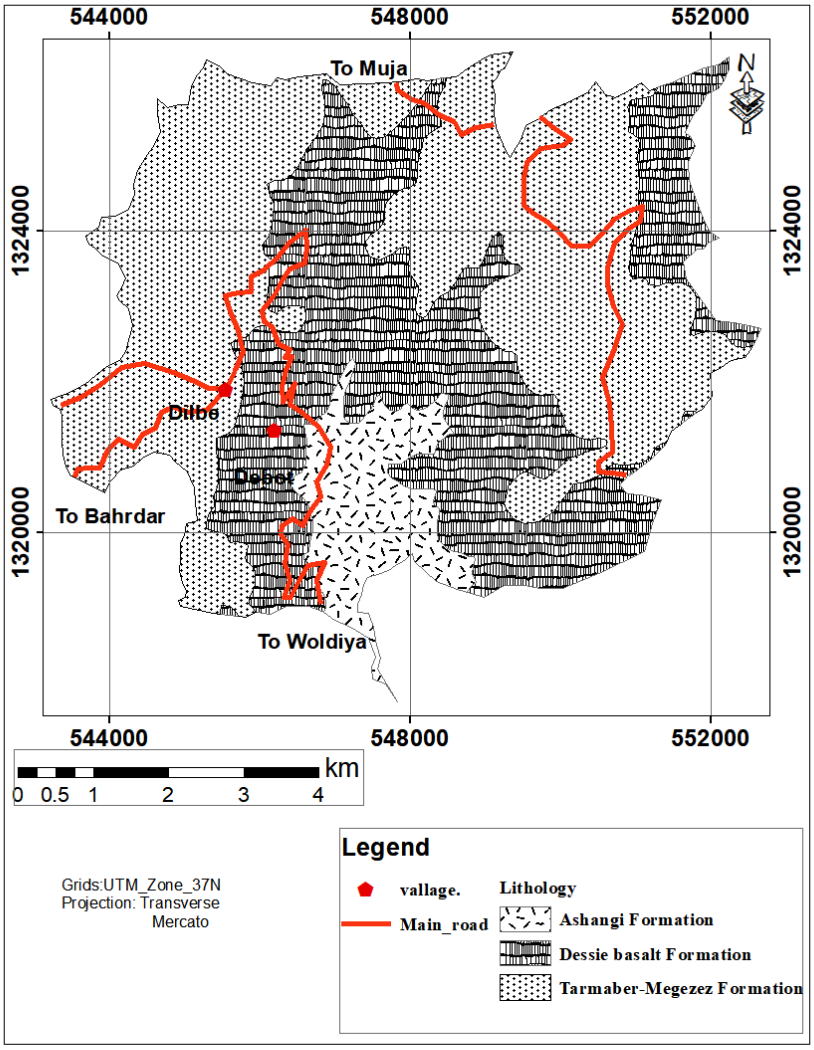


Fig 3.3 Generalized Local Geological map of the study area

Table 3.1 Area coverage of lithological formations in the study area

Name of Formations in the area	**Area coverage (Km^{2})**
Ashengi Formation	20
Dessie Basalt Formation	4
Tarmaber-Megazez Formation	26

(A) Ground cruck on cultivated area in Abayterfo Keble;
(B) Joints in Basalt in south east part of the study area.

Plate 3.5 Geological structure in the area

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Chapter Four Methodology

4.1 Introduction

Among the techniques which are used for landslide hazard zonation mapping statistical approach is the most popular technique (Raghuvanshi et al., 2014b). Many authors agree that statistical methods are more appropriate for hazard zoning, because of having minimum degree of subjectivity. In this method result of the inventory data are compared with the causative factors which influence landslides. Statistical analysis techniques are based on statistical determination of combination of causative variables in a given area. Based on the analysis for the interrelationship of the governing factors and the invented landslide activities quantitative estimations are made. Such assessment techniques facilitate to assigning weights to the governing parameters and it uses to rate the governing parameters which are used for the preparation of LHZ map (Fall et al., 2006). The statistical technique is based on a simple principle that “past is the key for future” (Carrara et al. 1991). It implies that the conditions resulted by various factors that have resulted into landslide in the past if reoccur in the area, landslide can trigger (Dai et al., 2002; Fikre Girma et al. 2015; Raghuvanshi et al. 2015; Tilahun Hamza and Raghuvanshi. 2017; Gemechis Chimidi et al., 2017).

On the other hand, in grid overlay analysis a grid of 10 x 10 m is prepared and overlaid over each prepared causative factor maps and geo-processing (intersection) is made to know the presence or absence of each causative factor sub-class within each polygon grid cell. Later, Landslide susceptibility Index (LSI) within each grid cell is computed for each factor class based on density ratio. Further, these LSI values for each factor class within a grid cell are summed up to get Total Landslide susceptibility Index (TLSI) values. Finally, based on these TLSI value zones of different probability of landslide hazard are delineated for each grid cell. Thus, a Landslide Hazard Zonation (LHZ) map for the given study area can be produced (Raghuvanshi et al. 2015).

4.2 Methodology adopted in the present study for LHZ mapping

For the present study an integrated grid overlay and GIS based statistical approach was followed. GIS based statistical approach was used to rate the controlling parameters which were responsible for landslide happening in the area to prepare LHZ mapping. For the statistical method used for the present study it was assumed that the past as well as the present are the key for future (Carrara et al. 1991; Varnes, 1984). To have the rate of various causative factors, individual factor maps were overlaid on active landslide map then quantitative prediction was made through density analysis of past landslide with respect to each causative factor class (Dai and Lee, 2001; Lee et al.,2004; Raghuvanshi et al., 2015; Tilahun Hamza and Raghuvanshi, 2017; Gemechis Chimidi et al., 2017).

For overlay analysis the study area has been divided into small units of a polygon grid (10 x 10 m). In order to prepare the grid, AutoCAD MAP software was used by importing geo-referenced study area boundary as a shape file to this software. Later, the grid file was overlaid over each decided causative factor maps and geo-processing (intersection) was done to know the presence or absence of each causative factor sub-class within each polygon grid cell. Later, the LSI which is calculated using statistical method was assigned to each causative factor sub-class, falling within each polygon grid cell. Then, to have the 'Total Landslide Susceptibility Index' (TLSI) all LSI found within each grid cell were summed up which was further utilized to provide the LHZ class within each grid cell.

In the present study six causative factors were considered for the evaluation of landslide hazard. These causative factors are; slope material, Land use land cover, aspect, slope, elevation and groundwater surface traces (Anbalagan, 1992; Lulseged Ayalew et al., 2004; Raghuvanshi et al. 2015; Tilahun Hamza and Raghuvanshi, 2017). Above mentioned causative factors were considered based on the relative importance in inducing instability to slopes in the present study area, as noticed during the field work. In order to accomplish the present study systematically, the study was conducted in three steps;

4.2.1 Desk study

During this stage various activities which were a base for the achievements of the objective of the present study were done. During this stage of investigation secondary data and required materials were procured from different organizations and sources. Some of the activities which were done during this stage are listed below;

- Literatures, articles and websites related to landslide and landslide hazard zonation, both unpublished and published written materials, maps and graphs were collected and studied in order to have a general background and a conceptual framework about the subject.
- Different type of base maps like, topographical and fact maps, slope material maps and Land use/ land cover map of the study area with the scale of 1: 50,000 were prepared.

- ❖ Metrological data has been collected from metrological agency to acquire good understanding about climatic conditions of the study area.
- ❖ Slope, Elevation, and Aspect map were prepared from Digital Elevation Model (DEM) at a resolution of 30 m obtained from ASTER data set by using Arc GIS.

4.2.2 Field investigation

Basically, this field investigation has been conducted in order to collect different types of primary data and to verify causative factor maps which were prepared from secondary data sources. At the time of field investigation facet wise observations were made. The activities that were carried out during field investigations were;

- Data pertaining to Locations, mode of failure and volume of past landslides were collected using facet map, topographic map and GPS.
- Surface manifestation of groundwater (springs) were recorded and documented facet wise. For this GPS point data at each spring site was collected.
- Data on artificial manmade activities like road or building construction, cultivation practices, slope cut, slope stabilization and excavation were observed and recorded.
- Pre-existing slope material map has been verified during field investigation.
- Land use and land cover units were observed and verified.

4.2.3 Post field data processing and analysis

After compilation of both the desk study and the actual field observation data, the data has been systematically grouped and analyzed using available techniques and computer programs. The following major activities were done during post field investigation.

- ➢ Landslide inventory polygon was created by overlaying field GPS failure point data on Google earth image and the thematic map layers of causative factors were prepared using secondary and primary data in Arc GIS. Later all these maps were transformed into raster.
- ➢ All parameters, possibly responsible for past landslides, has been quantified by overlay analysis' 'total pixel counts of a sub-class within a Landslide" to the ''total pixel counts of that sub-class with landslide did not occur in the area of study"
- ➢ By counting grid cells of each sub classes within each factor class, a hazard index value has been computed.
- ➢ Later, as per these hazard index values, appropriate weight was assigned to each of the causative factors classes.

- A polygon grid of (10 x 10 m) was created for overlay analysis and it has overlaid over each causative factor maps and geo processing was done to know the presence or absence of each causative factor sub-class within each polygon grid cell.
- Later, LSI ratings were assigned to each causative factor sub-class, falling within each polygon grid cell.
- Finally, within each grid cell all LSIs were summed up to have a 'Total Landslide Susceptibility Index' (TLSI) which was further utilized to provide the LHZ class.
- At the end LHZ map was validated through invented landslide map.

Fig. 4.1 presents the general methodology followed during the present research study.

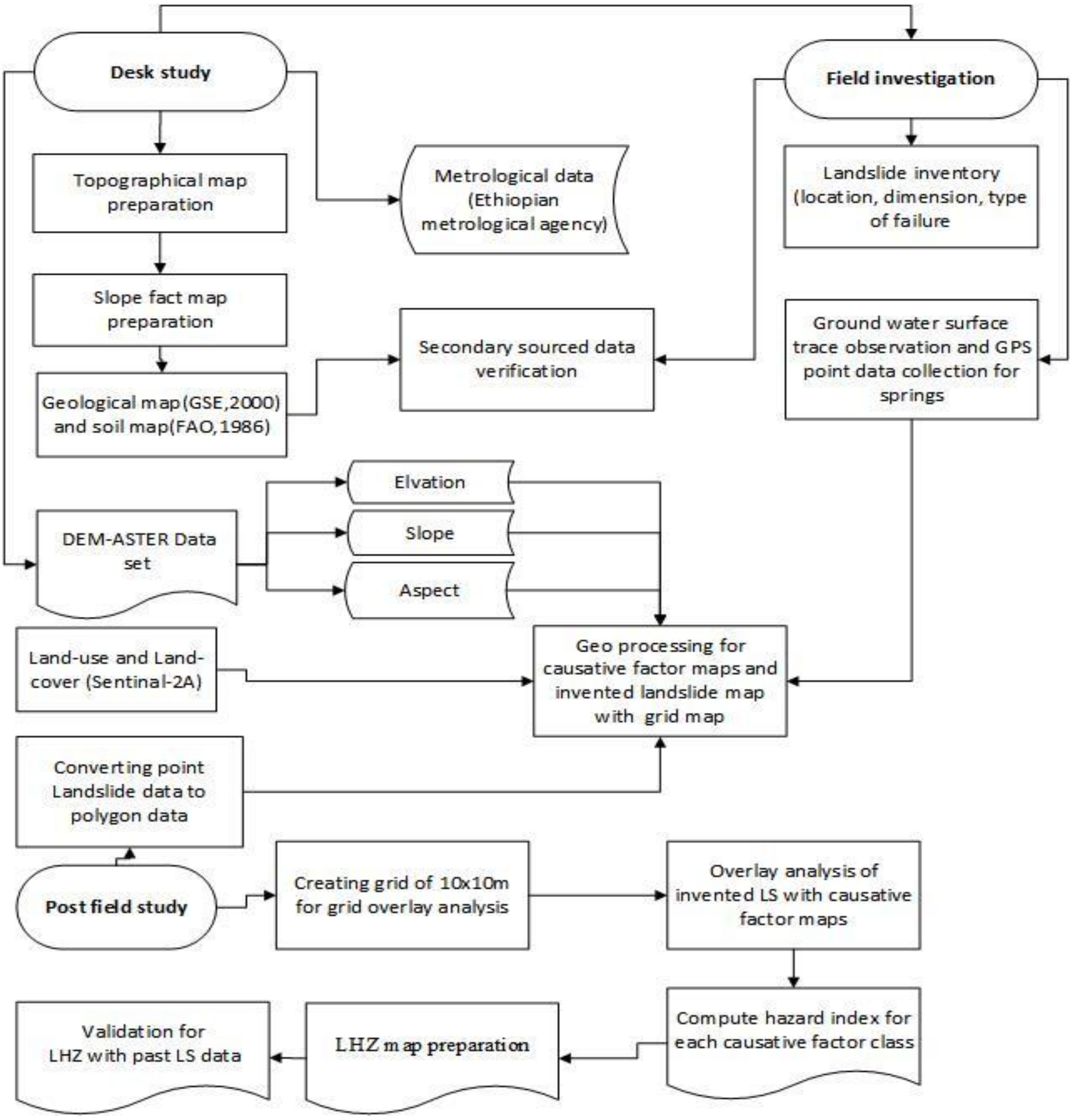

Fig. 4.1 Generalized methodologies followed for the present study

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Chapter Five Data Collection, Processing and Analysis

5.1 Governing factors and distribution

The intrinsic causative factor which affect the stability conditions of a slope are slope material, slope, aspect, curvature, land use/ land cover and ground water conditions (Raguvanshi et al., 2014a; Anbalagan, 1992).The causative factors considered for the evaluation of Landslide Hazard Zonation (LHZ) in the present study were Slope material, land use/land cover, ground water condition, slope, aspect and elevation. These causative factors were mainly considered based on their relative influence on slope instability in the area. In this study, therefore, evaluation of these causative factors with respect to past landslide distribution was made by conducting density analysis through raster maps overlay analysis and later percent area was computed. The thematic layers prepared for the analysis and their respected data source is presented in Table 5.1. Moreover, attempts were made to identify the likely triggering parameter of the invented landslides. According to the information collected from the local respondents and field manifestations the main triggering factors for major past and active landslides in the study area were heavy rainfall.

Table 5.1 Thematic layers and their respective data source

Causative factors	Source
Slope material	Geological map of Dessie area with a scale of 1:250000, (GSE, 2010) and soil map of Ethiopia from FAO (1986)
Slope	
Aspect	DEM data with a resolution of 30 m ASTER elevation data set
Elevation	
Land use land cover	Sentinale-2A and field observation
Ground water surface trace	GPS data collected during field work and topographical maps.

5.1.1 Slope material

According to Thomson (1971) as cited in Fikre Girma et al. (2015), nature and type of slope material have a great influence on landslide activity. 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 modified. In the present study area three types of soils are present, namely; colluvial, residual and alluvial soil. The rocks exposed in the study area were mapped as blocky rock mass and disintegrated rock mass.

Colluvial soils are mostly present in the Western and Eastern parts of the study area and constitute 27.76% of the total study area; whereas alluvial soils and residual soil constitute 15.2% and 21.6% of the study area, respectively (Fig. 5.1). The alluvial soil is exposed in the central part of the study area whereas; residual soil covers Northern and North eastern parts of the study area. The remaining parts of the study area are covered by disintegrated rock mass (20.58%) and blocky rock mass (14.86%), respectively. In totality 65% of the study area is covered by soils where as 35% of the study area is covered by disintegrated rock mass and blocky rock mass (Table 5.2).

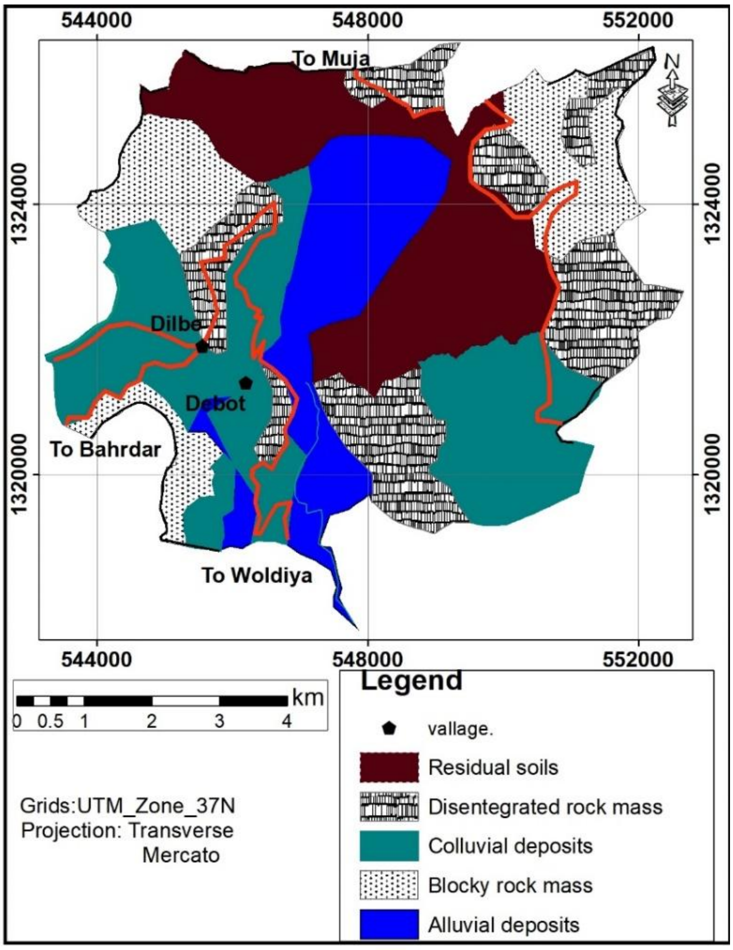


Fig 5.1 Slope material map of the study area

Table 5.2 Slope material classes with their respective area coverage

Slope material classes	**Area coverage**	
	Km^2	**%**
Blocky rock mass	7.43	14.86
Disintegrated rock mass	10.29	20.58
Residual soil	10.8	21.6
Alluvial soil	7.6	15.2
Colluvial soil	13.88	27.76
Total	**50**	**100**

5.1.2 Land use and Land cover

According to Fikre Girma et al. (2015) and Raghuvanshi et al. (2015), land use and land cover is one of the main factors in controlling landslide activity. In barren and sparsely vegetated land, the landslide activity become high because of relatively high weathering, erosion and other activities (Raghuvanshi et al., 2014a; 2014b; Wang and Niu, 2009; Anbalagan, 1992). The present study area land use land cover map was prepared from Sentinel-2A data through supervised classification using ERDAS Imagine. Further, the training pixels were controlled with the help of Google Earth image. Later, land use and land cover classes were prepared in Arc-map.

The present study area was classified in to seven land use land cover class, namely: urban/built up area, cultivated land, sparsely vegetated land, bare land, densely vegetated land, forest coverage and bush/shrubs land (Fig 5.2).

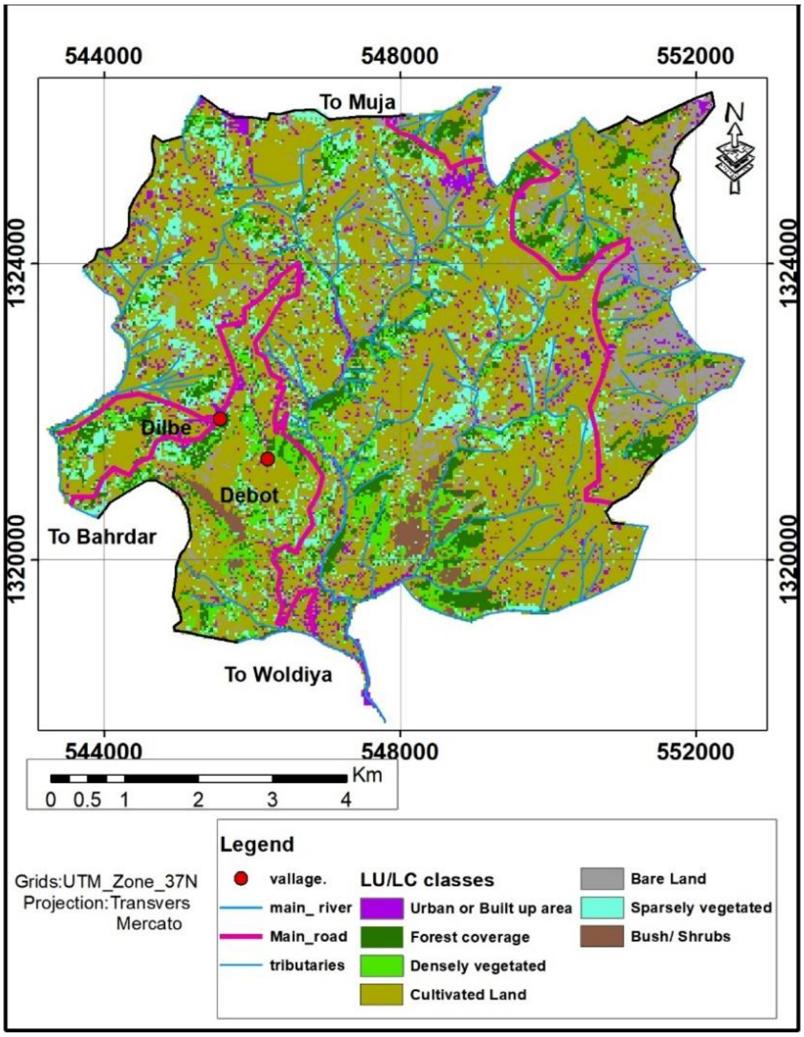


Fig 5.2 Land use Land cover map of the study area

The classes are sparsely distributed where cultivated land covers majority of the study area around 58.2% followed by sparsely vegetated land which covers 10.48% of the area. In area coverage, 7.72%, 2.92%, 6.32%, 8.28%, 6.08% land is covered by bare land, bush/shrubs land, densely vegetated land, and forest land and urban or built up area, respectively (Table 5.3).

Table 5.3: Land use Land cover classes with their respective area coverage

LU/LC classes	**Area coverage**	
	Km^2	**%**
Bare land	3.86	7.72
Bush/shrubs	1.46	2.92
Cultivated land	29.1	58.2
Densely vegetated land	3.16	6.32
Sparsely vegetated	5.24	10.48
Forest coverage	4.14	8.28
Urban or built up	3.04	6.08
Total	50	100

5.1.3 Ground water homogeneous zones

Groundwater plays a great role in inducing instability to the slopes (Raghuvanshi et al., 2014a; 2014b). Studies conducted for slope stability hazard mapping over relatively large areas makes it difficult to have direct observations of groundwater conditions within the slopes (Anbalagan, 1992). For this reason, in the present study indirect surface manifestation was recorded to assess the role of groundwater in inducing instability. It is reasonable to presume that spring location over the slope indicates ground water proximity and relative saturation of the slope mass (Raghuvanshi et al., 2014a). At the time of inventory data collection, spring locations were recorded. In total, 22 springs were located and mapped with the help of GPS hand held device. Later with relative density of springs within a certain elevation range ground water homogeneous zones were delineated as HGZ-I (2243-2843m), HGZ-II (2843-3143m) and HGZ-III (3143-3597m) (Table 5.4, Fig 5.3,).

Table 5.4: Ground water homogeneous zone with their area coverage

Ground water homogeneous zone	**Area coverage**	
	Km^2	**%**
HGZ-I (2243-2843m)	12	24
HGZ-II (2843-3143m)	25.8	51.6
HGZ-III (3143-3597m)	12.2	24.4
Total	**50**	**100**

In HGZ – I, 9 springs are present where as in HGZ-II and HGZ-III 11 and 2 springs were recorded, respectively.

The Ground water homogeneous zone map shows 24 %, 51.6 %, and 24.4 % of area coverage in HGZ-I, HGZ-II, HGZ – III, respectively (Table 5.4).

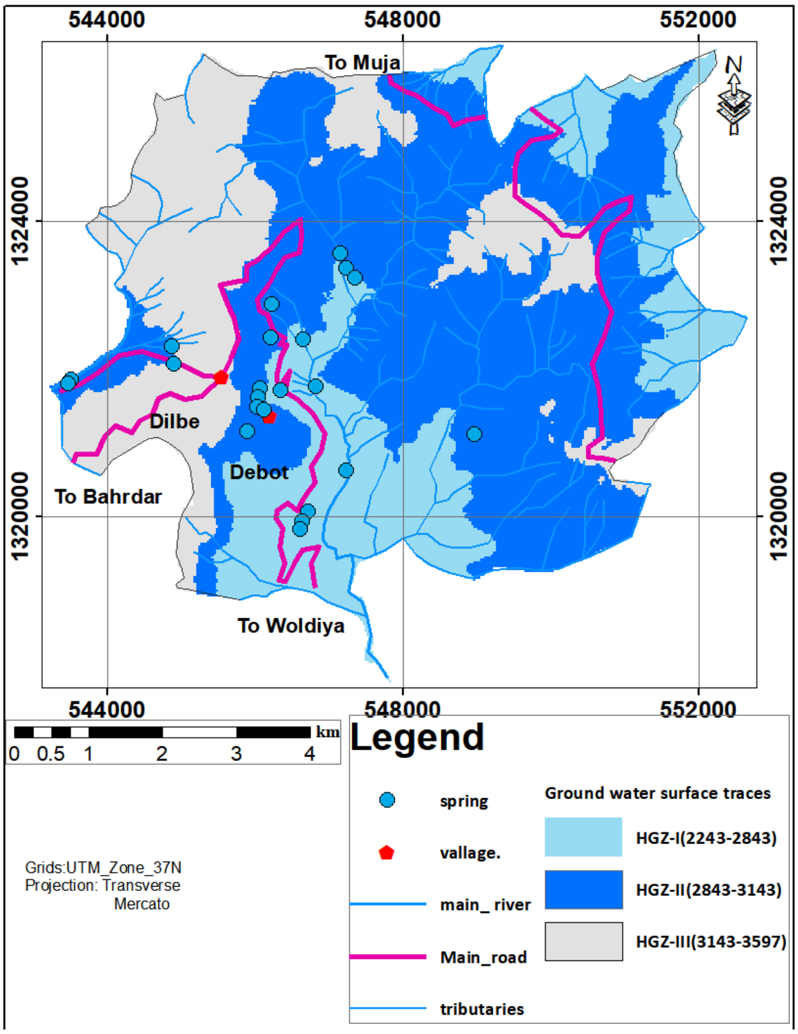


Fig. 5.3 Ground water homogeneous zone map of the study area

5.1.4 Slope

The probability of slope failure increases, as the slope becomes steeper (Raghuvanshi et al.,2014). Thus, the slope angle is an important controlling factor for landslide hazard analysis (Lulseged Ayalew and Yamagishi, 2004). As the slope becomes steeper, shear stress generally increases. According to Ahmed (2009), landslide frequency is expected to be minimum in gentle slopes. The slope map of the study area was extracted from DEM at 30m resolution from ASTER data set by using ArcMap-GIS tool (Fig 5.4). The range of slope angel in the study area varies from 0^o to 70^o. This slope range was classified in to five classes as; $0\text{-}5^o$, $5\text{-}10^o$, $10\text{-}25^o$, $25\text{-}38^o$ and slopes>38^o. The slope classification map (Fig.5.4), revealed that 21.8%, 30.4%, 17%, 24.8% and 6% of the area is covered by classes $0^o\text{-}5^o$, $5^o\text{-}10^o$, $10^o\text{-}25^o$, $25^o\text{-}38^o$ and >38^o, respectively (Table 5.5)

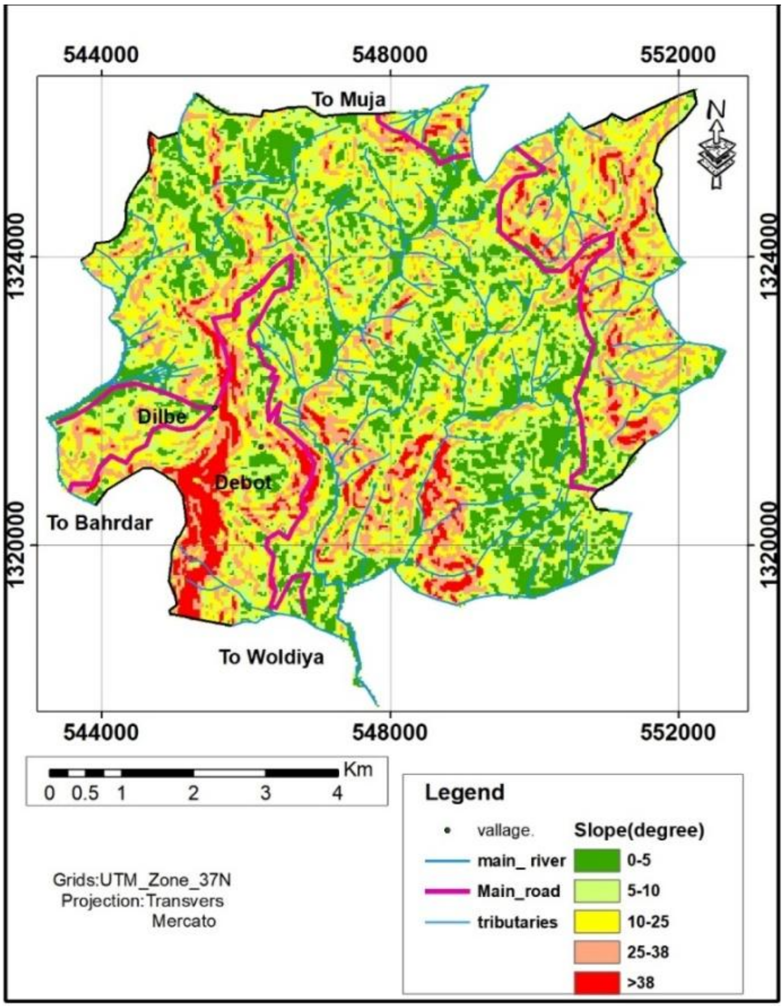


Fig 5.4 Slope map of the study area

Table 5.5 Slope classes with their respective area coverage

Slope classes	Area coverage	
	Km^2	%
0-5	10.9	21.8
5-10	15.2	30.4
10-25	8.5	17
25-38	12.4	24.8
>38	3	6
Total	**50**	**100**

5.1.5 Aspect

It is a real fact that slope aspect affects moisture retention and vegetation cover of a slope. Indirectly, aspect can control the susceptibility of a slope to landslides. It makes also a variation on rainfall distribution over the slopes. Therefore, slope aspect is considered to be an important factor for landslide hazard zonation (Wieczorek et al., 1997 as cited in Raghvanshi et al., 2015). For the present study the aspect map was extracted from DEM at 30m resolution from ASTER data set. For the present study aspect has been classified as; (i)

Flat (1), (ii) North (0– 22.5^o), (iii) North-east (22.5^o–67.5^o), (iv) East (67.5^o–112.5^o), (v) South-east (112.5^o–157.5^o), (vi) South (157.5^o–202.5^o), (vii) South-west (202.5^o–247.5^o), (viii) West (247.5^o–292.5^o), (ix) North-west (292.5^o–337.5^o), and (x) North (^{o}337.5-365^0) (Fig 6.5).The slope aspect map of the study area shows that 17.4%, 12.26%, 10.34%, 11.14%, 12.36%, 14.9%, 8.56%, 11.72% and 1.32% of the slopes fall into East, Southwest, Northwest, Northeast, South, Southeast, North, West and Flat aspect classes, respectively (Table 5.6).

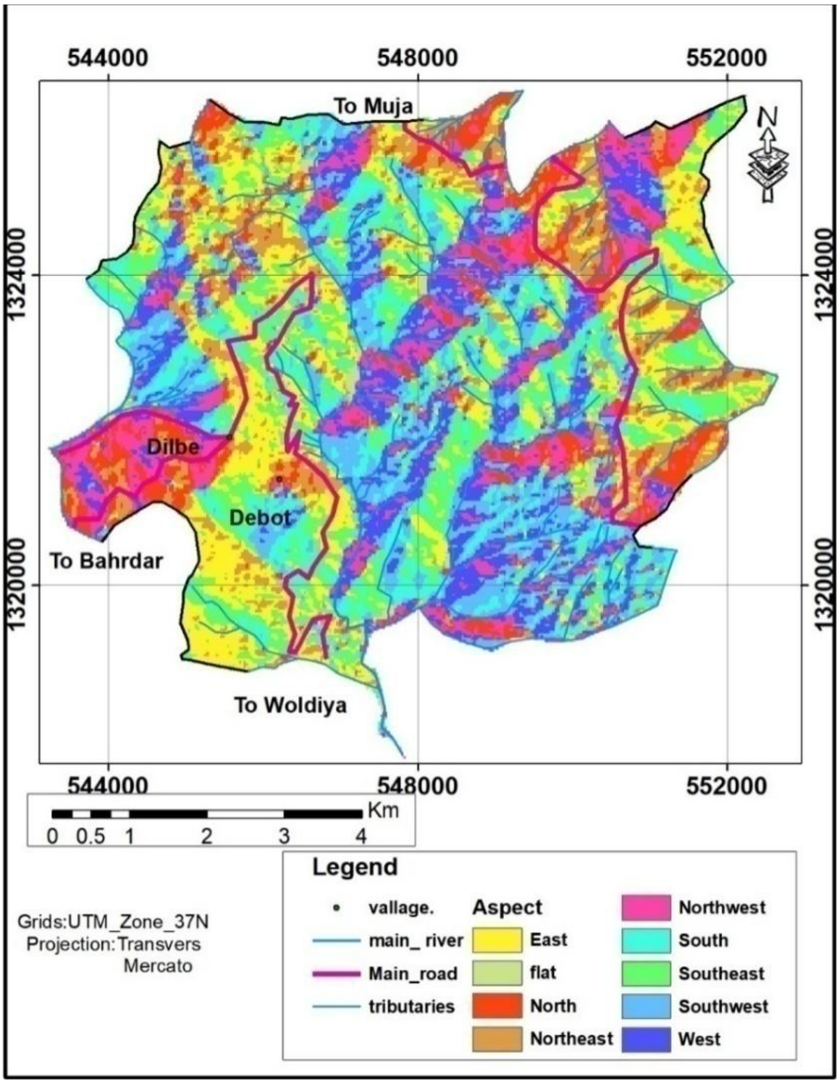


Fig 5.5 Aspect map of the study area

5.1.6 Elevation

According to Ahmed (2009), Elevation is considered to be a significant causative factor which can possibly control the landslide susceptibility of a slope through weathering, Erosion process and variation in humidity. The elevation of the study area was extracted from DEM at 30m resolution from ASTER data set. For the present study the elevation was classified by expert opinion based on the topography of the area into 4 classes; 2243-2543m, 2543-284m, 2843-3143m and 3143-3597m which covers 26.16%, 11.7%, 44.5% and 17.14% of the area, respectively (Fig 5.6, Table 5.7).

Table 5.6 Aspect classes with their respective area coverage

Aspect classes	Area coverage	
	Km^2	%
Flat	0.66	1.32
North	4.28	8.56
Northeast	5.57	11.14
East	8.7	17.4
Northwest	5.17	10.34
South	6.18	12.36
Southeast	7.45	14.9
Southwest	6.13	12.26
West	5.86	11.72
Total	**50**	**100**

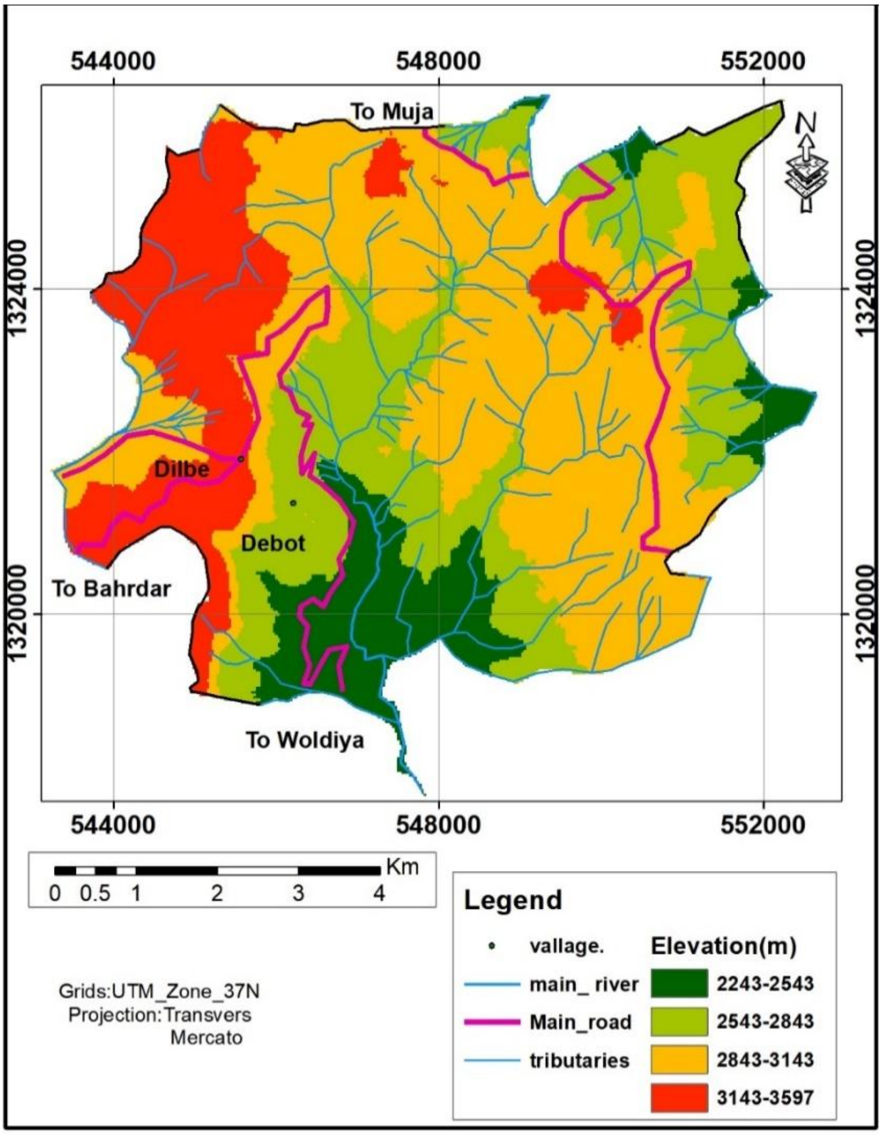


Fig 5.6 Elevation map of the study area

Table 5.7 Elevation class with their corresponding area coverage

Elevation class	Area coverage	
	Km^2	%
2243-2543	13.08	26.16
2543-2843	5.85	11.7
2843-3143	22.5	45
3143-3597	8.57	17.14
Total	**50**	**100**

5.2 Landslide inventory of the study area

5.2.1 Introduction

For landslide hazard evaluation and zonation various techniques has been employed in many studies. Among those techniques landslide inventory is considered as an initial tool for many landslide hazard zonation and evaluation studies. These techniques are simple in its application and it delineate areas that are affected by landslide processes for their location and dimensions, type and material characteristics (Tenalem Ayenew and Barbieri, 2004; Fall et al., 2006). Landslide inventory shows only landslide susceptibility for those areas where landslides have been observed. However, it may not provide information on landslide susceptibility which may have probability for future slope failure (Casagli et al., 2004). Even though Landslide inventory has thus limitation, it represents the most basic and simple method of landslide hazard assessment since it serves as the basic data source for having knowledge about conditions contributing to landslide occurrence (Casagli et al.,2004). Generally, inventory maps are used as a basis for almost all other landslide hazard zonation techniques or for an elementary form of a landslide hazard map.

5.2.2 Landslide distribution in the study area

For the understanding of landslide hazard and to evaluate the causative factors which are responsible for slope failure, identifying those areas which are, or could be, affected by a landslide is very essential. For this study landslide inventory data was collected thorough field investigation. Landslide location, dimension, material characteristics, mode of failure, location of spring were the data which was collected during the present field investigation. Facet wise observation was made to collect variety of primary data and to verify secondary source data in the field. The facets were prepared by delineating major or minor hill ridges, streams and on the basis of visual interpretation of topographic map and Arc GIS software (Anbalagan, 1992). A total number of 54 facets have been delineated in the study area (Fig. 5.7).

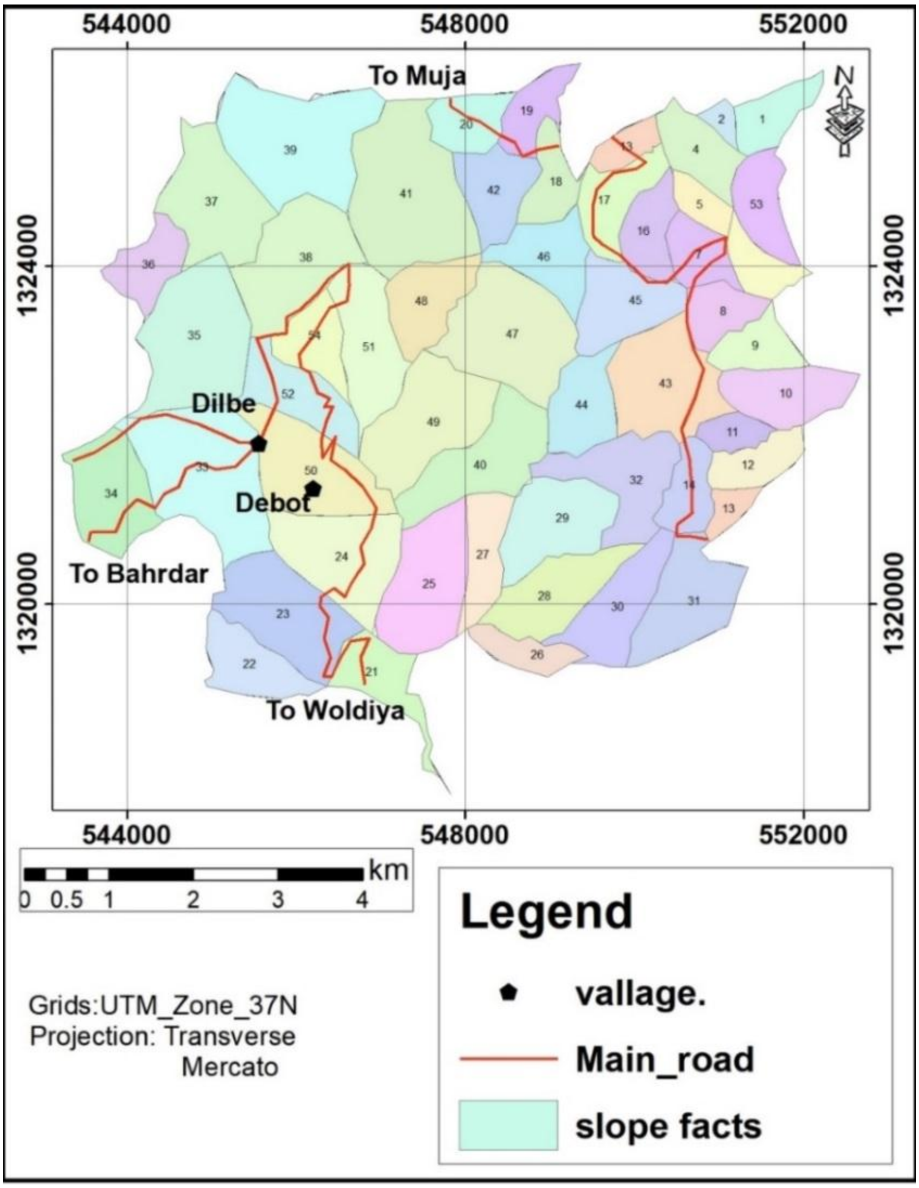


Fig 5.7 Slope Facet map of the study area

A total number of 30 landslides were observed in the area (Fig 5.8, Table 5.8). Based on observed failure mechanisms in the study area the landslides are grouped in to four classes namely: (i) rotational mode of failure, (ii) translational mode of failure, (iii) fall and (vi) complex type of failures. Further, all existing landslides in the study area were systematically studied and appropriate data necessary for hazard evaluation was collected. Thus, data on location, type of failure, dimension and material characteristic and possible triggering factor/s in past landslides was collected.

Out of 30 invented landslides in the area translational mode of failure and complex type of failure was observed in residual soil and alluvial deposit, respectively. Further, most of the rotational mode of failure, as observed, happened in colluvial and alluvial deposits.

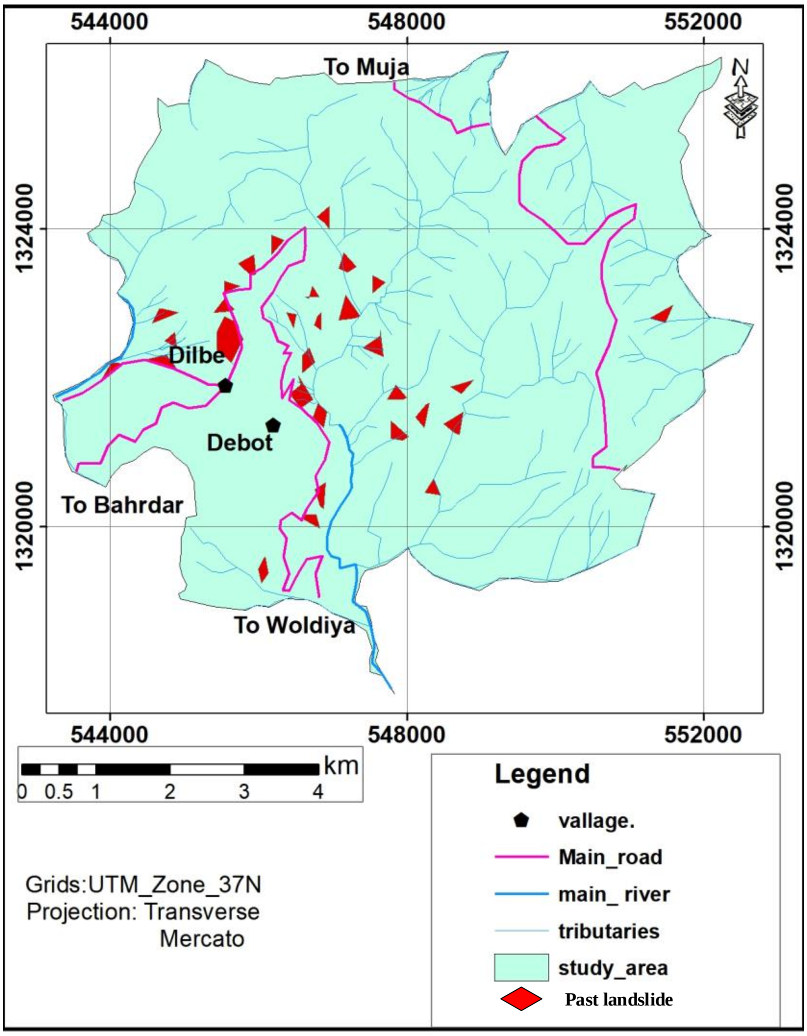


Fig 5.8 Inventory map of the study area

On the other hand, rock falls in the area were observed in disintegrated rock mass along Woldiya to Bahir Dar road section. Further, during field investigation 'informal questionnaires' were also used to gather information from the local respondents on landslide activities. in the past no systematic records were available for landslide event on the exact date, time and duration in the area however, according to local respondents most of the failures occurred during summer season (mid of July to September) as a consequence of the precipitation for the month of July and August. Therefore, the analysis showed that the main triggering factor for the landslide activity in the present study area is heavy rainfall.

5.2.3 Landslide manifestations in the study area

Landslide can occur quickly or at a slow rate. However, there may be signs before landslide cause danger on a slope or foundation collapses. Manifestations of landslides refer a change in morphology on the area and on any structures, which are founded on the slopes (USGS, 2004). In the present study area, various manifestations of landslides include features that are observed on active or recently active landslides, and old landslide features has been observed. Scarps, toes, bent or deformed trees, as well as damages to human-made structures such as cracked on roads and retaining wall, bending of houses was observed.

Table 5.8 Inventoried landslide in the study area

No.	Site	Location (UTM Zone 37 N)		Elevation (m)
		Easting	Northing	
1	Dilbe	0545776	1322476	3245
2	Dilbe	0545501	1322977	3189
3	Dilbe	0545485	1323155	3192
4	Dilbe	0545890	1323401	3147
5	Dilbe	0546177	1323610	3139
6	Sekela	0546897	1323490	2988
7	Imbawech	0547117	1323456	2873
8	Imbawech	0546480	1322740	2932
9	Imbawech	0546218	1323193	3023
10	Imbawech	0546299	1321706	2838
11	Abayterfo	0546529	1322244	2821
12	Imbawech	0546415	1321706	2791
13	Debot	0546733	1321439	2763
14	Debot	0546746	1320405	2696
15	Debot	0546639	1320190	2664
16	Debot	0546342	1319072	2544
17	Dilbe	0544891	1321940	3207
18	Dilbe	0544894	1322186	3166
19	Dilbe	0544848	1322258	3154
20	Dilbe	0544681	1322296	3134
21	Imbawech	0546540	1322810	2939
22	Yikurawerke	0547283	1322780	2828
23	Yikurawerke	0547378	1322780	2884
24	Yikurawerke	0548225	1321796	3048
25	Weraf	0548703	1321801	2963
26	Weraf	0548699	1321796	2991
27	Weraf	0548484	1321621	2997
28	Weraf	0547986	1321243	2969
29	Weraf	0548013	1321600	2999
30	Yikurawerke	0551500	1322900	2890

Scrap: is a steep (nearly vertical) surface on the undisturbed part of ground region of exposed soil and rock at upper edge of landslide which is formed due to the movement of material away from the undisturbed ground. Scrap can be classified as main scrap and minor scrap. Main scrap found at the upper edge of the landslide whereas minor scrap is found on the surface of disturbed ground produced by differential movement within the material (Cruden, 1993). In the study area landslide scrap was identified in Imbawoch secola kebelle at the back of Imbawoch Kidanemihret church in which the slope falls as earth slide which cause considerable damage to agricultural land (Plate 5.1D).

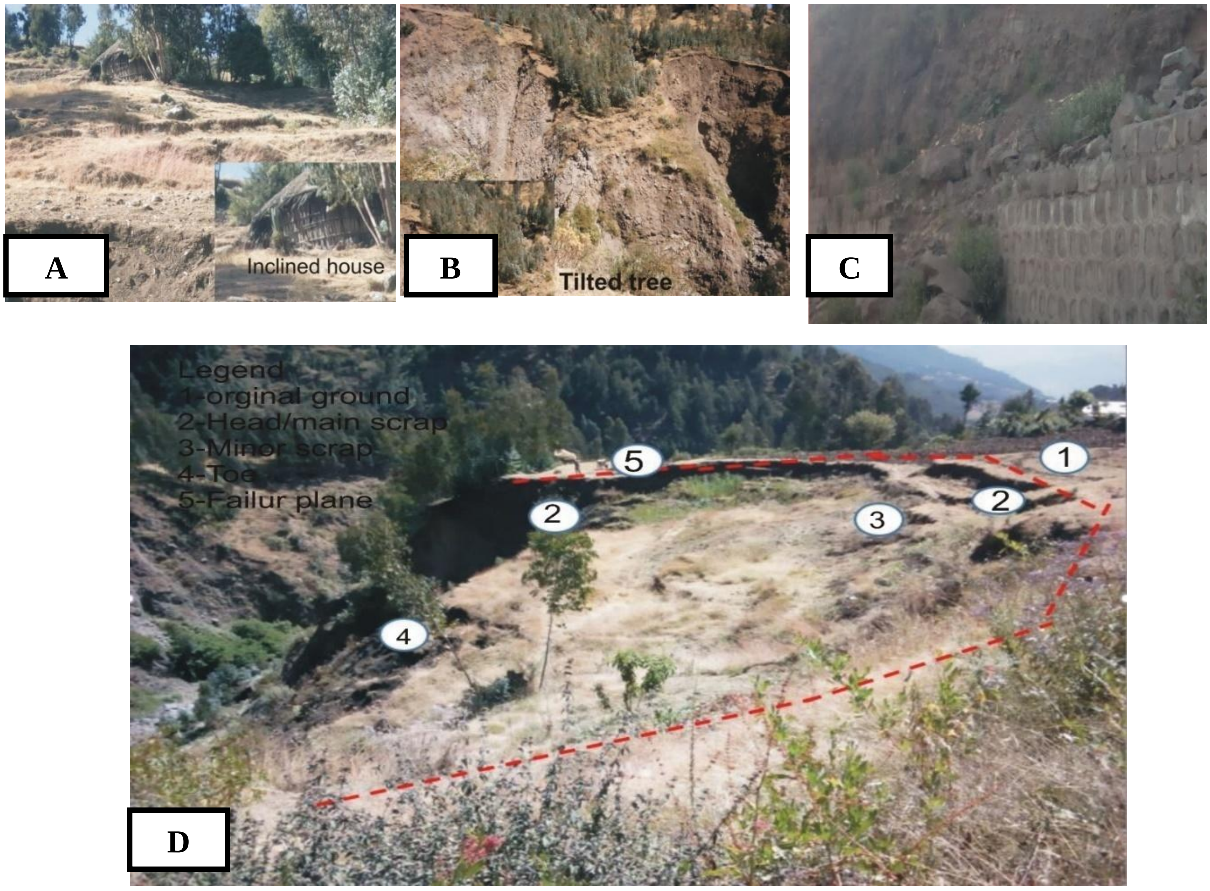
Toe: is usually the lower curved margin of the moving material of landslide it is found at most distant from the main scrap (Cruden and Varnes, 1996). In the study area many of the larger landslide toes have smaller failures with it and exhibited an over steepened slope and at the bottom which is enhanced by gulling with a concave upslope shape in map view.

Disturbed tree: Is one of the most indicators of landslide activities which are the response of vegetation to landslide activities. Landslide which occurs on a tree covered slope can produce various events like inclination of tree, shear of root wood and stem wood. The presence of young deciduous trees indicates unstable conditions because these types of trees are generally the first to re inhabit areas with removed vegetation. Unstable soils can also be identified by the presence of vegetation which has been disturbed in some manner (USGS, 2004). In the present study area many disturbed trees as well as houses were observed during the field investigation. As showed by (Plate 5.1D), the trees are inclined toward the slope in which the area also affected by gulling. Thus inclined trees were sought to grow straight up ward but the ground beneath it is subjected to slide

Damage to man-made structures: it is another indicator of landslide activity. Sidewalks and roads out of alignment, retaining walls that lean down slope and house inclination are examples of such structural damage in the study area (Plate 5.1 B and C)

5.2.4 Failure mechanism of landslide in the study area

Landslides can be caused by an interaction of various factors; geological, geomorphological, physical, and human activity (Varnes, 1978). Several classifications of landslide are available depending on a variety of criteria like (kinematics, material, fluid content, triggering process and style of activity (Varnes, 1978)). According to Crude and Varnes (1996) landslide can be classified based on material with movement type and velocity as falls, topple, slide, spread flow and complex type of movement. In the present study area four types of failure mechanisms was identified (A) rotational slide, (B) translational slide, (C) complex type of failure and (D) fall.



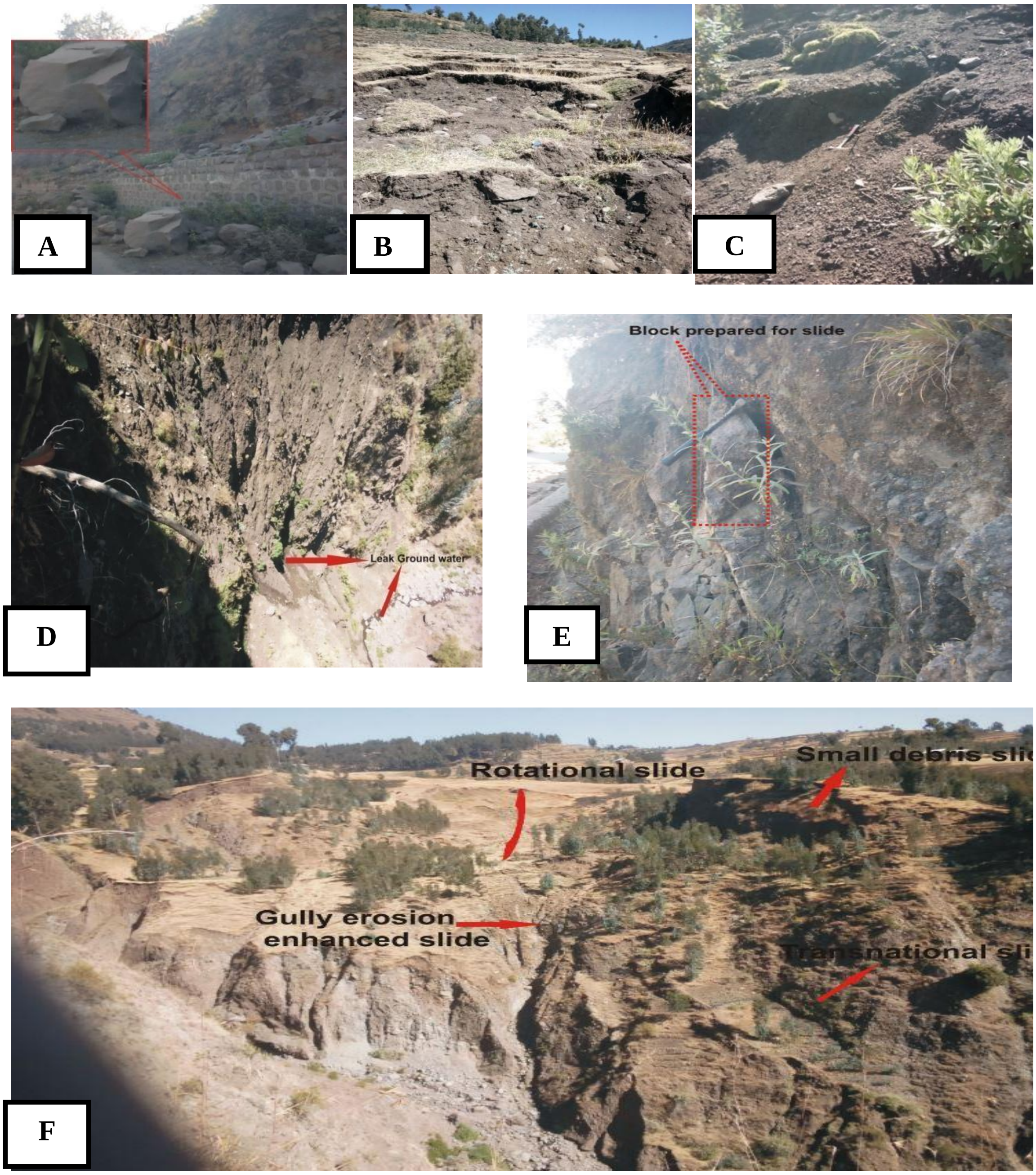
(A)Tilted tree due to landslide; (B) damaged (tilted) house in Sekela area; (C) damage on retaining wall and (D) Earth slide

Plate 5.1 Manifestation of landslide in the area

(A). Rock slide: Rock can slide as translational rock slide, wedge slide, rock slump (rotational slide), compound rock slide, or rock collapse however in the present study area, rotational rock slides were observed during the field work (Plate 5.2A). In the study area majority of rock slide happened on disintegrated rock mass. This type of failure in the area occurs along the roads and on gulley eroded river valleys. The major rock slides in the study area were observed along Sanka to Dilbe road near to Debot village which are observed in steep slopes of the area.

(B). Soil slide: Shallow landslides were observed in soil layer of the study area and often form slumps down valleys. Back tilting has seen near the scarp of the landslide and there is often a toe of displaced material. Most of soil slides in the study area were falls in rotational mode of failure. Soil slides in the study area happened due to the additional weight of water to the slope (Plate 5.2B)

(C). Rock fall: a rock fall refers to quantities of rocks falling freely along a vertical or sub-vertical cliff, proceeds down slope through Falling, bouncing and rolling after they are initially separated from the slope (Varnes, 1978). In the study area rock fall were observed along road cut exposures which were detached from a steep slope along a surface on which little displacement has occurred. Rock falls have highly damaged the road starting from Debot to Dilbe in the study area (Plate 5.2A).



(A) Rock fall along the road;(B) Typically, rainfall induced soil slide due to addition of weight in soil material; (C) Recent soil slide; (D) slide due to spring (E) Block which is prepared for slide/fall;(F)Complex mode of failure.

Plate 5.2 Landslide type in the area

(D). Complex type of movement: This type of movement is a combination of one or more failure types. In the study area a complex landslide was identified at the back of Imbawech kidanemhret which consist rotational slide and Debris slide. There is also gulling enhanced slide at the bottom of the slope (Plate 5.2 F).

5.3 Landslide hazard zonation

Landslide hazard zonation is a technique in which an area is divided into zones of varying degree of susceptibility for landslide. The degree of potential hazard in an area can be accessed on the basis of various instability inducing factors (Varnes, 1984). In this study for landslide hazard zonation, integraed statistical and grid overlay analysis was followed. For landslide hazard evaluation and zonation; slope, aspect, elevation, slope material, land use and land cover and groundwater condition were considered (Anbalagan, 1992; Raghuvanshi et al.,2014b; Gemechis Chimidi et al.,2017).

For the purpose of rating of various likely responsible causative parameters quantitative prediction was established based on the density analysis of invented landslides with respective causative factor classes. Using the tool raster calculator in Arc-GIS ratio was made between total pixel count for landslide occur to total pixel count for landslide did not occurred. Later, hazard index ratio was calculated.

For overlay analysis a polygon grid (10 x 10 m) was overlaid over each causative factor map and geo-processing (intersecting) was made to know the presence or absence of each causative factor sub-class within each polygon grid cell. Then, LSI ratings were assigned to each causal factor sub-class, falling within each polygon grid cell. Lastly, within each grid cell all LSIs were summed up to get a 'Total Landslide Susceptibility Index' (TLSI) which was further utilized to produce the LHZ classes.

5.4 Landslide Susceptibility Index (LSI) computation

Since the present study is based on the principal 'the past and the present is the key for future' the combination of causative factors which were responsible for past landslide may again contribute for present or future slope failure if similar combination reoccur in other regions of the present study area (Dai et al., 2002). Therefore, in order to assess the possible contribution of each causative factor on past landslide, Landslide Susceptibility Index (LSI) was calculated.

The LSI was formulated and proposed by an expressed given by Eq. (5.1).

$$LSI = \frac{Hazard\ index * LSV}{100} \ldots\ldots \left(Modified\ after\ Sarkar\ et\ al., 1995\right) \qquad \ldots\ldots 5.1$$

where; 'LSI' stands for Landslide Susceptibility Index and 'LSV' is the Landslide susceptibility value Hazard index (modified after Sarkar et al., 1995).

LSV were assigned to each of the governing factors, on the basis of the relative importance of each factor sub class in governing the stability condition of the slope in the present study area. The distribution of LSV to respective causative factor class was scaled to 100. At the beginning for all six causative parameters LSV of 10 was assigned and then on the basis of their possible contribution for instability additional values were added (Raghuvanshi et al., 2015). On the other hand, LSI was calculated through landslide percentage which was represents by the ratio between ''total pixel counts of a sub-class within a Landslide" to the ''total pixel count of that sub-class without landslide in the area of study" (Table 5.9). Through the raster calculator in ArcGIS, it was inferred that the total number of cells for the entire study area was 54257 whereas the number of cells covered by landslide has cell numbers equal to 1020.

In the present study slope material, land use land cover and ground water surface traces were given LSV of 20. It implies that as compared to other factor these causative factors were the most prominent causative factors. This was realized as past landslides occurred in each sub classes regardless of the dominance for any particular class. In slope material the landslide inventory shows 27%, 38.5% and 26.2% of past landslide occurrence in slope material classes of alluvial, disintegrated rock mass and colluvial soils, respectively. In land use and land cover class 20%, 24% and 26.1% of past landslide occurred in cultivated, bush and sparsely vegetated land, respectively.

On the other hand, 6.6% of past landslide occurred in bare, 7% on urban/built up area, 8.4% of past landslide occurred in forest and 7.4% in densely vegetated land. Thus, it implies that land use and land cover has better control in inducing instability to slopes in the study area. Similarly, 46.6%, 33.3% and 20% of past landslide occurred in ground water homogeneous zone of HGZ - I, HGZ – II and HGZ - III, respectively. Thus, in general it may be realized that landslides are not concentrated to some specific causative factor sub classes, almost in every sub classes landslide were recognized.

On the other hand, in elevation and slope causative factor classes concentration of past landslide are relatively realized in specific factor class for example; in the case of elevation 31.5% of past landslides occurred in class 2543-2843 m where as 26%, 35% and 7.5% of past landslides occurred in elevation class of 2843-3143m, 2243-2543m and 3143-3597m, respectively.

Table 5.9 Landslide parameter classes with their respective LSV and LSI.

Causative factors and corresponding factor class	Pixel count for Landslide did not occur		Pixel count for Landslide occurred		Hazard index	Landslide Susceptibility Index	Landslide Susceptibility Value
	Count	Ratio (a) ~~%~~	Count	Ratio (b) ~~%~~	(b/a)	LSI	LSV
Slope materials							
Residual soils	12043	22.20	58	5.69	0.26	0.051	20
Alluvial deposits	8141	15.00	261	25.59	1.71	0.341	
Colluvial deposits	15053	27.74	272	26.67	0.96	0.192	
Disintegrated rock mass	10705	19.73	429	42.06	2.13	0.426	
Blocky rock mass	8315	15.33	0	0.00	0.00	0.000	
Total	54257	100.00	1020	100.00			
Land-use and Land-cover							
Urban/ built up area	3593	6.62	60	5.88	0.89	0.178	20
Forest coverage	4580	8.44	80	7.84	0.93	0.186	
Densely vegetated	3371	6.21	60	5.88	0.95	0.189	
Cultivated land	31290	57.67	572	56.08	0.97	0.194	
Bare Land	4368	8.05	87	8.53	1.06	0.212	
Sparsely Vegetated	5757	10.61	137	13.43	1.27	0.253	
Bush land	1298	2.39	30	2.94	1.23	0.246	
Total	54257	100.00	1020	100.00			
Ground water surface traces							
HGZ-I (2243-2843)	12600	23.22	300	29.41	1.27	0.253	20
HGZ-II (2843-3143)	28321	52.20	520	50.98	0.98	0.195	
HGZ-III (3143-3597)	13336	24.58	200	19.61	0.80	0.160	
Total	54257	100.00	1020	100.00			
Elevation class							
2243-2543	6319	11.65	185	18.14	1.56	0.234	15
2543-2843	14191	26.16	361	35.39	1.35	0.203	
2843-3143	24401	44.97	276	27.06	0.60	0.090	
3143-3597	9346	17.23	198	19.41	1.13	0.169	
Total	54257	100.00	1020	100.00			
Slope							
0-5	12076	22.26	175	17.16	0.77	0.116	15
5-10	16498	30.41	270	26.47	0.87	0.131	
10-25	13452	24.79	299	29.31	1.18	0.177	
25-38	8914	16.43	189	18.53	1.13	0.169	
>38	3317	6.11	87	8.53	1.40	0.209	
Total	54257	100.00	1020	100.00			
Aspect							
Flat (0°)	375	0.69	16	1.57	2.27	0.227	10
N (0°-22.5°)	2496	4.60	18	1.76	0.38	0.038	
NE (22.5°-67.5°)	6147	11.33	107	10.49	0.93	0.093	
E (67.5°-112.5°)	9374	17.28	220	21.57	1.25	0.125	
SE (112.5°-157.5°)	8122	14.97	192	18.82	1.26	0.126	
S (157.5°-202.5°)	6701	12.35	143	14.02	1.14	0.114	
SW (202.5°-247.5°)	6728	12.40	117	11.47	0.93	0.093	
W (247.5°-292.5°)	6393	11.78	104	10.20	0.87	0.087	
NW (292.5°-337.5°)	5678	10.47	83	8.14	0.78	0.078	
N (337.5°-360°)	2243	4.13	20	1.96	0.47	0.047	
Total	54257	100.00	1020	100.00			

This implies that past landslides are concentrated in elevation class of 2243-2843m. Therefore, a nominal LSV value of 15 was assigned to elevation and with a similar reason; similar nominal LSV values were assigned to slope.

Further for aspect causative factor class LSV of 10 was assigned due to the concentration of past landslide in a specific aspect sub classes like 20% occurred in south where as 6.6% in the aspect class of Northwest. This implies that there is a high difference in the distribution of past landslide within each slope aspect sub classes.

5.5 Grid overlay analysis for landslide hazard evaluation

In this study, for overlay analysis the present study area was overlaid with 10 x 10 m polygon grid cells. In total 5226 polygon grid cells covered the total study area (50^2 Km). The grid was prepared by using AutoCAD MAP software (Fig 5.9).

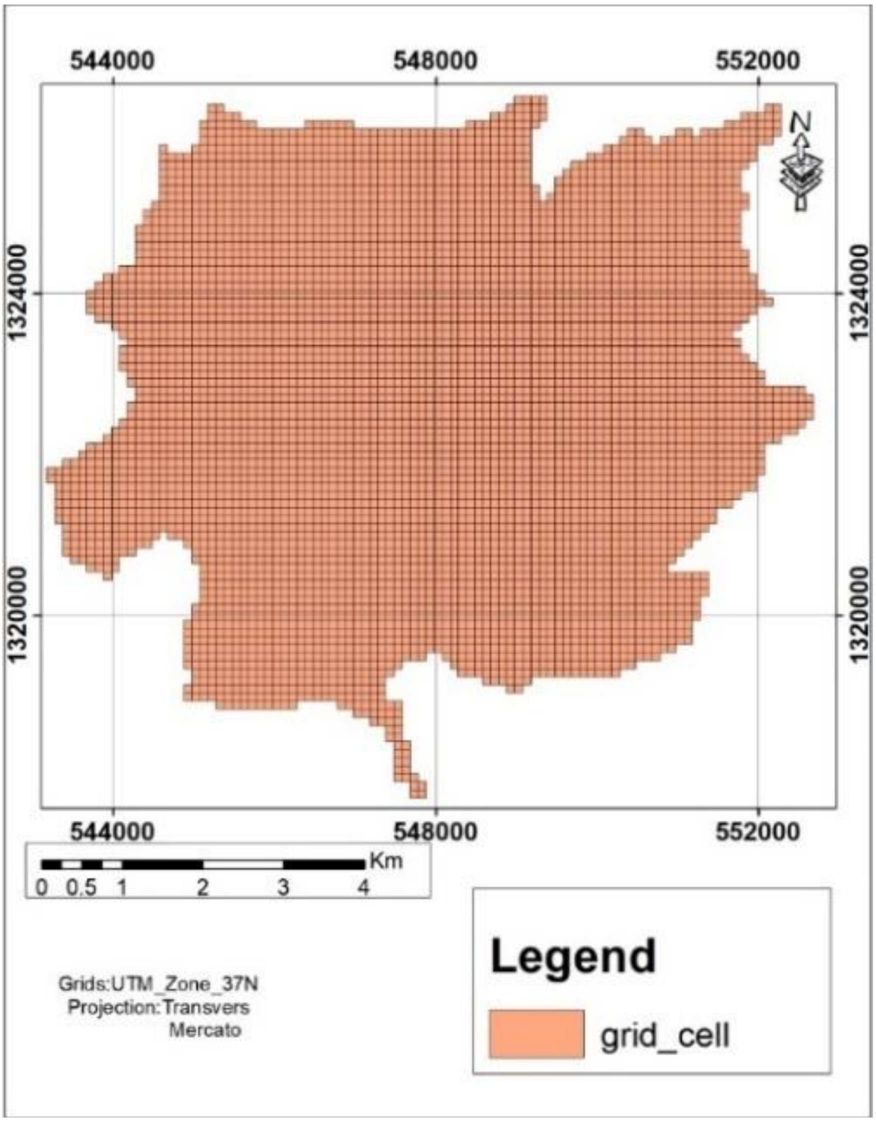


Fig 5.9 Polygon grid of the study area

For overlay analysis each of the grid cells were assigned with a unique ID for the purpose of geo-processing with various causative factors. Thus, the '*dbf' file component of 'grid shape file' was edited in MS-Excel and IDs from 1 to 5226 were assigned to the grid cells.

The created grid file (1–5226 cells) was overlaid on each of the causative factor map in GIS environment so that specific sub-classes of six causative parameter classes can be deduced within each grid cell. Later, all six geo-processed causative factor maps were merged together by using "merge themes' option in ArcMap. The intersection was done individually for each of the causative factor layer by merging two intersecting causative factors at a time through 'merge themes' option. Thus, a final composite grid map with six attribute data columns was obtained. Finally, one single file with a complete data set of 1–5226 cells and an attribute table for all six causative factors within each grid cell was created. Further, '*. dbf' file component of composite shape file was edited in MS Excel and each of the sub factor class was assigned by LSI numeric values by using find and replace command. Thus, for each grid cell 6 representative LSI values (Table 5.9) for respective causative class were assigned. Finally, LSI values for all 6 causative factor classes within each grid cell were summed up to obtain Total Landslide Susceptibility Value (TLSI). Further, based on the field evidence of past landslides, the obtained TLSI values were classified to represent zones of relative landslide hazard. Thus, the study area was divided into zone of various landslides susceptibility. The TLSI values obtained from analysis falls within range 0.58 to 1.34 (Table 5.10). Thus, it is reasonable to consider that the TLSI value 0.58 represents very low hazard and the TLSI value 1.34 or above represents very high hazard.

Table 5.10 TLSI value for zonation of each class

No.	Value for zonation	Zone Designation	Class
1	0.58-0.78	VLH	Very low hazard
2	0.79-0.99	LH	Low hazard
3	1.00-1.11	MH	Moderately hazard
4	1.12-1.33	HH	High hazard
5	>1.33	VHH	Very high hazard

Based on logical consideration, field evidence and judgment the landslide hazard zones were classified as; Very low hazard (VLH), Low hazard (LH), Moderate hazard (MH), High hazard (HH) and Very high hazard (VHH). By taking different distribution of TLSI range on trial basis for various landslide hazard classes, landslide hazard zonation map was prepared for each attempt by overlaying it on past landslide data. The most reliable validation results were obtained for TLSI distribution as shown in Table 5.10. The same distribution of TLSI for various landslide hazard classes thus, was utilized to prepare the final LHZ map for the study area (Fig. 5.10).

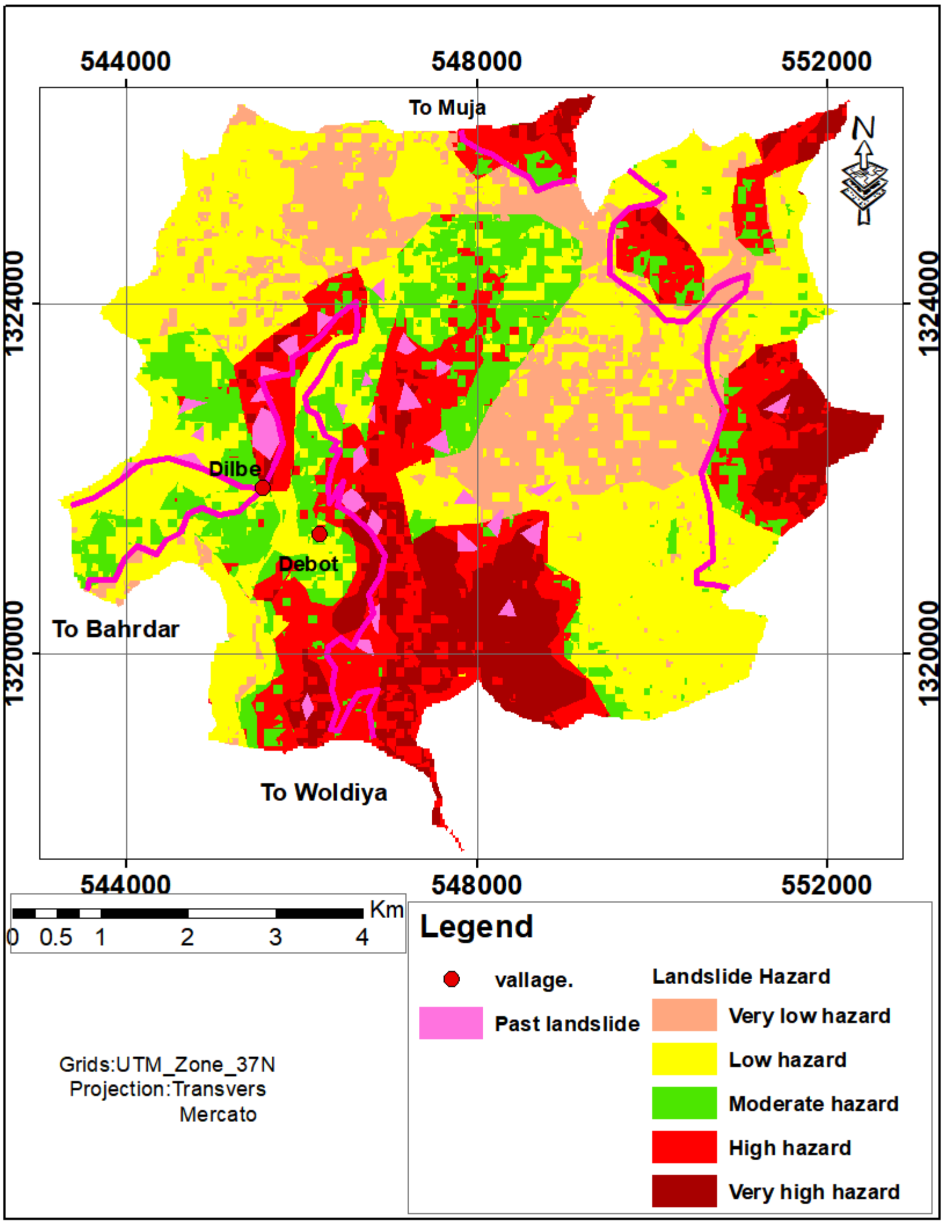


Fig 5.10 Landslide hazard zone map of the study area

The LHZ map of the study area prepared by grid overlay method (Fig. 5.10) shows that 11.54% (5.774km^2) of the study area has a 'very high landslide hazard' (VHH) potential and 19.8% (9.91km^2) area has 'high landslide hazard' (HH) potential. Whereas, the areas that account for 'medium hazard' (MH), 'low hazard' (LH) and 'very low hazard' (VLH) are 14.3% (7.18km^2), 38.2% (19.1km^2) and 16% (8km^2), respectively

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Chapter Six Results, Discussion and Interpretation

6.1 Landslide inventory

In the present study area, landslide cause considerable damage on road construction, agricultural land and also people are permanently displaced from their residence around Abayterfo Keble. The inventory data of the present study revealed that 30 landslide had occurred in the past. These landslides occurred mainly as; fall, rotational slide, translational slide, and complex type of failure. The invented landslides were dominated in central and western parts of the study area. Among 30 landslides 76% were failed with rotational mode of failure, 17% were failed with fall and the remaining 7% failed with translational and complex mode of failures. Majority of these slides occurred in disintegrated rock mass and in unconsolidated deposits. Also, in the present study area past landslides were occurred in gullies and stream banks of alluvial deposits (Plate 5.2D). Besides, slides also occurred in talus deposits which were transported from the steep sloppy area along the main road in the study area. Most of the rock falls in the area were observed in disintegrated rock mass along the road which extends from Woldiya to Bahir Dar. As revealed by the local respondents and through the field observations most of the landslides have occurred during the late rainy season (July-August) indicating a rise in groundwater level due to recharge by heavy rainfall. This indicates that the main triggering factor for past landslide is heavy rainfall. There was also slope failure around Abay terfo kebele which was triggered mainly by the spring (Plate 5.2). In general, slope material, rugged topography and complex hydrological condition had played an important role in destabilizing the slopes of the study area.

6.2 Governing factors influence and Hazard potential

6.2.1 Slope material

The overlay analysis of past landslide with slope material map (Fig. 5.8) reveal that about 26% of past landslide occurred in colluvial soil, 27% in alluvial soil, 38.5% in disintegrated rock mass and 8.5% in residual soil. It means that 62% of landslide activity has occurred in slopes that are covered by soil and 38.5% in disintegrated rock mass. No landslide activity was recorded in blocky rock mass. More concentration of landslide in unconsolidated material is related with their low shear strength and when saturated may result into washing of finer particles and may become more prone to instability (Raghuvanshi et al., 2014a; 2014b; Anbalagan, 1992).

6.2.2 Land use and Land cover

As determined from raster map overlay analysis, the relation between past landslide and Land use and Land cover shows that 26.1% past landslides falls in sparsely vegetated land, 24% of landslide falls in Bush or shrubs land, 7% falls in built up area, 6.6% falls in bare land, 7.4% falls in densely vegetated area, 8.4% falls in forest coverage and 20% of landslide falls in cultivated land. The result revealed that past landslides were observed to be distributed in all classes of land use and land cover without any dominance of a particular class. Relatively, in sparsely vegetated and bush land areas more concentration of landslides was observed. This may be related to unconsolidated material which is generally highly susceptible to instability (Raghuvanshi et al., 2014b).

6.2.3 Ground water condition

The analysis showed that among the invented landslide in the study area 46.6% falls in HGZ-I (2243-.2843m), 33% falls in HGZ-II (2843-3143m) and the remaining 20% falls in HGZ-III (3143-3597m). This shows that past landslides are concentrated in HGZ -I and HGZ -II. It shows direct relation of landslides with the concentration of springs in the area (Raghuvanshi et al., 2015).

6.2.4. Elevation

From the total landslide occurred in the area, 35% falls in elevation class of 2243-2543m, 31.5% falls in 2543-2843m elevation class, 26% falls in elevation class of 2843-3143m and the remaining 7.5% falls in elevation class of 3143-3597m. As the result revealed past landslides are concentrated in elevation class range 2543-2843m. More concentration of landslide in the elevation class of 2243-2843m may be due to cultivation activity in this elevation range with an addition of presence of a good number of springs in this range of elevation area (Raghuvanshi et al., 2015).

6.2.5. Slope

The overlay analysis of past landslides over slope map of the study area showed that 7% of past landslides falls in 0-5^o, 15% falls in 5-10%, 27% falls in 10-25^o, 20% falls in 25-38^o and 31% falls in the slope class >38^o. The more distribution of landslide in steeper slopes may be due to increment of shear stress and tangential component of weight within slope (Ahmed, 2009; Raghuvanshi et al., 2015). Further, concentration of past landslides in the slope class of

10^o-25^o may possibly be related with the presence of unconsolidated material (Raghuvanshi et al., 2014a: 2014b).

6.2.6. Aspect

The result revealed that out of total invented landslides 18%, 20%, and 16% falls in slopes that are inclined towards Southeast, South and East directions, respectively. Slopes oriented towards North, Northeast and Southwest directions have 9%, 7.7% and 11% of landslides. On the other hand, slopes oriented towards West, Northwest and Flat directions have 7.68%, 6.6% and 3.2% of landslides, respectively. This shows that most of the slopes in the area are inclined towards East and Southeast directions. Also few landslides, particularly flow type were also recognized in relatively flat areas where mainly colluvial soils were present. This remarkably showed the concentration of landslides in slopes facing toward South, Southeast and East directions. This fact may possibly be correlated to the general ground water flow direction in the study area.

6.3. Landslide hazard zonation and distribution

Based on the calculated TLSI values, the study area was classified in to five classes of hazard as; very low hazard (VLH), low hazard (LH), moderate hazard (MH), high hazard (HH) and very high hazard (VHH) (Table 5.8). Further, perusal of Fig. 6.1 clearly shows that very high hazard (VHH) and high hazard (HH) zones are largely concentrated in the southern, northern and Eastern parts of the study area. The area delineated as VHH and HH zones have good concentration of springs. Majority of the areas in VHH and HH zones have slopes that ranges between 10^o to 38^o and generally have unconsolidated deposits and some disintegrated rock mass. The moderate hazard (MH) zones are distributed towards Northern Central and Western regions of the study area. On the other hand; low hazard (LH) zones are scattered in the study area. Very low hazard (VLH) zones are mainly concentrated in the Northern and Eastern parts of the study area. Very low hazard and Low hazard zones falls in slopes that have mainly blocky rock mass as slope material with majority of slopes having inclination of 0^o-5^o and also these zones have minimum number of springs.

6.4. Validation of LHZ map

The validation of prepared LHZ map during present study was made by overlay analysis with past landslides in the area (Fig. 6.1). The result showed that 74% (22) of past landslides fall within very high hazard (VHH) and high hazard (HH) zones of the prepared LHZ map.

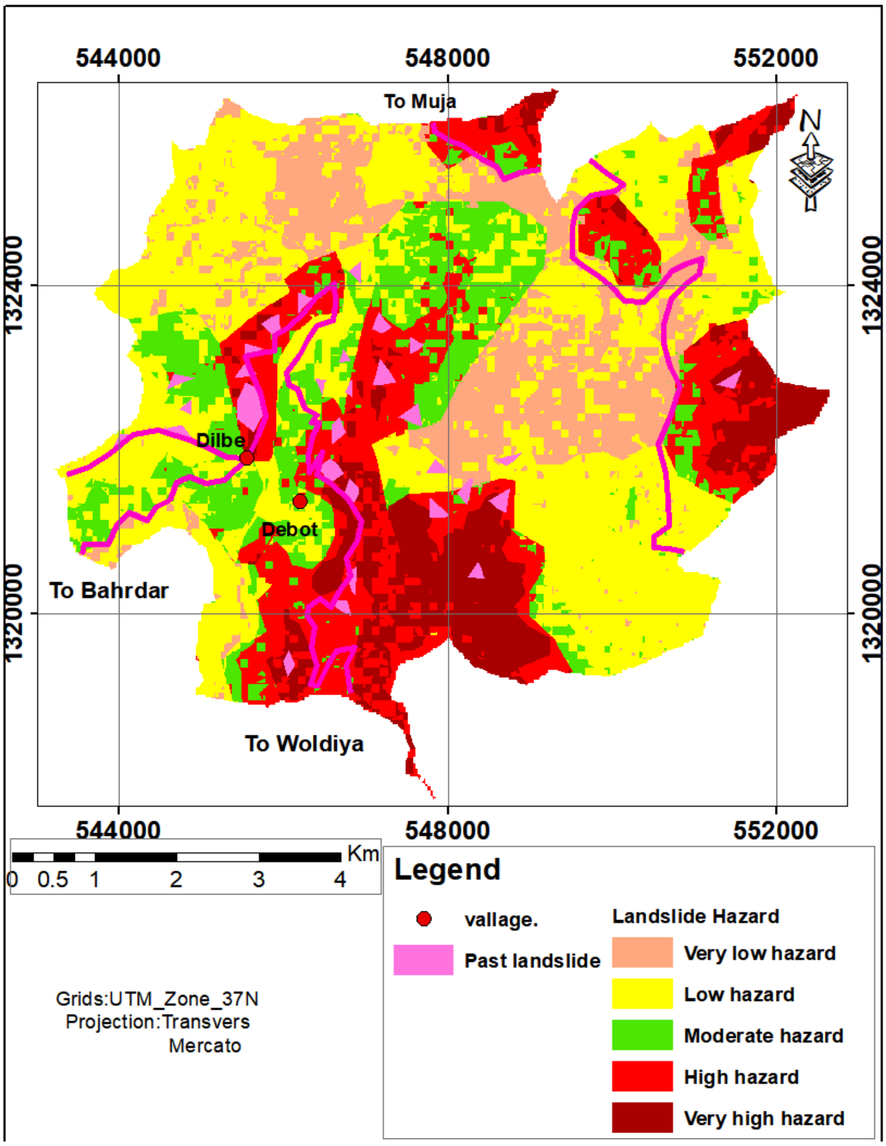

Fig 6.1 Validation of LHZ map with past landslides in the study area

Further, 17% (5) of past landslides fall on moderate hazard zone that also have reasonable probability of landslide occurrence. Thus, it may be safely concluded that about 91% of the past landslides validate with the LHZ map prepared during the present study. Only 9% (3) of past landslides fall within low hazard (LH) and very low hazard (VLH) of the LHZ map. This may be due to certain factors which may not be considered at the scale (1:50,000) at which the present LHZ map was prepared (Shiferaw Ayele et al., 2014). These additional factors that are important in inducing instability to slopes are; characteristics of discontinuity surfaces, interrelationships of discontinuities, pore water pressure in soil mass, water forces acting within the discontinuity surfaces, shape factor of particles in coluvial material etc. These factor can only be considering in study which is conducted at a scale >5000 (deterministic approach) (Tilahun Hamza and Raghuvanshi, 2016).

6.5. Evaluation of causative factor based on the prepared LHZ map

The results of the present study showed that 85% of total area, 79.2% of total area and 57.7% of total area which is covered by slope class >38^0, 10^0-25^0 and 25^0-38^0**,** respectively are fall under hazardous zone. This implies that slopes in the study area which has inclination in the range 10^0 to 38^0 are highly susceptible for landslides. Within this slope class the slopes are covered by weak disintegrated rock mass and unconsolidated alluvial deposits which possess weak shear strength and can easily fail when saturated (Raghuvanshi et al., 2015).

On the other hand, slopes inclined at angle >38^0 falls in hazardous class because as the slope angle increases the shear force due to gravity pull increases and the slope will be more susceptible for failure (Raghuvanshi et al., 2015; Tilahun Humza and Raghuvanshi, 2017). Similarly, elevation classes 2243-2543 m and 2543-2843 m are more susceptible to instability as 85% and 79% of their area coverage fall under hazardous zone, respectively fall within these classes. The possible reason of susceptibility within elevation range 2243-28m may be related to groundwater occurrence at shallow depth and general saturation of slopes as within this elevation range concentration of springs was observed. Besides, slope material present within this range is weak unconsolidated material which in general possesses poor shear strength.

The results also showed that the slopes that are inclined towards South, Southeast and Eastern directions are more susceptible for slope instability. The concentration of hazardous zones towards South, Southeast and Eastern directions may possibly be related to ground water flow direction in the area as most of the springs in the area are located on slopes which are inclined towards South, Southeast and Eastern directions.

Further, the land use and land cover classes does not show dominance of any particular class with respect to susceptibility for landslides, as the hazardous zones are almost evenly distributed in various land use land cover classes.

Majority of the area which is covered by unconsolidated deposits (alluvial and colluvial) and disintegrated rock mass show high susceptibility for landslides. In case of weak disintegrated rock mass the shear strength (degree of weathering may affect the relative strength of the rocks) of the material is low, thus it becomes highly susceptible for slope instability. On the other hand, according to Anbalagan (1992) and Raghuvanshi et al. (2015) weak unconsolidated deposits are susceptible for landslide. In general, the unconsolidated deposits are loose soils that are comprised of sub-angular to rounded rock fragments of variable shape and size in a matrix of sandy silty soils. When saturated such material may result into washing out of finer matrix particles with water and may become more susceptible for instability (Raghuvanshi et al., 2015; 2014a; Anbalagan, 1992). Further, majority of the area which is covered by GHZ-I (85.5%) and GHZ-II (87%) fall on hazardous zone. This is due to a fact that these zones have high concentration of springs in the present study area. Thus, slopes falling within this zone are highly susceptible for slope instability.

Finally, in general it may be concluded that the major influencing factors that are possibly responsible for landslides in the present study area are geological and geomorphological associated with gravity movement triggered by seasonal heavy rainfall.

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Chapter Seven Conclusion and Recommendations

7.1 Conclusion

The present study area, Dilbe and its surrounding area, is located in North-western Central Ethiopian plateau in North Wollo distinct of Amhara Regional State along the main route that originates from Woldiya to Bahrdar Town and has a total coverage area of 50 km^2. The area is about 576 km from Addis Ababa. The present study area is characterized by rugged topography with an elevation difference of 2243 to 3597m. The area is severely affected by landslides and related slope instability problems. As a result roads and agricultural lands are damaged and also local people are displaced from their residences.

The main objective of the present study was to evaluate the factors responsible for landslide activity in the area and to produce landslide Hazard Zonation (LHZ) Map of the study area by classifying the area in to zones of relative susceptibility of landslide. In order to achieve the objectives of the study, GIS based integrated statistical and grid overlay approach was followed.

For the present study six causative factors namely; slope, elevation, aspect, slope material, land use/land cover, and ground water conditions were considered and representative data for these causative factors was collected from secondary and primary data sources. Further, the data on past landslides was collected and mapped through field investigation and Google earth image interpretation. In this study, the area has been classified into 54 slope facets and the invented landslide and field data on various causative factors were collected slope facet wise. For the purpose of rating of the controlling parameters responsible for landslide occurrence in the area, GIS based statistical approach was followed. All parameter maps and invented landslide map were processed and brought to GIS environment for further processing and analysis. Quantitative predictions were made through density analysis of past landslide with respective to each causative factor class by overlaying individual factor maps on active landslide map. Thus, density ratio was made between total pixel counts for landslide occurred to total pixel count for landslide did not occurred. Thus, hazard index for each parameter sub class was computed which was later utilized to compute landslide susceptibility index (LSI).

Further, for grid overlay analysis the study area has been overlaid with a polygon grid of 10 x 10 m. This overlay analysis was done to know the presence or absence of each causative factor sub-class within each polygon grid cell. Within each grid cell depending on presence of various factor classes, LSI values were assigned. The sum total of LSI values for six parameters within each grid cell provided total landslide susceptibility index (TLSI), which finally formed the basis to produce LHZ map of the study area.

The landslide hazard map of the present study area has revealed that 11.54 % (5.75 km^2), of the study area falls under very high hazard zone, 19.8% (9.9 km^2) of the area falls under high hazard zone, 14.36% (7.18 km^2) of the area falls under moderate hazard zone, 38.2% (19.1km^2) of the area falls under low hazard zone and 16% (8 km^2) of the area falls under very low hazard zone.

Later, the prepared Landslide Hazard Zonation Map of the present study area was validated by comparing it with the invented actual past landslide data of the area. 30 past landslides were considered to validate the prepared hazard map. The result showed that 74% of past landslides fall within very high hazard (VHH) and high hazard (HH) zone of the prepared LHZ map. Also, 17 % of the invented landslide falls within moderately hazard zone of the area, which also has reasonable probability of landslide occurrence. This shows that almost 91% of past landslide validates with the prepared LHZ map of the area. The remaining 9% of past landslides fall under very low (VL) and low hazard (LH) zone of the prepared LHZ map. This may be due to certain factors that cannot be considered at scale at which present study was conducted.

Finally, in general it may be concluded that the major influencing factors that are possibly responsible for landslides in the present study area are geological and geomorphological factors associated with gravity movement triggered by seasonal heavy rainfall.

7.2. Recommendations

During the recent years the landslides in the present study area have caused damage to cultivated land, infrastructure; especially damage to road, that extends from Woldiya to Bahrdar, and to settlements around Imbawech sekela (Abayterfo) Kebele. This shows that population, property and infrastructure are exposed to considerable landslide risk in the present study area. Further, with population growth, demand for land for settlement, infrastructure and agriculture more landslide risk is anticipated in the area. Therefore, it is an urgent need to do proper planning and adopt adequate mitigation measures to minimize landslide related risk in the area. This needs a call for more detailed slope stability studies particularly in those areas which have been delineated as high hazard and very high hazard zones in the present study area.

On the other hand, the Government and other administrative bodies in the area must create awareness among local people for landslide prone areas and related risk. Further, the results of the present study showed that road extending from Woldiya to Bahirdar is damaged by landslide activity and much of it falls within delineated high hazard zone. In addition, some churchs (Ganot Gyorgis, Imbawech Kidanemhiret church, Debot Tekle Hayimanote church and Debot Iyesus) and Elementary School in Debot area also falls within high hazard and very high hazard zone. Therefore, through this present study local administrative bodies are being informed for landslide and related slope instability risk to which local population, property and infrastructure are exposed. Thus, it is recommended to adopt appropriate mitigation measures to minimize the risk of landslides in the area.

All care was taken to conduct present study systematically well supported with actual data collected from primary and secondary sources. The collected data was thoroughly prepared and analyzed following appropriate scientific methodology. However, all these efforts were made under constraints of limited time and resources. Therefore, it is strongly recommended to conduct more detailed systematic studies before implementing findings for real application and planning.

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References

Ahmed S. (2009). Slope Stability Analysis Using GIS and Numerical Modeling Techniques.Unpublished MSc Thesis, VrijeUniversiteit, Brussel, 120pp.

Alebachew Beyene & Mohamed Abdeselam G., (2005). Tectonics of the Afar Depression: a review and synthesis. *Journal of African Earth Sciences*, **41**: 41-59.

Aleotti, P., Chowdhury.R., (1999). Landslide hazard assessment: summery, review and new perspective. *Bull. Eng. Geol. Environ*. **58**:21-44

Anbalagan, R., (1992). Landslide hazard evaluation and zonation mapping in mountainous terrain. *Eng. Geol.***32**: 269-277.

Arnous, M. O., (2011). Integrated remote sensing and GIS techniques for landslide hazard zonation: a case study WadiWatier area, South Sinai, Egypt. *Journal of Coastal Conservation*.**15**:477-497.

Arora, K.R., (1997). Soil Mechanics and Foundation Engineering. Standard Publisher Distributers, Delhi, India, 427-428

Asfawosen Asrat, Eshete Gebretsidik, Tadesse, S., Getaneh, A., Fekede, K., (1996). Land mass movement of November 10, 1994 in Goffa District, Northern Omo Zone, Southern Ethiopia. **In**: Third Ethiopian Geoscience and Mineral Engineering Congress, 15–17 November 1996, Addis Ababa, pp. 18–19.

Bekele Abebe, Dramis, F., Fubelli G., Mohammed Umer, AsfawossenAsrat, (2010).Landslides in the Ethiopian highlands and the Rift margins. *J. Afr. Ear. Sc.* **56**:131–138.

Berhanu Ermias, Raghvanshi T. K., Bekele Abebe. (2017). Landslide Hazard Zonation (LHZ) around Alemketema Town, North Showa Zone, and Central Ethiopia - A GIS based Expert Evaluation Approach**.** *International Journal of Earth Sciences and Engineering*,**10**(01):33-44

Berhanu Temesgen, Mohammed Umer, AsfawossenAsrat, Berakhi, O., Ayele, A., Dramis, F. (1999). Landslide hazard on the Debicho, Wendo Genet area: the case of June 18, 1996 event. *SINET – Ethiopian Journal of Earth Sciences* **22**: 127–140.

Bommer, J.J., Rodrı´guez, C.E., (2002). Earthquake-induced landslides in Central America. *Eng. Geol*. **63**: 189–220.

Carrar A, Cardinali M, Detti R Guzzetti F, Pasqui V, Reichenbach P (1991). GIS techniques and statistical modeling in evaluating landslide hazard. *Earth Surf Process Landf* **6**:427-445

Carrara, A., Cardinali, M., Guzzetti, F., (1992). Uncertainty in assessing landslide hazard and risk. *ITCJ*. **2**:172–183.

Casagli, N., Catani, F., Puglisi, C., Delmonaco, G., Ermini, L., Margottini, C., (2004).An inventory-based approach to landslide susceptibility assessment and its application to the Virginio River Basin, Italy.*Environ. Eng. Geosci*.**3**: 203–216.

Chau.K.T, Y.L. Sze, M.K. Fung, W.Y. Wong, E.L. Fong, L.C.P. Chan., (2004).Landslide hazard analysis for HongKongusing landslide inventory and GIS Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Yuk Choi Road, Hung Hom, Kowloon, Hong Kong,429–443

Cruden D.M. and Varnes D.J. (1996). Landslide types and processes. In: Turner A.K, Schuster R.L (eds), Landslides investigation and mitigation, Special Report 247, Transportation Research Board, National Research Council, Washington, D.C., 36-75.

Dai, F.C.,Lee, C.F., (2001). Terrain-based mapping of landslide susceptibility using a geographical information system: a case study. *Can. Geotech. J*. **38**: 911–923.

Dai, F.C., Lee, C.F., (2002). Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong. *Geomorphology* **42**, 213–228.

Dai, F.C., Lee, C.F., Ngai, Y.Y., (2002). Landslide risk assessment and management: an overview. *Eng. Geol*. **64**: 65–87.

Damtew Tsige, Emer T.Q.,Kifle Weldaregay, (2017). Geotechnical Conditions and Stability Analysis of Landslide Prone Area: A Case Study in Bonga Town, South-Western Ethiopia. *International journal of scientific and engineering research,* **8**:2229-5518.

Daniel Gemechu. (1977). Aspect of climate and water balance in Ethiopia.Addis Ababa University press, Addis Ababa, 79pp.

Derege Ayalew, Barrey, P., Marty, B., Reisberg, L., Gezahegn Yirgue & Pik.R. (2002). Source, genesis, and timing of giant ignimbrite deposits associated with Ethiopian continental flood basalts. *Geochemicaet CosmochimicaActa*, **66**: 1429-1448.

FAO (Food and agriculture organization of United Nations) (1986) Ethiopian highlands reclamation study, Government of Ethiopia by the Food and Agriculture Organization of the United Nations, Rome, 334 pp.

Fall, M., Azzam, R., Noubactep, C., (2006). A multi-method approach to study the stability of natural slopes and landslide susceptibility mapping. *Eng. Geol*. **82**: 241–263.

Fikire Girma, Raghuvanshi T.K.,Tenalem Ayenew, Tirufat Hailemariam, (2015). Landslide hazard zonation in Ada Berga District, Central Ethiopia – a GIS based statistical approach. *Journal of Geomatics,* **9**: 1-14.

Gemechis Chimidi, Raguvanshi. T.K., Suryabhagavan, K.V. (2017). Landslide hazard zonation in and around Gimbi town, Western Ethiopia-a GIS statistical approach. Appl Geomat. **9 (4)** : 219–236.

GSE (Geological Survey of Ethiopian), (2010). Geosciences Report on Dessie area, Unpublished Report, Addis Ababa, Ethiopia, p. 68.

Guzzetti F., Carrara, A., Cardinali, M., Reichenbach, P., (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, central Italy. *Geomorphology*. **31** (1–4), 181–216.

Henok Woldegiorgis, Raghuvanshi T. K. Balemwal Atnafu (2014). Landslide hazard zonation using expert evaluation technique: a case study of the area between gohatsion town and the abay (Blue Nile) river, central Ethiopia.. *J. Sci.***37**(2):75–94,

Highland, L.M. and Bobrowsky, P. (2008). *The Landslide Handbook- A Guide to Understanding Landslides*. U.S. Geological Survey, Reston, Virginia, 147 pp.

Hoek, E. and Bray, J.W. (1981). *Rock Slope Engineering (revised third ed*.). Ins. of Mining and Metallurgy, London, 358Pp.

Hofmann, C., Courtillot, V., Feraud, G., Rochette, P., Yirgu, G., Ketefo, E &Pik, R. (1997). Timing of the Ethiopian flood basalt event and implications for plume birth and global Change. Nature, **389**: 838-841.

Johnson, R.B., Degraff, J.V., (1991). Principles of Engineering Geology. John Willy and Sons, New York, pp. 497

Kanungo, D.P., Arora, M.K., Sarkar, S., Gupta, R.P., (2006). A comparative study of conventional, ANN black box, fuzzy and combined neural and fuzzy weighting procedures for landslide susceptibility zonation in Darjeeling Himalayas. *Eng. Geol.***85**:347–366.

Kanungo, D. P., Arora, M. K., Sarkar, S., and Gupta, R. P., (2009). Landslide Susceptibility Zonation (LSZ) Mapping – a review. *Journal of south Asia disaster studies*. **2**:1-81.

Keefer, D. K., (2000). Statistical analysis of an earthquake-induced landslide distribution — the 1989 Loma Prieta, California event. *Eng. Geol*. **58**:231–249.

Keefer, D.K. (2002). Investigating landslides caused by earthquakes- a historic review. *Sum of Geophys.***23**:473-510.

Kifle Woldearegay, (2013). Review of the occurrences and influencing factors of landslides in the highlands of Ethiopia: With implications for infrastructural development. *Momona Ethiopian Journal of Science,* **5**(1):3-31.

Kobashi, S. and Suzuki, M. (1988). Hazard index for the judgement of slope stability in the Rokko mountain region. *Auztria*, **1**: 223-233.

Lee, S., Rhyu, J.H., Won, J.S., Park, H.J., (2004). Determination and application of the weights for landslide Susceptibility mapping using an artificial neural network at south, Korean. *Eng. Geol.***71**: 289–302.

Leroi, E., (1997). Landslide risk mapping: problems, limitation and developments inCruden, Fell (Ed.), Landslide Risk Assessment. Balkema, Rotterdam, pp. 239–250.

Lulseged Ayalew and Yamagishi.H. (2004). Slope failure in Blue Nile basin, as seen from landscape evolution perspective. *Geomorphology***57**: 95-116

Lulseged Ayalew, Yamagishi, H. and Ugawa, N. (2004). Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan. *Landslides.***1**:73–81.

Marrapu.B.M. and Jakka R.S, (2014). Landslide Hazard Zonation Methods: A Critical Review. *International Journal of Civil Engineering Research*. **5**:215-220.

Mengesha Tefera, TadiwosChernet. &WerknehHaro, (1996).Explanation of the Geological Map of Ethiopia, Ethiopian Institute of Geological Surveys, Addis Ababa, **3 :** 79.

Oldeman,L., Hakkeling, R & Sombroek,W., (1991). World map of the status of human-induced soil degradation: an explanatory note, Wageningen: ISRIC; Nairobi: UNEP, 34p.

Price, D.G., (2009). Engineering Geology Principles and Practice. Springer-Verlag, Berlin, Heidelberg, Germany. Pp 460.

Raghuvanshi, T.K, Jemal Ibrahim, Dereje Ayalew, (2014a). ‘’Slope stability susceptibility evaluation parameter (SSEP) rating scheme – an approach for landslide hazard zonation. *J. Afr. Earth Sci*. **99**: 595–612.

Raghuvanshji ,T.K, P.M. Kala and M. Singh (2014 b). Landslide disaster management and reduction-An approach through remote sensing and Gis. In: Landscape Ecology and Water Management,proceeding of International Geographical Union (IGU) Rohatic Conference, Advance in Geographical and Enviromental Science(M.singh,R.B. Singh and M.I. Hassen:Editor), Sringer Japan. Vol_2,pp.33-40

Raghuvanshi, T.K., Negassa, L., Kala, P.M. (2015). GIS based Grid Overlay Method versus Modeling Approach – A Comparative Study for Landslide Hazard Zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia. Egypt. *J. Remote sensing SpaceSci.***18**: 235-250.

Sarkar, S., Kanungo, D.P., Mehrotra, G.S., (1995). Landslide hazard zonation: a case study in Garhwal Himalaya, India. Mount. *Res.Dev*. **15** (4): 301–309.

Sarkar.S and Kanugo D.P., (2004). An Integrated Approach for Landslide Susceptibility Mapping using Remote Sensing and GIS. *Geotechnical Engineering division, central building research institute,***70**: 617-625.

Shiferaw Ayele, Raghuvanshi, T.K. and Kala, P.M. (2014). “*Application of Remote Sensing and GIS for Landslide Disaster Management - A case from Abay Gorge, Gohatsion – Dejen Section, Ethiopia*” **In:** Landscape Ecology and Water Management, Proceedings of International Geographical Union (IGU) Rohtak Conference, Vol-2, Advances in Geographical and Environmental Sciences, (Singh, M, Singh, R.B, Hassan, M.I. eds.), Springer Japan, pp 15-32. (DOI: 10.1007/978-4-431-54871-3_2), http://link.springer.com/book/10.1007/978-4-431-54871-3

Singhroy.V., (1995). Sar integrated techniques for geohazard assessment.*Adv. Space Rer,***15**: (11)67-(11)78.

Tenalem Ayenew and Barbieri, G. (2004). Inventory of landslides and susceptibility mapping in the Dessie area, Northern Ethiopia.*Eng. Geol.* **77**:1–15.

Tesfaye Demissie, Genet Yohannes, Abraham Mammo, YibeltalTesfaye, YonasTeshome, Getachew Burusa, Mohammed Edris and Meran Wenduante (2010).Geology geochemistry and gravity survey ofthe dessie area. un published report, Pp 68.

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

Tilahun hamaz and Raghuvanshi, T.K.,(2017) GIS based Landslide Hazard Evauation and Zonation- a case from Jeldu District, Central Ethiopia, journal of king soud, university- science, **29(2)**:151-165

Tsion Aragaw, 2017. An integrated expert evaluation and statistical approach for landslide hazard evaluation and zonation- A case along Alemketemaftra Route Corridor -Northern Shewa zone, central Ethiopia, Unpublished MSc Thesis, Addis Ababa university, Ethiopia. 97 pp.

USGS (United State Geological Society) (2004). www.pubs.usgs.gov/fs/2004/3072/pdf/fs2004-3072.pdf: accessed on March, 20, 2018.

Van Westen, C. J., Van Asch, T. W. J. and Soeters, R. (2006). Landslide hazard and risk zonation - why is it still so difficult? *Bull. Eng. Geol. Env*. **65**: 167–184.

Van Westen, C.J., Rengers, N., Terlien, M.T.J. (1997). Prediction of the occurrence of slopeinstability phenomena through GIS-based hazard zonation. *Geol. Rundsch*, **8**6: 4004– 4414.

Van Westen, C.J., (1993). Remote Sensing and Geographic Information Systems for Geologic Hazard Mitigation. In: Space Congress, Bremen, Germany, Vol 30. Environmental Assessment of Geological Hazards: 63-71.

Varnes, D.J., (1996). Landslide Types and Processes. In: Turner, A.K., Schuster, R.L. (Eds.), Landslides: Investigation and Mitigation, Transportation Research Board Special Report 247. National Academy Press, National Research Council, Washington, D.C. 247:36-75

Varnes, D.J. (1978). Slope movements types and processes. In: Schuster, R.L., Krizek, R.S.(Eds.), Landslides: Analysis and Control. Transportation Research Board, National Academy of Sciences, Special Report 176, 2, Washington, DC, pp. 20–47.

Varnes, D. J. (1984). Landslide hazard zonation: a review of principles and practice. **In**:International Association of Engineering Geology Commission on Landslide and Other Mass Movements on Slopes. United Nations Educational, Scientific and Cultural Organization (UNESCO), 7 place de Fontenoy, 75700 Paris, France, 60 pp.

Wang, X. and Niu, R. (2009). Spatial forecast of landslides in three gorges based on spatial data mining. *Journal of sensors*, **9**: 2035-2061.

Wieczorek, 2009, *U.S.* Geological Survey, 12201 Sunrise Valley Drive, Reston, Virginia 20192-0002, USA

Wolfenden, E. (2003). Evolution of the southern Red Sea Rift: Birth of a magmatic margin. Unpublished Ph.D. thesis, Royal Holloway, University of London, 237 pp.

Zanettin, B. & Justin-Visentin, E. (1974).The volcanic in central Ethiopia.The volcanic of western Afar and Ethiopian Rift Margins. *MemoriedegiIstuti di Geologia Mineralogia dell universtia di padova* **31**: 1-19.

Zerihun Dawit, (2016). Landslide hazard evaluation and zonation in the area kindodidayeworeda, south west Ethiopia, Unpublished MSc Thesis, Addis Ababa university, Ethiopia, 105 pp.

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Annexure

Appendix1.1: Shows monthly rainfall distribution of the study area in the year (1995-2016). *(Source Ethiopian metrological agency)*

year	Jan.	Feb.	Mar.	Apri.	May.	Jun	July	Auge	Sep.	Oct.	Nov.	Dec.	Total
1995	11.3	9.8	77.2	77.2	57.4	20.8	222	294.2	34	4.6	0	6	814.5
1996	17.1	4.8	124.3	99.2	97.6	50	206	275	68.4	1.8	51.9	9.1	1005.2
1997	7.1	11.7	93.8	40.7	39.2	96.1	163.6	162.5	21.4	40.7	61	13.1	750.9
1998	13	0	14.3	21.7	68.2	0	238.2	273.2	14	5.1	0	13.1	660.8
1999	15.2	0	0	31.4	5	4.1	312.8	266.9	49.6	25.8	0	4.6	715.4
2000	0	0	8.9	81.5	4.1	6	213.4	272.2	36.3	17.1	44.6	20.6	704.7
2001	0	0	11.8	76.7	24	9	285.1	309.5	4.5	0	0	3.1	723.7
2002	36.5	22.9	63	15	3.9	2.8	196.4	157.9	12.2	0	0	36.9	547.5
2003	0	21	38.2	23.7	0	79.9	193.5	246.8	30.9	0	14.3	0	648.3
2004	0	20.1	20.1	44.2	0	98	159.5	208.1	0	18	0	2.6	570.6
2005	0	0	43.7	55.6	122.5	0	257.2	191	34.4	0	0	0	704.4
2006	0	2	109.8	15	69.25	3	200	180	32	5	6	10	632.05
2007	6	7	30.4	45	16	7.5	204	160	30	3	8	9	525.9
2009	4	4	40	55	35	11.8	208.2	158.9	0	0	0	12	528.9
2010	0	3.1	15.7	95.4	42.1	0	293.1	401.7	37.9	4.3	6	17.6	916.9
2011	11.4	0	75	65	58.8		377.5	325	39.7	0	5.5	0	957.9
2013	0	0	24.8	35.7	14.4	21.6	238.5	256.6	42.2	18.8	0	0	652.6
2014	5.2	62.9	44.4	17.4	48.5	0	196.5	274.8	109.3	0	4	0	763
2015	0	13	42.5	0	75.6	36.9	46.3	223	11.4	0	17	13	478.7
2016	0	7.2	17.6	26	35.7	0	262.4	223	90	6	11	9	687.9
average													661.5