Addis Ababa University
School of Graduate studies
School of Earth Sciences

Landslide Hazard Assessment and Zonation Using Bivariate Statistical Analysis Approach:- The Case Study in Gora Gommany Village and Its Surrounding Area in Alaltu District, North Showa Zone, Central Ethiopia

A Thesis submitted to:

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Masters of Science in Engineering Geology

By: Getahun Beyene

December, 2016

Addis Ababa, Ethiopia

Landslide Hazard Assessment and Zonation Using Bivariate Statistical Analysis Approach:- The Case Study in Gora Gommany Village and Its Surrounding Area in Alaltu District, North Showa Zone, Central Ethiopia

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This is to certify that the thesis prepared by **Getahun Beyene** entitled: **"Landslide Hazard Assessment and Zonation Using Bivariate Statistical Analysis Approach:- The Case Study in Gora Gommany Village and Its Surrounding Area in Alaltu District, North Showa Zone, Central Ethiopia"** and submitted in partial fulfillment of the requirements for the degree of Master of Science in **Engineering Geology** complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented on any other university.

All sources of materials used for this thesis have been duly acknowledged.

Getahun Beyene

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Place and date of submission:

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School of Earth sciences

December, 2016

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ABSTRACT

Landslide Hazard Assessment and Zonation Using Bivariate Statistical Analysis Approach:- The Case Study in Gora Gommany Village and Its Surrounding Area in Alaltu District, North Showa Zone, Central Ethiopia.

Getahun Beyene

Addis Ababa University, 2016

Landslide is one of the major geo-environmental hazards causing damage to life and property in the Gora Gommany Village. Considering the disastrous effects of the landslides, it is necessary to access the landslides in the present study area. To reduce the damage caused by landslides a Landslide Hazard Zonation map (LHZ) is developed. Landslide Hazard zoning contributes towards sustainable development and planning for mitigation of disaster in the study area.

The methodology adopted for the present study was bivariate statistical analysis approach which is based on the past landslides in the area. The Landslide Susceptibility Index (LSI) based on GIS approach and weight evidence modeling (WEM) approaches were followed for preparation of Landslide Hazard Zonation map of the study area. In the present study area 31 past landsides were detected for the analysis of landslide hazard evaluation and Zonation. Six prominent causative factors are considered: Slope material, Slope, Elevation, Landuse landcover, Groundwater and Aspect. For all causative factors the thematic map with scale of 1:50,000 were prepared. The Landslide Susceptibility Index (LSI) was computed for all subclasses of causative factors using Landslide Susceptibility Value (LSV). The calculation of the weight of the parameters was performed to give the weight sum map. For the validation of Landslide Hazard Zonation Map (LHZ) the landslide inventory data was overlaid on LHZ map. The weight sum map was finally classified into five distinctive classes of Landslide Hazard Zonation map.

The result obtained shows that Very Low Hazard (16%), Low Hazard (23%), Moderate Hazard(12%), High Hazard(24%) and Very High Hazard(25%). The area coverage for Very Low Hazard, Low Hazard, Moderate Hazard, High Hazard and Very High Hazard is 6km^2, 9km^2, 5km^2, 9km^2 and 9km^2, respectively. The result of validation shows that for weight evidence modeling approach map was less verification than Landslide Susceptibility Index (LSI) based on GIS approach map.

CHAPTER ONE INTRODUCTION

1.1 Background

A landslide can be defined as the down slope movement of rock and soil near the earth's surface under the influence of gravity (Cruden and Varnes, 1996). The severity of the consequences associated with these processes varies significantly depending on the setting of a given landslide event and damage to infrastructure as well as human injuries and fatalities.

Landslides can occur on any terrain with the given right conditions of soil, moisture and the angle of slope. Mass movements are a serious concern in hilly or mountainous terrain especially for buildings, roads, and features engineered into hillsides. Different phenomena cause landslides; like prolonged rainfall, earthquakes, rapid snow melting, anthropogenic and developmental activities.

In order to reduce the damage caused by landslide initiations and reactivations, a landslide susceptibility map is needed (Van Den Eeckhaut et al., 2009). The basic requirement in landslide assessment is the identification of potential landslide areas or zones based on the geological, topographical and geomorphologic conditions. This is achieved with the help of landslide susceptibility maps, where the area is divided into homogenous zones with different degrees of susceptibility to the occurrence of landslides.

Landslides are among the serious geological hazards common in many parts of the world. They constitute a major hazard to population, property and infrastructure in many hilly and mountainous areas. They cause billions of dollars worth damage to the properties and thousands of deaths and injuries each year worldwide. Academicians argue over such hazard as the most frightening. However, the most important is the necessity to evaluate them in terms of their suddenness, severity, aerial extent, potential economic losses, degree of warning and the level of possible mitigation measures (Van Den Eeckhaut et al., 2009).

In Ethiopia, the magnitude of landslide occurrence and its resulting damage has been increasing in recent times (Lulseged Ayalew, 1999). Even though its impact is local, it is a catastrophic event and claiming a vast number of human lives and destroying a great deal of property.

Various researchers tried to assess the situations of these occurrences and consequences in different parts of the country, especially in the highlands, because about 60% of the populations in Ethiopia live in the highlands with an altitude more than 1750m, where landslide activities are prominent (Lulseged Ayalew, 1999).

The occurrence of various landslides types in Ethiopia produces the hazards. It is common in highlands and mountain areas such as in Wondogenet area, Kombolcha – Dessie road, Tarmaber, Blue Nile Gorge and other parts of Ethiopia are repeatedly facing problems with mass movements. These have caused significant economic losses and human fatalities (Lulseged Ayalew, 1999).

The present study area is characterized as one of a landslide prone area. Its topography is highland and rift margin that is sensitive for sliding. Slope failure in the study area is enhanced from time to time. However the landslide study was not conducted to give remedial measures for such problems in the present study area. Due to the landslide problem the damage of property and the loss of life are very common for long years. Both causative factors and triggering factors are identified during the present study. The present study is desired to give remedial measures on landslide problem for the settlers by detecting distinctive hazard zone maps of the study area.

1.2 Criteria for Landslide Map

Division of the land surface into zones of varying degrees of stability based on an estimated significance of causative factors in inducing the instability is landslide hazard zonation (LHZ) (Anbalagan and Singh, 1996). This involves a critical assessment and analysis of the past occurrences of landslides, their locations, frequencies, and magnitude in relation to various geo-environmental factors that influence landslides and mass movements. There are numerous factors that affect slope instability include the geology, structure, slope, hydrology, landuse, relative relief, and evidence of past and present landslides.

The Landslides Hazard Zonation map helps to identify and delineate unstable hazard prone areas, further it help planners to choose favorable locations for sitting development schemes, such as; building and road constructions.

The recognition of hazard areas helps to adopt suitable precautionary measures. This is applied during feasibility studies of project planning, when an economical and rapid hazard assessment technique is required. The three important criteria for landslide maps most useful to planners and the general public are landslide inventories, landslide susceptibility map, and landslide hazard map (Anbalagan and Singh, 1996).

1.2.1 Landslide Inventory Map

Landslide inventory map denote areas that are identified as having failed by landslide processes. The simple reconnaissance inventories show only delineate broad areas where landslides appears to have occurred. Simple inventories give an overview of the areal extent of landslide occurrence and highlight areas where more detailed studies should be conducted. The complex inventories depict and classify each landslide and show scarps, zones of depletion and accumulation, active and inactive slides, geological age, rate of movement and other pertinent data on depth and kind of materials involved in sliding (Anbalagan and Singh, 1996).

In detail inventory, understanding of the different landslide processes and design of remedial measures to regulate development in landslide prone areas is common. These provide a good basis for the preparation of derivative maps, such as indicating slope stability, for rating landslide hazard and to identify landuse (Anbalagan and Singh, 1996).

1.2.2 Landslide Susceptibility Map

Based on landslide inventory a landslide susceptibility map depicts areas that have the potential for landslides. These areas are determined by correlating some of the principal factors that contribute to landslides like geology, slope morphology, landuse landcover, and groundwater condition with the past distribution of landslides. These maps indicate only the relative stability of slopes; they do not make absolute predictions (Anbalagan and Singh, 1996).

1.2.3 Landslide Hazard Map

Landslide Hazard maps show the areal extent of threatening processes which denote past and recent landslide occurred, and it is important, the likelihood in various areas that a landslide will occur in the future. For a given area, hazard map contain detailed information on the types of landslides, extent of slope subject to failure and probable maximum extent of ground movement. These maps can be used to predict the relative degree of hazard in a landslide area. Areas may be ranked in a hierarchy such as low, moderate, and high hazard areas (Anbalagan and Singh, 1996).

For the present study landslide hazard zonation is performed by Statistical method approach which is based on the statistical determination of the combinations of different variables that were responsible for instability of slopes in a given area. In Statistical approach, both simple and multivariate statistical methods can be employed to evaluate the landslide hazards (Dai and Lee, 2001).

The major limitation of statistical methods is gathering large data on landslide distributions and various factors over large areas which, requires considerable time, resource and manpower (Van Westen et al., 1997). Another constraint with these techniques is quality and quantity of data on landslide frequency and various factors on which statistical correlations are established. Thus, the findings are highly influenced with the volume of data gathered and its quality. From both statistical methods, bivariate statistical approach is adopted for the present study. The reason for this technique followed is in the study area past landslides are distributed. This data can be collected as secondary data and primary in field by using GPS. Later using GIS 10.1 software the thematic map of causative factor is performed.

1.3 Objectives of the present study

1.3.1 General objective

The general objective of the present study is to evaluate the major factors for the cause of the landslide in the study area and to produce a landslide hazard zonation map by using bivariate statistical analysis approach.

1.3.2 Specific objectives

The present study is aimed to achieve the following specific objectives.

- To detect and evaluate the major causative factors responsible for the landslide in the area.
- To produce maps for the major causative factors and rating them by hazard.
- To produce landslide hazard zonation map based on major causative factors analyzed from the total estimated hazard ratings.

1.4 Description of the Study Area

1.4.1 Location and Accessibility

The study area is located in Oromiya Regional State, North Showa Zone in the eastern part of Alaltu District, Central Ethiopia. Alaltu District is surrounded by Kimbibit District in the Northern part, Jida District in the Western part, Amhara Region in the East and Northeast and East Showa Zone in the Southern part (Fig.1.1). The study area is located between 039° 9’18’’E to 039°14’16’’E and 09°07’20’’N to 09°11’14’’N longitude and latitude respectively. It covers a total area of about 38km^2. The Study area can be accessed from Addis Ababa by road to Debre Berhan town and the total distance from Addis Ababa to the study area is 70km. The first 55km is asphalt road and the next 10km, after departing to the road to Mikawa town (which is Alaltu District town) is gravel roads and finally the remaining 5km to the site can be accessed on foot or by motor bikes.

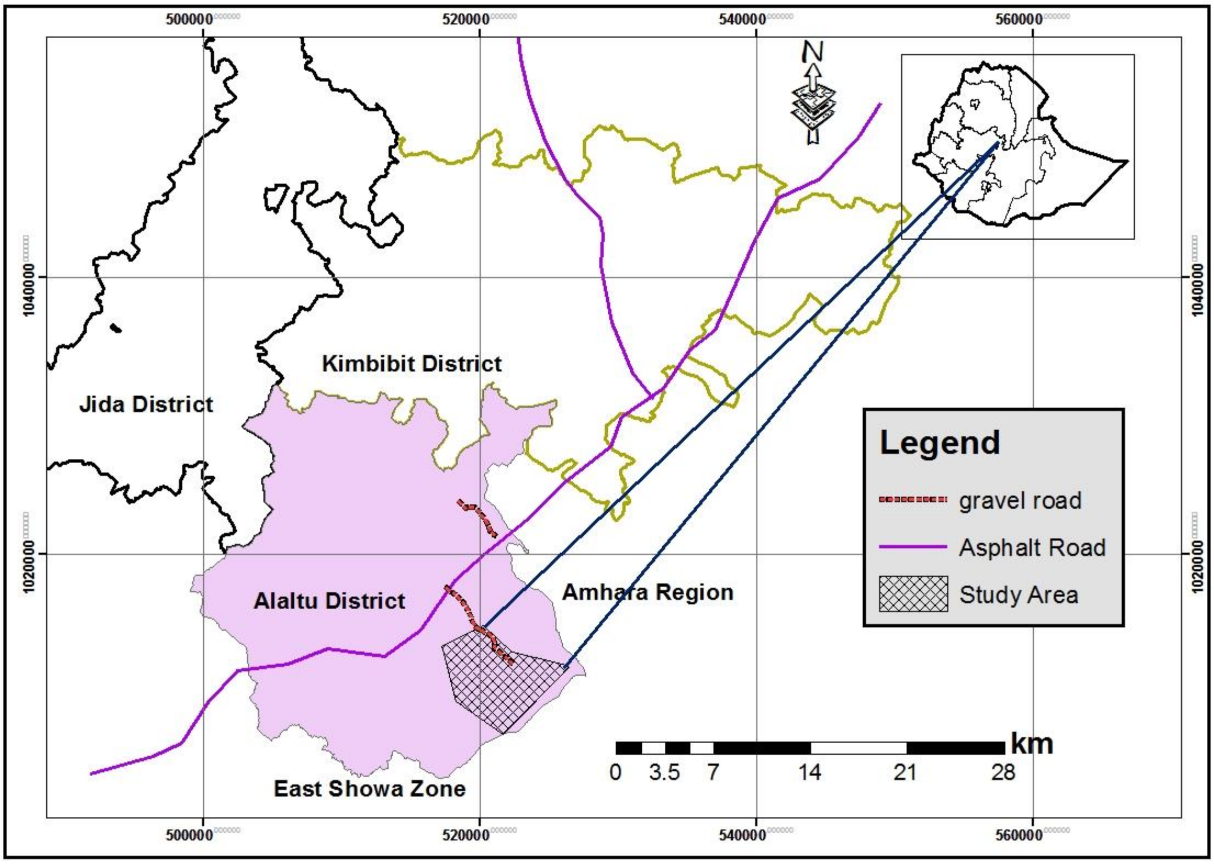


Fig.1. 1 Location map of the study area

1.4. 2 Climate of the Study Area

Long term climate changes can have a significant impact on slope stability. An overall decrease in precipitation results in a lowering of the water table, as well as a decrease in the weight of the soil mass and decreased solution of materials.

On the other hand, an increase in precipitation or ground saturation will raise the level of the groundwater table, reduce shear strength, increase the weight of the soil mass and may increase erosion. Periodic high intensity precipitation can significantly increase slope instability temporarily (http:// geomorphic factor on landslide).

It has been observed that in general the average annual temperature decreases with an increase in altitude. Based on this, five traditional temperature or climatic zones are differentiated in a description presented by the Ethiopian Mapping Agency in the National Atlas of Ethiopia (EMA, 1981). The description taken from the Atlas is given below and next to each traditional name for the temperature zone, the English equivalent name is written in brackets as suggested in another source by Daniel Gamachu (1977). "KUR"(Alpine), 3300m and above, the mean annual temperature is 10^{o}C or less.

"DEGA" (Temperate), 2300m to about 3300m, the mean annual temperature is between 10^{o}C and 15^{o}C."WEINA DEGA" (Sub-tropical) 1500m to about 2300m, the mean annual temperature is between 15^{o}C and 20^{o}C. "KOLLA" (Tropical), 500m to about 1500m, hot temperature, about 30^{o}C. "BEREHA" (Desert), < 500m, very hot temperature 30^{o}C to 40^{o}C.

Based on the elevation range of the area and according to the five traditional climatic zones differentiated by the Ethiopian Mapping Agency as described above, the study area falls in both temperate and subtropical climatic zones hence elevation range from 1820m to 2589m above sea level(Fig.1.2).

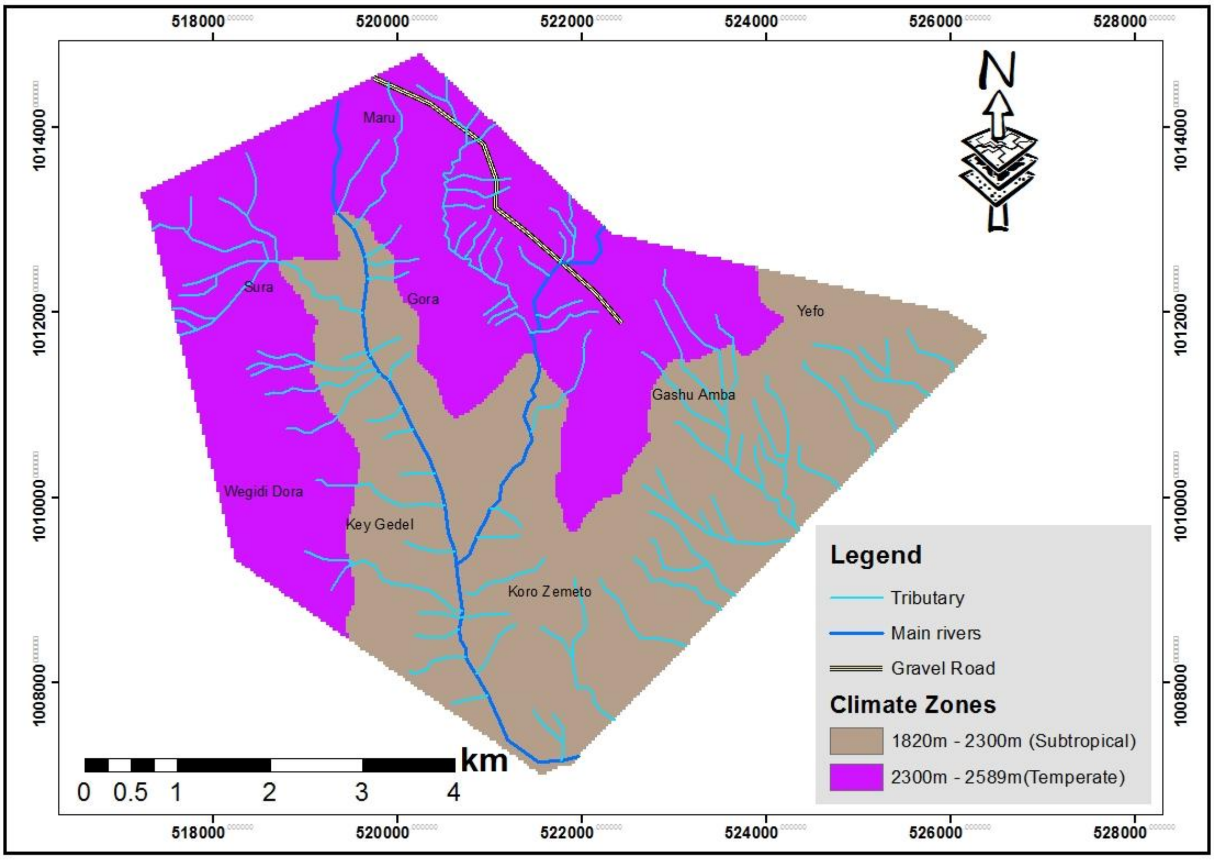


Fig.1. 2 Climate zone map of the study area

The Alaltu District has two rainy seasons, namely "meher (Gana)" which refers to the long rains, usually lasting from June to the beginning of September, and the "belg (Arfasa)" season which refers to the short rains which usually fall between March and May. *Belg* production is very important in the altitude zones of northern Shewa where frost is a common occurrence during the "*Gana"* season. However, the *belg* season is highly unreliable being characterized by variability and delay or absence of rain. In some years, it falls only for few weeks and the *belg* crop cannot be harvested; in other years, the rains fall regularly for a reasonable period of time.

In addition to this the rainfall data of Debre Berhan town which is near to the study area from the year 2000 to 2014 were collected from the Ethiopian Meteorological Agency. Rainfall data of Debre Berhan town was considered because there is no station in Alaltu district.

The Data collected from this station indicates that the highest precipitation recorded (in precipitation 2000 to 2014) was 1083.5mm in the year of 2007 and the highest monthly precipitation recorded was 432.6mm in July during the year of 2006 (refer table1.2). The annual and average monthly precipitation is presented as (Fig.1.3 and Fig.1.4). Table 1.1 shows average monthly precipitation data.

Table 1. 1Average monthly precipitation of Debre Berhan station from 2000 to 2014

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2000	0.0	0.0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8
2001	0.0	33.8	71.2	-	64.6	34.9	406.7	260.4	32.2	4.1	0.0	.4
2002	18.1	28.0	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	0.0	8.4
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.1	288.7	74.2	-	0.0	7.4
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0.0
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0.0
2006	17.3	24.4	61.0	38.3	19.8	35.2	432.6	224.2	59.8	8.6	-	26.3
2007	2.0	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	0.0
2008	0.3	1.7	0.0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2
2009	47.2	0.0	8.1	31.4	14.9	13.7	423.4	273.1	31.4	36.6	1.2	25.3
2010	47.2	21.6	55.7	119.3	42.2	35.4	242.3	312.2	53.8	0.3	8.5	3.9
2011	0.3	7.0	76.8	38.6	111.2	73.4	357.4	312.3	79.0	0.0	4.3	0.0
2012	0.0	0.0	5.2	93.3	57.9	56.0	351.6	394.5	92.4	0.0	0.0	0.0
2013	0.8	0.0	48.8	54.2	23.9	40.1	358.5	204.4	79.6	63.1	11.5	0.0
2014	0.0	16.0	67.7	44.1	46.9	16.8	260.3	291.0	110.0	55.9	0.0	0.0
sum monthly	207.5	213.4	608.4	867.5	605.2	830.3	5086.7	4352.1	1217.5	229.8	117.9	82.7
Mean monthly	**13.8**	**14.2**	**40.6**	**57.8**	**40.3**	**55.4**	**339.1**	**290.1**	**81.2**	**15.3**	**7.9**	**5.5**

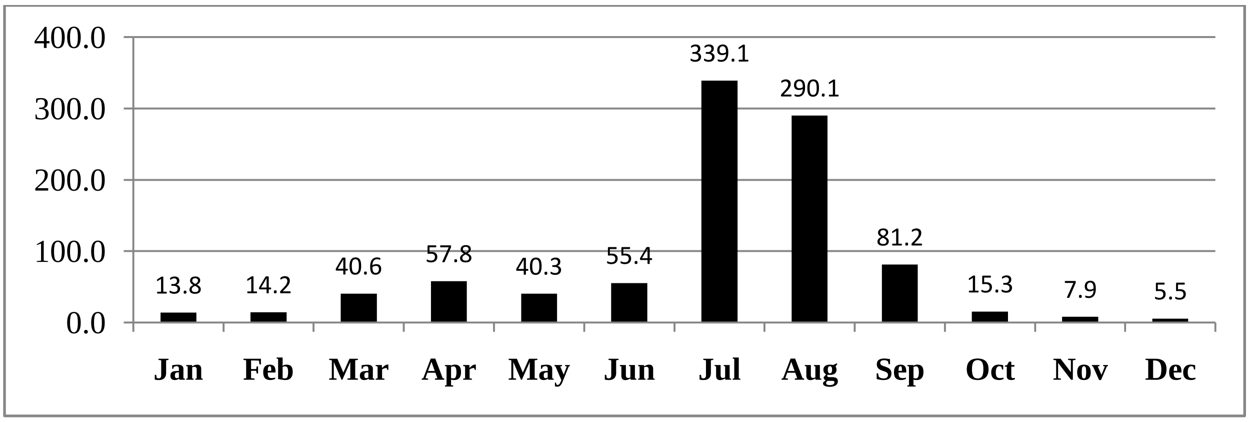


Fig.1. 3 Average Monthly precipitations in mm for the years 2000 to 2014 for Debre Berhan station

Generally, the maximum, minimum and average annual rainfall in the study area was found to be 1083.5mm, 830.1mm and 961.3mm, respectively (refer table1.2). The maximum annual rainfall is recorded in the year 2007 whereas the minimum in the year 2002. The monthly maximum rainfall is always in the months of July and August for all the recorded data.

Table 1. 2 Annual precipitation of Debre Berhan station from 2000 to 2014 year

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual pp(mm)**
2000	0.0	0.0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8	**985.3**
2001	0.0	33.8	71.2	0.0	64.6	34.9	406.7	260.4	32.2	4.1	_	3.4	**911.3**
2002	18.1	28.0	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	_	8.4	**830.1**
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.1	288.7	74.2	_	_	7.4	**1005.5**
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0.0	**1023.2**
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0.0	**932.4**
2006	17.3	24.4	61.0	38.3	19.8	35.2	432.6	224.2	59.8	8.6	_	26.3	**947.5**
2007	2.0	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	0.0	**1083.5**
2008	0.3	1.7	0.0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2	**946.7**
2009	47.2	0.0	8.1	31.4	14.9	13.7	423.4	273.1	31.4	36.6	1.2	25.3	**906.3**
2010	47.2	21.6	55.7	119.3	42.2	35.4	242.3	312.2	53.8	0.3	8.5	3.9	**942.4**
2011	0.3	7.0	76.8	38.6	111.2	73.4	357.4	312.3	79.0	0.0	4.3	0.0	**1060.3**
2012	0.0	0.0	5.2	93.3	57.9	56.0	351.6	394.5	92.4	0.0	0.0	0.0	**1050.9**
2013	0.8	0.0	48.8	54.2	23.9	40.1	358.5	204.4	79.6	63.1	11.5	0.0	**884.9**
2014	0.0	16.0	67.7	44.1	46.9	16.8	260.3	291.0	110.0	55.9	0.0	0.0	**908.7**

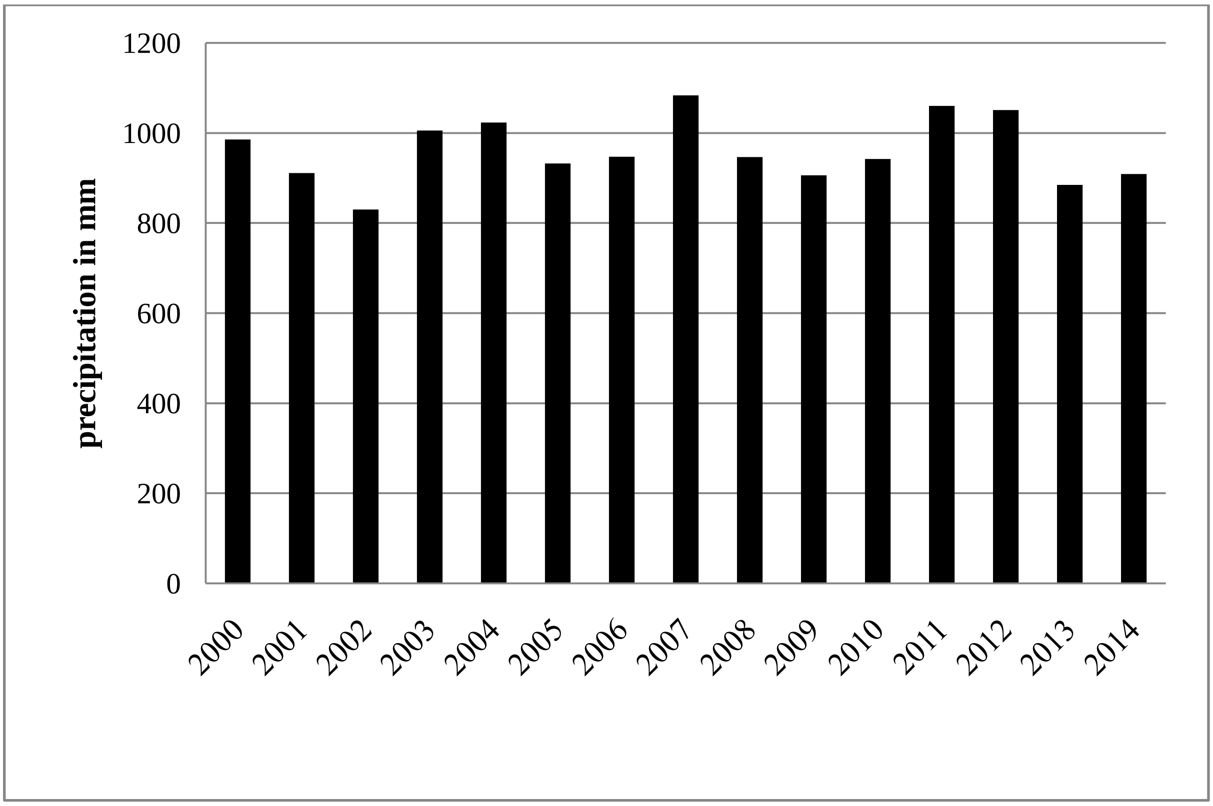


Fig.1. 4 Annual precipitations in mm of the years 2000 to 2014 for Debre Berhan station

1.4.3 Physiographic and Drainage Pattern of the Study Area

The study area is a part of Debre Berhan topographic map sheet with the scale of 1:50,000 which include part of the central Ethiopia plateau and western most part of the rift margin and floor of the Main Ethiopian Rift (MER). The study area has a high rugged topography and characterized by steep terrains. Further, the study area morphology is gentle to steep slope as observed during the field investigations. The elevation ranges from 1820m to 2589m as visualized from DEM (Digital Elevation Model with 30m resolution, source: SRTM) of the study area. Mikawa River and Defo Bar River are the main rivers in the study area and there are number of streams joining this river. These rivers are the tributaries of the Awash River. In general, as observed from the topographical sheet of the area the study area and during field work and form dendrite drainage pattern map (Fig.1.5).

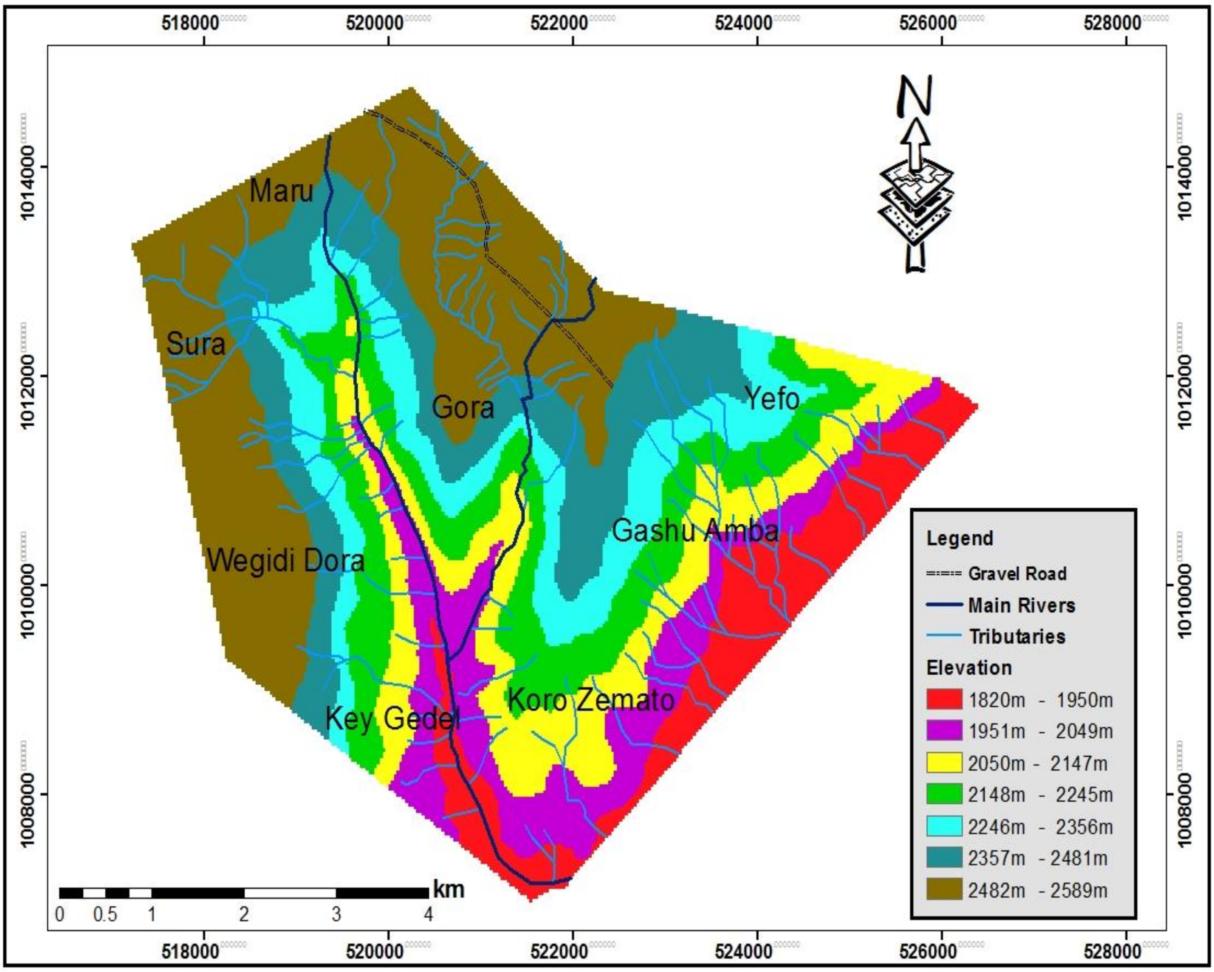


Fig.1. 5 Physiographic Map of the Study area

1.4.4 Vegetation cover of the study area

In the study area it has been observed that the area is sparsely vegetated. Mostly shrubs and bushes are observed. From the topographical sheet, part of the study area is sparsely covered by small bushes.

However, during field investigations it is observed that much of east and western part of the study area has been changed to cultivate land and bare land. The dwellers are using most of the land for cultivation; in addition, because the area has very rugged and steep terrains the people are forced to cultivate moderately gentle slope areas. There are also some parts of the area which are used for grazing purpose. Furthermore, acacia trees are also observed in the southern part of the study area.

1.4.5 Soil cover of the study area

The development of soils is mainly dependent on the type of rock from which they are derived and the condition of the depositions directed by climate and geomorphologic position. The highlands are dominated by shallow black to gray silt soil derived from the volcanic rock (Colluvial Soil). The river valleys and their main tributaries are covered by silt to sandy soil and alluvial depositions.

Most parts of the study area are covered by superficial quaternary sediments: - Colluviums and Alluvium soil types. Alluvium soils are generally deposited by streams as they move from higher to lower ground. Colluvium soils are mainly exposed in the southern portions of the study area. Colluvium soils are in situ developed soils by the decomposition of rocks on which it lies due to physical and chemical weathering or landslides. The Colluvium soil in the study area is mainly intercalation of silty-gravel soil with black cotton soil. This black cotton soil forms cracks and even large gullies in various parts of the study area.

1.4.6 Seismicity of the study area

The ‘Seismic Risk Map' produced by Laike Mariam Asfaw (1986) for a hundred year return period and 0.99 Probability shows that the study area falls within 8MM scale. Based on the MM scale intensity the estimated horizontal earthquake acceleration comes out to be 0.2g, as determined from the MM intensity graph (Johnson and Degraff, 1988). Fig1.6 shows the location of the study area in seismic zone map of Ethiopia.

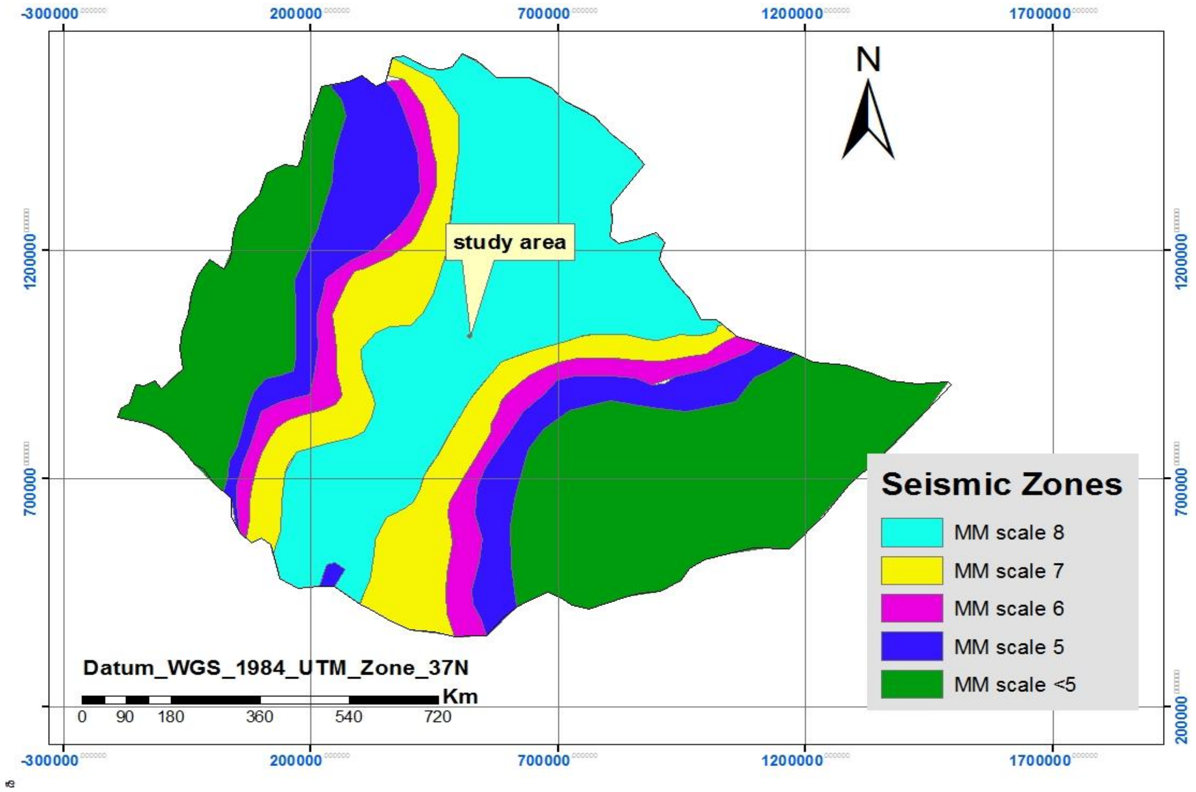


Fig.1. 6 Seismic risk map of Ethiopia 100 year returns period, 0.99 probabilities (Source: Laike Mariam, 1986)

1.5 Importance and Justification of the Present Study

The primary significance of the study is to identify the causes or factors and mode of the slope failure and to map hazard zonation and distinguishing the possible hazard during worst condition. As a result, the possible remedial measures have been suggested by taking the possible feasibility into consideration. By investigation of this study the area is categorized based on the hazard levels like very high hazard, high hazard, moderate hazard, low hazard and very low hazard.

Instability related issues in engineered as well as natural slopes are the common challenges to both researchers and professionals. In construction areas, instability may result due to rainfall, increase in groundwater table or change in stress conditions. Similarly, natural slopes that have been stabled for many years may suddenly fail in response to changes in geometry, external forces or loss in shear strength (Abramson et al., 2002).

According to Lulseged Ayalew (1999) the Ethiopian plateaus have a record of instability in both the superficial materials and the bed rock. Landslides in the region include deep seated rotational slumps, massive translational slides, progressive creep movements, debris and mud flows on the other hand, rock falls exist largely as discernible block topples and wedge failures all along movements, valley walls and road cuts.

The effect of landslides and rock falls are known to be severing in many localities and demanded an integrated study since the beginning of 1990 (Lulseged Ayalew and Yamagishi, 2003).

Prior to the present study no landslide study was conducted in the study area. Thus, the present research study will serve as a base study for other researchers who want to conduct a research in the present study area based on slope stability. In addition it is important for planners and engineers to know the landslide hazard potential areas in the study area before conducting construction activities like road and buildings. Topographically the study area is rugged (refer plate1.1).

Plate1. 1 Rugged topography in Gora Village

1.6 Statement of the problem

Several landslides have occurred in the last eight years in the study area. People have been permanently displaced from their residences, as they lost their houses and farm plots. The information gathered from the local people and surrounding of the study area indicates that there was loss of life during the landslide which occurred in 2007 in the study area. The numbers of cattle died were 21 whereas 6 peoples also injured. The landslide problem is increased from time to time hence it suddenly makes failures of slope on cultivated land and on settlement or houses.

1.7 Outcome of the study

The present research work contributes towards the general understanding of the landslide conditions of the area. The findings from the results may be important for decision makers to solve the problem before causing a great economical loss and damage to infrastructures and human life in the study area.

Landslide Hazard Zonation map prepared for the area will help to conduct further study on the detailed slope stability analyses on the slope that are identified as very low hazard, low hazard, moderate hazard, high hazard and very high hazard zones. It will also help in adopting proper remedial measures by giving much attention to the event.

1.8 Methodology and Materials used for the study

To achieve the present study the following materials and methods had been employed.

1.8.1 Materials and sources of data used for the study

- The regional geological map and geological description of the area was important and acquired from Ethiopian Geological Survey with map Ethiopian map index of NC-37-11 and its scale is 1:250,000(Daniel Meshesha et al., 2010)
- Gathering basic information data which is obtained from Zonal and District Disaster Prevention & Preparedness Offices.
- The source of meteorological data of the study area was obtained from Ethiopian Meteorological Service Agency which last for 15 years (2000 to 2014) Debre-Berhan station.
- The topographic map of the study area was obtained from Ethiopian Mapping Agency with scale of 1:50,000
- Books, scientific, Journals, reports, published & unpublished Thesis, Internet resources
- GPS and digital camera are important materials

In the present study bivariate statistical approach is adopted to perform landslide hazard evaluation and landslide hazard zonation of the study area which is based on data driven or past landslides. The inventory data of past landslides from secondary data like engineering geological map, precipitation (rainfall data), geological map, satellite images and other recorded data on loss of life and damage of property is considered. Furthermore, during field work prone areas for past landslide locations are gathered using GPS instrument to delineate as a polygon. Finally the inventory data is analyzed by using GIS software for six prominent causative factors as thematic map by overlaying.

The Landslide Susceptibility Index is computed for subclass of causative factors. Later, the weighted sum of the causative factors was overlaid and then landslide zonation is classified as very low, low, moderate, high and very high hazard.

1.8.2 Methods

1.8.2.1 Reconnaissance study

- Review of the literature to the objectives of the study
- Materials and data mentioned above were collected and reviewed for interpretation
- Interviews and discussions have been made with the villagers and concerned officials to have a background information of the area and landslide problems of the study areas.

1.8.2.2. During field work

- Mapping the study area on topographic map.
- Taking notes on the observed geological features in the study area.
- Taking reading for geological features and locations for springs and streams
- Prominent causative factors will be considered to prepare the landslide hazard zonation map. These causative factors are; slope material, aspect, slope, elevation, landuse landcover and groundwater.
- Mode of failures of past landslides is detected.

1.8.2.3. Post field

- Analysis of data which was collected during the field works and from the secondary sources
- Delineation and creations base maps of the study area from topographic and Geological maps.
- Mapping the actual data from the field to fill the gap between the available existing data on the map and the present data in study area using GPS on the base map.
- Generation of the main contributive factor maps for the area using GIS techniques
- Preparing a Landslide Hazard Zonation map which comprises the information of the relative susceptibility of the area to landslides
- Suggesting the detail planning for settlers and engineering structures in the future based on the prepared landslide hazard zone and writing final report

The flow chart of general methodology adopted for the present study is described hereunder.

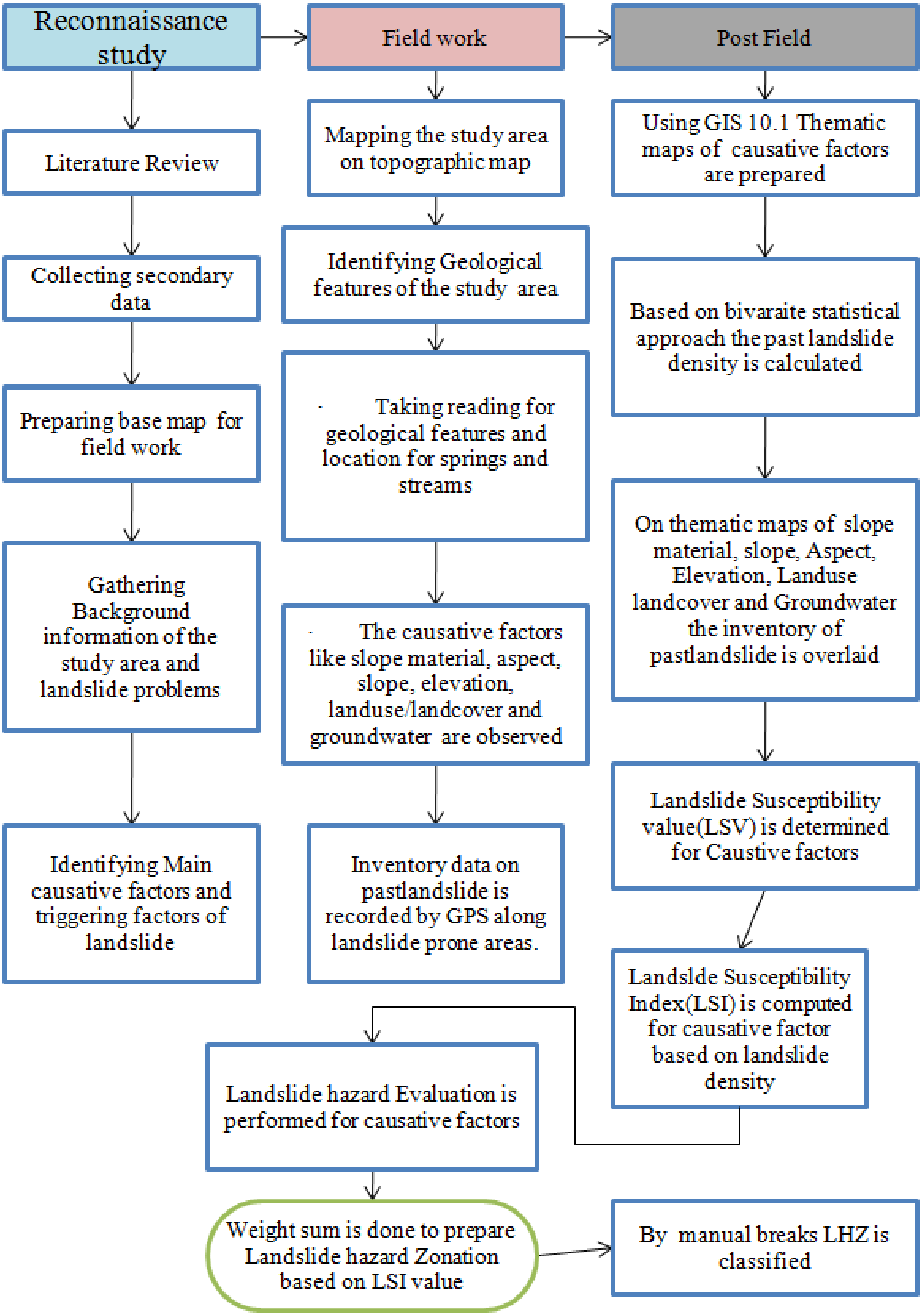


Fig.1. 7 Flow chart of general methodology adopted for the present study

CHAPTER TWO LITERATURE REVIEW

2.1 Introduction

The study of landslides has drawn global attention mainly due to increasing awareness of its socio-economic impacts and also increasing pressure of urbanization on the mountain environment (Aleotti and Chowdhury, 1999). Therefore, it is necessary to make landslide hazard assessment to help identify dangerous areas for development by examining the potential risk of landslides. Furthermore, management projects can be developed to avoid, prevent, or substantially mitigate the potential hazard. The occurrence of slope failure generally depends on complex interaction among a large number of partially interrelated factors. Analysis of the landslide hazard requires an evaluation of the relationship between various terrain conditions and landslide occurrences (Raghuvanshi et al., 2015).

Slope failures are generally considered as fairly well predictable hazards and economic losses due to such hazards can be reduced significantly (Hansen, 1984). Landslides continue to prevail in both the developed and developing countries, with larger casualties in developing nations but with severe economic losses in the industrialized world (Guzzetti et al., 1999).

According to Schuster (1995), world-wide landslide activities are expected to continue in the 21st century for the following reasons: (i) increased urbanization and development in landslide-prone areas, (ii) continued deforestation of landslide-prone areas, and (iii) increased precipitation caused by changing climatic conditions.

According to Varnes (1984), landslide is the result of wide variety of processes which include geological, geomorphologic, meteorological factors and human induced activities. The important terrain factors include drainage, slope, aspect, elevation, etc. A complete landslide hazard assessment requires an analysis of all these factors leading to instability in the region. Some of these factors can be derived by image interpretation. With the advancement in efficient digital computing facilities, the digital image analysis techniques have gained enormous importance (Carrara, 1983; Van Western and Terlien, 1996). In addition to this, the spatial and temporal thematic information derived from remote sensing and ground based information need to be integrated for data analysis. This can be achieved using GIS which has the capabilities to handle voluminous spatial data (Van Westen and Terlien, 1996).

Landslide hazard assessment (LHA) estimates the probability of occurrence of landslides in a territory within a reference period (Varnes, 1984; Fell, 1994; Van Westen et al., 2006).

It is deduced from information on (i) landslide susceptibility expressed as the spatial correlation between predisposing terrain factors (slope, landuse, superficial deposits, etc.) and the distribution of observed landslides in a territory (Brabb, 1984; Crozier and Glade, 2005) and, (ii) the temporal dimension of landslides related to the occurrence of triggering events (rainfalls, earthquakes, etc.). In most cases, landslide frequencies are difficult to obtain due to the absence of historical landslide records. Therefore, LHA is most of the time restricted to landslide susceptibility assessment (LSA) which is considered as a 'relative hazard assessment' and does not refer to the time dimension of landslides (Sorriso, 2002).

In Ethiopia, landslide generated hazards are becoming serious concerns to the general public and to the planners and decision makers at various levels of the government. However, so far, little efforts have been made to reduce losses from such hazards. With the ongoing infrastructural development, urbanization, rural development and with the present land management system, it is foreseeable that the frequency and magnitude of landslides and losses due to such hazards would continue to increase unless appropriate actions are taken in Ethiopia (Kifle Woldearegay, 2013).

The magnitude of landslide occurrences and its damage have been increasing from time to time in the Western, Southern, and Central highlands of Ethiopia. Lulseged Ayalew and Yamagishi (2003) studied Slope failures in the Blue Nile basin, as seen from landscape evolution perspective. Shiferaw Ayele et al. (2014) utilized remote sensing and GIS approach to delineate Landslide Hazard zones in Abay Gorge (Gohatsion-Dejen), Central Ethiopia. The various causative factors considered for this study were, geology, groundwater condition, drainage, slope, structures, aspect, landuse landcover and manmade factors.

Bivariate statistical analysis evaluates each factor map (for example: slope, geology, landuse) in turn with the landslide distribution map and weighting values based on landslide densities are calculated. Brabb et al. (1972) provided an early example of such an analysis.

2.2 Classification of Landslides

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

Though rock falls are common slope failures in the highlands of Ethiopia, so far, little is reported on the association of rock falls with rainfalls. Table 2.1 shows the classification of landslides.

Table 2. 1Classification of slope movement (Varnes, 1978)

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	SOILS	
				Predominantly course	Predominantly fine
Falls			Rock fall	Debris fall	Earth Fall
Topples			Rock Topple	Debris topple	Earth Topple
Slides	Rotational	Few Units	Rock Slump	Debris slump	Earth slump
	Translational	Many Units	Rock block slide Rock slide	Debris block slide Debris slide	Earth block slide Earth slide
Lateral Spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
Complex			Combination of two or more principle type of movements.		

A slump is the form of slide most common in thick, homogenous, cohesive materials such as clay (Selby, 1993).

A slide is a down slope movement of a soil or rock mass occurring on surfaces of rupture or on relatively thin zones of intense shear strain. In rotational landslide the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope (Raghuvanshi et al., 2015).

The mass in a translational landslide moves out or down, outwards along a relatively planar surface with little rotational movement or backward tilting. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil (Raghuvanshi et al., 2015).

A topple is a block of rock that tilts or rotates forward on a pivot or hinge point and then separates from the main mass, falling to slope below, and subsequently bouncing or rolling down the slope. Falls are abrupt movements of masses of geological materials that become detached from steep slopes or cliffs. Movement occurs by free-fall, bouncing, and rolling (Selby, 1993).

2.3 Factors influencing landslides

Due to natural conditions or manmade actions, landslides have produced multiple human and economic losses (Fleming and Taylor, 1980; Guzzetti et al., 1999). In general, the factors which influence whether a landslide will occur typically include slope angle, climate, weathering, water content, vegetation, overloading, and geology and slope stability. How these factors are interrelated is important in understanding what causes landslides along with an understanding of the impact humans have on these factors by altering natural processes. Typically, a number of elements will contribute to a landslide (Subramani and Krishnan, 2015).

According to Carrara (1983) and Cruden & Varnes (1996) it can be noted that landslides are caused by one or a combination of two or more of the following factors: (a) change in slope gradient (b) increasing the load that the land must bear (c) shocks and vibrations (d) change in water content (e) groundwater movement (f) frost action or wedging (g) weathering of rocks and (h) removal or changing the type of vegetation covering slopes, etc

The force that is responsible for the occurrence of landslide is gravitational force. Gravity is the force that pulls everything towards the center of the earth. Therefore, materials which are on slope are more susceptibility to force of gravity, which causes landslide, than material which is on relatively flat areas (Nelson, 2010).

Generally, the factors which are responsible in causing and triggering slope instability can be grouped as geological factors, geomorphic factor, hydrological factors, landuse landcover, manmade activities and seismicity.

2.3.1 Geological Factors

Most of the slope failures are shallow which involves only the upper few meters of the surficial deposits. Therefore, particular attention should be given to the geological mapping to the deposits near and at the surface (Varnes, 1984).

Different rock types (or lithology) have varied composition and structure, which contribute to the strength of the material. Therefore, the stronger rocks give more resistance to the driving forces as compared to the weaker rocks, and hence are less prone to landslides and vice versa (Kanungo et al., 2009).

The geological factors which induce the slope instability are based on:

i) Lithology

Rock which are rich in clay (montmorillonite, bentonite), mica, calcite, gypsum etc are prone to landslide because these minerals are prone to weathering. Lithological units, such as; basalts, shale, sandstones and lime stones have different shear strength characteristics because of the varying conditions under which they were formed. They also have different mineral constituents and fabrics (Malik, 1996; Upreti and Dhital, 1996).

ii) Geological structures

Occurrences of inclined bedding planes, joints, fault or shear zone are the planes of weakness, which create conditions of instability. Their strength is generally less as compared to the strength of the surrounding intact rock. It is therefore imperative to know their orientation in relation to slope angle, direction, and strength along such potential weak planes (Sidle and Ochiai, 2006).

The more the discontinuity or the line of intersection of two discontinuities tends to be parallel to the slope, the greater the risk of failure. When the dip of the discontinuity or plunge of the line of intersection of two discontinuities increase, the probability of failure also increase, because the angle of friction for the discontinuity surfaces may be reached. Moreover, till the dip of the discontinuity plane or the plunge of the line of intersection of the two discontinuities does not exceed the inclination of the slope, the failure potential remains high (Sidle and Ochiai, 2006).

2.3.2 Soil properties

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

Another attributed effect is the presence of soils that contain a high proportion of a type of clay mineral called smectites or montmorillonite. Such clay minerals expand when they become wet as water enters the crystal structure and increases the volume of the mineral. When such clays dry out, the loss of water causes the volume to decrease and the clays to shrink or compact (Malik, 1996).

2.3.3 Geomorphic factors

It is known that the common force tending to generate movements on slopes is gravity. Review of the previous studies show that most of the reported debris/earth slides/flows and rockslides have taken place in areas with slope angles between 15 to 45 degrees. As indicated by different researchers (example: Tenalem Ayenew and Barberi, 2005; Kifle Woldearegay, 2005), the low probability of occurrence of landslides in low slope gradient is likely to be due to the corresponding increase in the factor of safety. On the other hand, absence of major debris/earth slides and debris/earth flows on terrains with slope gradients greater than about 50 degrees is related to the insignificant thickness or even absence of unconsolidated deposits on such terrains because most of the steep slopes are dominated by slightly weathered rocks. The moderately steep terrains are often covered by unconsolidated deposits, which are more vulnerable to rainfall triggered slope failures (Lohnes and Handy, 1968; Swanston, 1978).

Slope gradient is important with regard to landslide initiation. In most studies of landslides, the slope gradient is taken into account as a principal causative or trigger factor. Slope gradients are sometimes considered as an index of slope stability, and because of the availability of a digital elevation model (DEM) can be numerically evaluated and depicted spatially (O'Neill and Mark, 1987; Gao, 1993). Elevation is usually associated with landslides by virtue of other factors such as slope gradient, lithology, weathering, precipitation, ground motion, soil thickness and landuse. For example; higher mountainous areas often experience larger volumes of precipitation, both rain and snow falls (Gao, 1993).

2.3.4 Hydrologic factors

The role of hydrology for landslide initiation is the main factor for slope instability. Changes in irrigation or surface runoff can cause changes in surface drainage and can increase erosion or contribute to loading a slope or raising the groundwater table. High groundwater level result increase pore water pressure and decrease shear strength, thus facilitating slope failure. Conversely, the lowering of the groundwater table as a result of rapid drawdown by water supply wells, or the lowering of a lake or reservoir, can also cause slope failure as the buoyancy provided by the water decreases and seepage gradients steepen (http:// geomorphic factor on landslide).

Some of the most significant hydrologic processes in this respect are precipitation (spatial and temporal distribution of rainfall), water recharge into soil (and the potential for overland flow), lateral and vertical movement within the regolith, evapotranspiration and interception.

Another aspect of water that affects slope stability is pore water pressure. In some cases fluid pressure can be built in such a way that water can support the weight of the overlying rock/soil mass. When this occurs, friction is reduced, and thus the shear strength holding the material on the slope is also reduced, resulting in slope failure. Pore water pressure built up within a regolith is directly related to the increase in groundwater table. Presumably, such actions are also controlled by subsurface flow parameters that mean precipitation, soil physical properties and infiltration capacity. The dynamic conditions of pore water pressure built up during different storm events are directly related to landslide initiations (Shimelies Ahmed, 2009).

2.3.5 Seismicity

The occurrence of earthquakes in steep landslide prone areas greatly increases the likelihood that landslides will occur, due to ground shaking alone or shaking caused dilation of soil materials, which allows rapid infiltration of water. Seismically triggered landslides are widespread phenomena within tectonically active mountain ranges. Most of these slope failures are reported to be of small size, such as rock or soil falls, and only a few of them affect large volumes of soil or rock material (Jibson et al., 1994; Harp and Jibson, 1995).

In general, seismically generated landslides usually do not differ in their morphology and internal processes from those generated under non seismic conditions. However, they tend to be more widespread and sudden. The most abundant types of earthquake induced landslides are rock falls and slides of rock fragments that form on steep slopes (Jibson et al., 1994).

According to Chowdhury (1978), acceleration of earthquake acting on a slope induces a temporary change of stress, which can break the equilibrium. External impact from seismic activity results in increased shear stresses and also reduces shear strength by increasing pore water pressure. Therefore, measurement of earthquake parameters, particularly in seismically active areas, is very important for landslide prediction. Rock falls, disrupted rock slides, and disrupted slides of earth and debris are the most abundant types of earthquake induced landslides; whereas earth flows, debris flows, and avalanches of rock, earth, or debris typically transport material the farthest.

There is one type of landslide that is typical for earthquakes that mean liquefaction failure which can cause fissuring or subsidence of the ground. Liquefaction involves the temporary loss of strength of sands and silts which behave as viscous fluids rather than as soils. This can have devastating effects during large earthquakes. The present study area has higher seismic value when we refer from Ethiopian zones of seismic value (refer fig.1.6 in Chapter 1).

2.3.6 Manmade factors

Landslides may result directly or indirectly from the activities of people. Some typical examples are:

- Undercutting during construction of highways and railroads increases the average slope gradients and increases the chance of slope failures.
- Overloading of hill slopes by housing construction is common. This extra weight may increase the chance of slope failure.
- Clear cutting of trees promotes soil erosion and weakens the support of soils by tree roots. It also reduces evapotranspiration and raises the water tables.

2.4 Techniques used in landslide hazard zonation

For landslide hazard zonation different techniques may be adopted which can be classified into three groups; expert evaluation, statistical and mechanical approach (Leroi, 1997).

2.4.1 Expert Evaluation

Expert evaluation technique includes landslide inventory mapping and heuristic approaches. Landslide inventory maps highlights the location and extents of recorded landslides thus helps in demarcating landslide susceptible areas whereas heuristic technique includes opinion in classifying the landslide hazard which is based on quasi-static variables (Dai and Lee, 2001).

The main criticism of the methodology of expert evaluation is the subjectivity in the decision making (Van Westen et al., 1997; Leroi, 1997), because the landslide hazard maps produced by different researchers according to expert evaluation can be very different (Carrara et al., 1992). However, it is evident that the approach based on expert evaluation will remain the most widely used and the most versatile. This means it will be necessary to relay on more sophisticated techniques for landslide hazard or susceptibility evaluation (statistical methods and mechanical methods) and on state of the art geographical data management tools, in order to be integrated into the overall methodology of landslide danger or hazards mapping (Fall et al., 2006).

2.4.2 Mechanical Approach

Mechanical approaches include deterministic numerical methods which quantify the stability of the slopes by a safety factor. These methods also facilitate to predict, simulate and evaluate the stability of the slopes condition by considering different instability factors with relatively good accuracy. These mechanical approach methods requires exhaustive geological and geotechnical input data which for obvious reasons is time consuming and requires special skills in data collection.

Thus, these deterministic numerical methods cannot be economically applied effectively for large areas. The advantage of the application of mechanical models (deterministic or numerical models) in landslide hazard assessment is that these models are physically sound. With these models it is possible to quantify the stability of the slopes by a safety factor (Van Westen et al., 1997).

In landslide susceptibility or hazard assessment of large areas, the mechanical methods should only be applied to study the stability of slopes, which cannot be determined with sufficient accuracy with the other methods of landslide hazard assessment. The successful use of one method or another strongly depends on many factors such as the scale of the study area, the accuracy of expected results, the availability of data, etc. (Fall et.al, 2006)

GIS technology could provide a powerful tool to model the landslide hazards for their spatial analysis and prediction. This is because the collection, manipulation and analysis of the environmental data on landslide hazard can be accomplished much more efficiently and cost effectively (Carrara and Guzzetti, 1999; Guzzetti et al., 1999). Many GIS-based analysis models and quantitative prediction models of landslide hazard have been proposed since the beginning of GIS application in geo-hazards research in the late 1980 (Carrara, 1983; Van Westen, 2006; Carrara et al., 1992; 1999).

2.4.3 Statistical Approach

Statistical methods are based on the statistical determination of the combinations of different variables that were responsible for instability of slopes in a given area. For this approach, both simple and multivariate statistical methods can be employed to evaluate the landslide hazards (Dai and Lee, 2001).

The major limitation of statistical methods is gathering large data on landslide distributions and various factors over large areas which require considerable time, resource and manpower (Van Westen et al., 1997). Another constraint is quality and quantity of data on landslide frequency and various factors on which statistical correlations are established. Thus, the findings are highly influenced with the volume of data gathered and its quality (Fall et.al, 2006).

Some GIS-based landslide analysis models, such as statistical models, are based on the assumption that an area where landslides occur is now under prone to landslide environments and that areas under those environments have high potential of new landslides occurrence, or future landslides will occur under circumstances similar to those of past landslide.

Such prone areas are depicted by factors affecting the occurrence of landslides, such as rock and soil types, slope angles and landuse that are usually digitized as layers or themes in GIS (Fall et.al, 2006).

2.4.3.1 Multivariate statistical analysis

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

2.4.3.2 Bivariate statistical analysis

In bivariate statistical method, each landslide casual factor map (for example geology, slope, landuse, aspect) is combined with the landslide inventory. The weights are derived from either landslide abundance or densities in each attribute class within each factor (Gupta and Joshi, 1990; Van Westen et al., 1997; Suzen and Doyuran, 2004). Frequency analysis approach, information value model (IVM), weights of evidence model (WEM), weighted overlay model are examples of bivariate statistical methods used in landslide hazard zonation mapping.

Information Value Model (IVM) is a bivariate statistical method for spatial prediction of landslides based on relationships between landslide occurrence and related parameters (Sarkar et al., 1995). The information values are determined for each subclass of landslide related parameter on the basis of presence of landslide in a given mapping unit. The weights of evidence model (WEM) use different combinations of landslide causative factors in order to describe their interrelation with landslide distribution (Van Westen et al., 1997)

Frequency ratio is based on observed relationships between landslide distribution and each causative factor related to landslides. This method can be used to establish spatial correlation between landslide location and landslide explanatory factors (Lee and Min, 2001). Frequency ratio for each subclass of individual causative factor is calculated based on their relationship with landslide occurrence.

Landslide Susceptibility Index (LSI) is computed by summing of frequency ratio values of each factor. Weighted overlay is based on the relationship of landslide causative factors with the landslide frequency (Sarkar et al., 1995).

2.4.3.2.1 General methodology adopted for the present study with justification

For the present study, bivariate statistical analysis modeling was evolved and validated to derive a landslide susceptibility map of the study area. For this purpose, landslide conditioning factors such as slope material, slope, elevation, landuse landcover, groundwater surface traces, aspect and a landslide inventory data were analyzed within a GIS environment.

For the present study about 31 past landslides (inventory data) were collected for analysis in thematic maps of causative factors. Therefore, this method is feasible for evaluation of causative factors and to prepare hazard zonation map of the study area. In bivariate statistical analysis, each factor map is combined with the landslide distribution map, and weighting values based on landslide densities are calculated for each parameter class (Suzen and Doyuran, 2004). According to Suzen and Doyuran (2004) the main advantage of bivariate statistics based approach is the easy updating of the landslide hazard mapping and its ease to use for land planning.

The approach followed for landslide hazard zonation is based on an assumption that "past is the key for future". For each causative factor suitable subclasses are made. This suggests that combination of factors which has resulted into past landslide activity in the affected area may also be responsible for any future landslide activity in some other area if a similar combination of causative factors prevailed in that area. From various bivariate statistical analysis methods both landslide susceptibility index (LSI) and weight evidence modeling (WEM) is evolved to prepare landslide hazard zonation map of the study area.

The Landslide Susceptibility Index (LSI) as modified by Raghuvanshi et al. (2015) is given by (eq.2.1). In order to evaluate the relative contribution of a subclass of each causative factor on past landslide, Landslide Susceptibility Index (LSI) was calculated.

$$`LSI = \frac{\text{Landslides} \ \ \% \text{ in density}}{100} \text{ x LSV} \ldots\ldots\ldots\ldots \text{(eq.2.1)}$$

Where:- 'LSI' is the Landslide Susceptibility Index and 'LSV' is the Landslide susceptibility value which can be assigned to each of the factor based on the relative importance of that factor in controlling the stability condition of the slope in the given area.

In the present case LSI is computed by considering Landslide percentage which represents the ratio between "total pixel counts of a sub-class within a Landslide" to the "total pixel count of a subclass in the area of study".

The LSI values were calculated for each subclass of all six causative factors: - slope material, slope, elevation, landuse landcover, groundwater surface trace and aspect map is performed. The weight map of the causative factors is overlaid by using the weight sum in spatial analyst tool in Arc tool. The weight summation gives one weight map; this map is later classified based on manual classification as the inventory of landslide is overlaid. Finally, by using the weighted sum tool the final map of the landslide hazard zone map was produced. The classified zonation indicates the landslide hazard zonation that ranges from very low to very high hazard zone.

In the second method, the weight of landslide density is calculated using weight evidence modeling approach for all parameters of the present study. This technique is a useful model for evaluation of the relationship between landslide occurrence locations and related conditioning factors. This method is able to calculate the probability of landslide occurrence in each class of conditioning factors. The Weight of evidence modeling (WEM) method is applied where sufficient data are available to estimate the relative importance of the evidence by statistical means. The basic principle of WEM is obtained according to the density of known landslide locations in each class of the variables, addressed as 'evidence' such as slope, lithology and aspect (Van Westen et al., 2006).

In the present study for prominent causative factors: slope materials, slope, elevation, landuse landcover, groundwater and aspect thematic maps are performed based on landslides inventory data and obtain landslides density. Later, the weight of each parameter is statistically analyzed using WEM techniques. Weight of the parameters is deduced by using equation (eq.2.2).

$$\ln W_i = \ln\left(\frac{\text{DensClass}}{\text{DensMap}}\right) = \ln\left[\frac{\frac{\text{Npix (Si)}}{\text{Npix (Ni)}}}{\frac{\sum \text{Npix (Si)}}{\sum \text{Npix (Ni)}}}\right] \ldots\ldots\ldots \text{(eq.2.2)}$$

Where,

$\boldsymbol{W_i}$: − Is the weight given to a certain parameter class

$\boldsymbol{DensClass}$: − The landslide density within the parameter class

$\boldsymbol{DensMap}$: − The landslide density within the entire map

$\boldsymbol{Npix(Si)}$: − Number of pixels, which contain landslides, in a certain parameter class

$\boldsymbol{Npix(Ni)}$: − Total number of pixels in a certain parameter class

Based on the result of weight sum map the hazard zonation map is performed.

2.5 Landslide Mapping

Landslide mapping can be based on one or a combination of the following activities: aerial photo interpretation, ground survey and a data base of historical occurrences of landslides in an area (Schuster, 1995; Soeters and Van Westen, 1996). However, in the absence of historical data, one has to rely on field survey and photo interpretation technique. Satellite image is generally unsuitable for landslide mapping except where data products can be enlarged to at least 1:50000 scales (Soetres and Van Westen, 1996).

Images are classified by categorizing all pixels into landcover classes or themes as noted by (Lillesand, 2004). For any given image, the spectral pattern for each pixel is used as the numerical basis for the categorization. Different features exhibit different properties like spectral reflectance and emittance. This is the most straight forward approach to landslide hazard zonation because aerial and space image contain a detailed record of features on the ground at the time of data acquisition (Lillesand, 2004).

Aerial photograph can serve as the source for data on existing landslides, type of bedrock, and vegetation cover. Typically, large scale photography is necessary for mapping existing landslides. The photo scale depends on the size of landslides in the study area (Sheila, 2006).

A map of existing landslides serves as the basic data source for understanding conditions contributing to landslide occurrence. Normally, such a map is prepared by the interpretation of aerial photographs which is supported by field verifications (Cruden and Varnes, 1996). The map may be prepared at different levels of details concerning existing landslides. A simple inventory identifies the definite and probable area of existing landslides and is the minimum level required for a landslide hazard assessment (Sheila, 2006).

There are several considerations to keep in mind when gathering data on existing landslides.
First the time and effort required to conduct an inventory varies with (i) geological and topographic complexity, (ii) size of an area and (iii) desired level of inventory detail. Second, more detailed inventories will require large map scales to reveal the small features of this added detail. Third, additional data gathering can add details to an existing inventory. This enables a previously completed simple inventory to be transformed into an intermediate inventory with less time and effort than producing the intermediate inventory solely from field work and aerial photography (Varnes, 1984).

Satellite images have the advantage of having multi temporal characteristic which makes them useful for change detection. However, updating available data using satellite image requires intensive field work to fill in the missing details. This indicates that satellite images need to be used in combination with other data generation methods (Lillesand, 2004).

There are three principles which guide landslide hazard assessment.

(i) Landslides in the future will most likely occur under geomorphic, geologic and topographic conditions that have produced past and present landslides.

(ii) The underlying conditions and processes which cause landslides are understood.

(iii) The relative importance of conditions and processes contributing to landslide occurrence can be determined and each assigned some measure reflecting its contribution (Varnes, 1984).

2.6 Literature Review for Landslide Hazard Zonation (LHZ) Map Preparation

Several landslide susceptibility assessment methods are presented in the literature. These methods can be broadly grouped into direct and indirect and qualitative and quantitative (Van Westen et al., 1997; Van Westen et al., 2006). In direct method, the researcher determines the degree of susceptibility based on her/his knowledge and experience. However, in indirect mapping, the researcher uses either statistical models or deterministic models to predict landslide prone areas, based on the information obtained from the interrelation between landslide controlling factors and landslide distribution (Van Westen et al., 2006).

Qualitative assessment method evaluates the landslide susceptibility without landslide inventories. This method evaluates the actual landslide based on the spatial distribution of landslide controlling factors. This method is dependent on the experience and skills of the expert preparing the map. It requires a prior knowledge on factors controlling landslides. Heuristic method is example of qualitative method (Soeters and Van Westen, 1996). Quantitative methods include statistical and deterministic modeling of landslide susceptibility combining landslide inventory and landslide controlling factors (Van Westen et al., 1996).

Landslide inventory also called frequency method are the simplest form of landslide mapping. The susceptibility estimation is based on the number of landslide occurrence (Wright et al., 1974). Landslide inventory maps provide quantitative measure on landslide distribution. They provide straight forward comparison of different regions. However, landslide inventories assume continuous landslide density in space and cannot provide estimates on future landslides. An inventory of landslide can be prepared by collecting the historical information on individual landslide events and by using satellite images and aerial photographs and field survey (Soeters and Van Westen, 1996; Duman et al., 2005).

In physically based models, the landslide susceptibility is determined using slope stability models resulting in the calculation of factor of safety (Soeters and Van Westen, 1996). These models provide the best quantitative information on landslide susceptibility that can be directly used in the engineering works.

In statistical methods, landslide casual factors or parameters are derived and combined with the landslide inventories to predict the future occurrence of landslides (Carrara et al., 1991; Guzzetti et al., 1999; Dai et al., 2001). Statistical methods can be distinguished into multivariate and bivariate. In multivariate method, all relevant landslide casual factors or parameters are treated together (Carrara, 1983; Carrara et al., 1991, Lee and Min, 2001; Suzen and Doyuran, 2004). As a result, interaction effects of multiple factors are displayed by this method. Logistic regression (Dai et al., 2001) and determinant analysis are the main types of multivariate statistics used in landslide susceptibility analysis. Artificial neural network (ANN) classifiers are another type of multivariate method.

In bivariate statistical method, each landslide casual factor map (for example geology, slope, landuse, vegetation) is combined with the landslide inventory. The weights are derived from either landslide abundance or densities in each attribute class within each factor (Gupta and Joshi, 1990; Van Westen et al., 1997; Suzen and Doyuran, 2004). Information value method, weight of evidence modeling and Frequency ratio are types of weight estimation methods employed in bivariate statistical method. In the present study the bivariate approach is evolved based on the landslide inventory data using GIS software to map the landslide hazard zonation.

CHAPTER THREE   GEOLOGICAL SETTING AND HYDROLOGY

3.1 Introduction

Geology and hydrology have vital role for controlling the occurrences of landslide based on types of lithology and drainage situation of the area. The geology of Ethiopia underlies by rock types range in age from Precambrian to Cenozoic. These rocks are categorized into the following geological formations:-Precambrian rocks, Paleozoic-Mesozoic sedimentary rocks, Cenozoic volcanic rocks and associated sediments (Mengesha Tefera et.al., 1996).

3.2 Regional Geology

The general geological setting of Ethiopia is explained by Kazmin (1975). According to him the basement rock upon which all the younger formations were deposited contains the oldest rocks, with ages of 600 million years and is exposed in areas where the younger rocks have been eroded. Uplift occurred at the end of the Precambrian times, which was followed by a long period of erosion. Then subsidence began in the Mesozoic, with age some 225 million years ago. Extensive fracturing and volcanism occurred in the early Cenozoic which covered the western half of Ethiopia and the Afar depression. The origin of these volcanic directly related to rifting in this area that started during the tertiary period to the present (Faure, 2001).

The major physiographic regions of Ethiopia are four categories, widely known as the western plateau, southeastern plateau, the main rift and the afar depression. The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro-Arabian Shield. The Precambrian basement is covered for the most part by glacial and marine sediments of Permian to Paleocene period and Tertiary volcanic rocks with related sediments (Mengesha Tefera et.al., 1996).

Getaneh Asseffa (1981) has extensively studied the Mesozoic sediments in the Abay River and its tributaries and he called it Goha-Tsion formation. The previous researchers considered this formation as a bed or strata. However, from the modern stratigraphical nomenclature point of view and its lithological association (gypsum, shale and limestone with intercalation of dolomite), Getaneh's naming is more logical (Serawit Amene and Tamirat Mojo, 1996).

3.2.1 Cenozoic volcanic rocks and associated sediments

Volcanism started during the Eocene-late Oligocene with the eruption of flood basalts that have generally been related to either one or two mantle plumes impinging the base of the lithosphere under Afar or Afar-Northern Kenya rifts.

According to Peccerillo et al. (1997), the Ethiopian volcanic can be related to two main magmatic stages. The first is the Oligocene – Pliocene large fissure eruptions of basalts which build up thick flood lava sequence (known as Ashange and Aiba basaltic formations) associated with late ignimbrite sheet (Alaji Rhyolitic formations). This magmatic stage was closed by the formation of huge basaltic shield volcanoes (Tarmaber formation). However in the recent studies about the continental flood basalts of northwestern part of Ethiopia, the whole formations were considered as a single unit which was flooded in less than 1 my around 30my ago (Hofman et al., 1997; Pik et al., 1998).

The second stage of volcanic activity is related to Pliocene to Recent in age and is more closely related to the formation of rift valley and Afar. In this group the volcanic rocks are associated with basaltic cinder cone and lava flows that are aligned along extension faults parallel to the rift and intermediate rocks are very scarce. Recent classification for continental flood basalt of Northwestern part of Ethiopia was followed as Lower formation, upper formation and the shield volcano. Both the lower and upper formation of the continental flood basalt was emplaced 30 my ago with short period less than 1my (Hofman et al., 1997).

The earliest flood basalts forming the Ethiopian Plateau apparently erupted in a rather short time interval (<5 Ma) with the greatest eruption rates occurring from 31 to 28 Ma. This strong eruption was concomitant with the onset of continental rifting in the Red Sea-Gulf of Aden systems by 29 Ma, however predates the main rifting phases associated to the development of the Main Ethiopian Rift (MER). However, limited volumes of basalts with age 45 Ma have been described in southern Ethiopia, in the Broadly Rifted Zone separating the MER from the Kenya rift. Immediately after the peak of volcanic activity related to the flood basalt emplacement, a number of large shield volcanoes developed on the surface of the volcanic plateau. The flood basalts, forming the Ethiopian plateau, erupted apparently in short time interval (<5Ma) with the greatest eruption rates during 31 to 28 Ma (Hofmann et al., 1997; Pik et al., 1998; Ukstins et al., 2002; Daniel Meshesha and Shinjo, 2007). This eruption, covering an area of >500,000 km2, is inferred to mark the appearance of the Afar mantle plume head (Mohr and Zanettin, 1988; Hofman et al., 1997; Pik et al., 1998; Ukstins et al., 2002) and its origin could be linked southwestern to the African Super plume beneath southern Africa (Daniel Meshesha and Shinjo, 2007).

In the northwestern Ethiopian plateau, the flood basalt is further subdivided into three main magma types, distinguished by their contrasting geochemical signatures (Pik et al., 1998): Low-Ti basalts (LT-type) located in the northwestern part of the plateau and High-Ti basalts (HT1- and HT2-type) located in the eastern part of the plateau. The Ethiopia plateau, including part of the study area (map index NC 37-11) is composed of thick Tertiary volcanic successions (Mengesha et al., 1996) and the volcanism is classified into three stages separated by a long period of volcanic quiescence; the pre-Oligocene (alkaline to tholeiitic basalts), the Oligocene-Miocene and the Miocene-Pliocene (Zanettin et al.,1978). Zanettin et al. (1980) later reclassified the volcanism as Oligocene-Late Miocene Alaji basalts and rhyolites, and the Tarmaber basalts.

Following Zanettin et al. (1978, 1980) classification scheme, Berhe et al. (1987) divided the volcanic rocks of Ethiopian plateau into First Stage (Ashange, pre-Oligocene), Second Stage (Aiba, 34-30Ma), Third Stage (Alaji, 30-26 Ma) and Fourth Stage (Tarmaber, 25-13Ma). The Tertiary volcanic successions are mainly consisting of Ashange basalts, Aiba basalts, Alaji rhyolites and basalts, Tarmaber basalts and Balchi rhyolites (Kazmin, 1979).

The earliest fissure flood basalts on the Ethiopian plateau are represented by Ashange basalt 49-46 Ma (Davidson, 1983). The Ashange basalts are several hundred meters to kilometers thick and lie below pre-Oligocene unconformity (Zanettin et al., 1980). The Ashange Formation has been affected by a compression episode, which resulted in the tilting and folding of the basalts prior to eruption of the Aiba Basalts (Zanettin et al., 1980).

It consists of alkaline to mildly alkaline basalts (Berhe et al., 1987; Mengesha et al., 1996) with inter bedded pyroclastic and rare rhyolites. The Aiba basalts (34-28Ma; Kazmin, 1979; Zanettin et al., 1980) are a thick cover of flood basalts (200-600m) erupted on the Ashange peneplain as the result of distensile crustal movement (Zanettin and Justine, 1973).

Tarmaber basalts (tholeiitic to mildly alkaline) have been classified into Tarmaber-Gussa (26-16Ma) and Tarmaber-Megezez (16-13Ma) that cover the Oligocene Alaji (Alaji-Sirro) and Miocene Alaji (Alaji-Molale) respectively (Mengesha Tefera et al., 1996).

According to Kazmin et al. (1980), the Tarmaber-Megezez basalts are erupted from centers along the developing rift shoulder. Finally, the Balchi rhyolites (8-2Ma) overlying either the Tarmaber basalts or the Alaji rhyolites.

3.3 Local Geology of the Study Area

The description of the local geology is based on the Geology of Debre Berhan area and its map index is (NC 37-11). The geology is compiled mainly from previous works by (Daniel Meshesha et al., 2010). Lithology is considered as one of the main cause factor for slope instability.

The main lithological units of the study area can be grouped as kesem basalt (Tkb), Sela Dingay-Debre Berhan-Gorgo ignimbrite, Tarmaber Megezeze basalt (Ttb) and Quaternary superficial deposits (Alluvial and Colluvium deposits).

3.3.1 Tertiary volcanic rocks

The tertiary volcanic rocks are the earliest volcanic rocks in the present study area. The rocks consist of thick succession of aphanitic basalts and ignimbrites which are overlain by central volcano (plagioclase phyric-basalts). Within the Tertiary volcanic rocks, thin beds of volcano clastic sediments (tertiary sediments) are also found.

3.3.1.1 Kesem basalt (Tkb)

The Kesem basalt is found at the lower stratigraphic sections of Germame drainage basins; covering 42% of the lithological map (refer Fig.3.1). The Kesem basalt is strongly fractured, irregularly to columnarly jointed, spheroidally weathered, aphanitic to porphyritic in texture and forms very steep cliffs. The Kesem basalt consists of dominantly aphanitic basalt intercalated with plagioclase phyric basalts and thin beds of ignimbrite (plate 3.1).

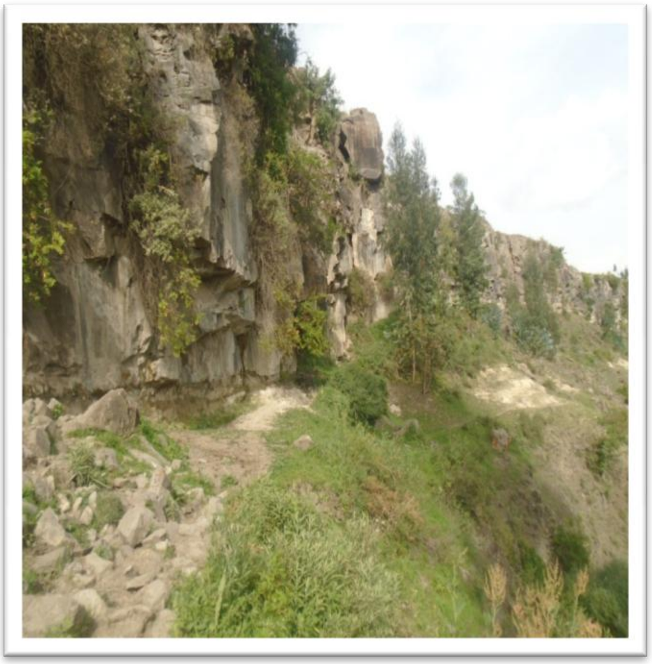


Plate 3. 1 Fall of kesem basalt in key-Gedel

The aphanitic basalt is the most abundant, fine grained, dark gray to black (fresh color) to bluish gray (weathering color) and columnar jointed. It is characterized by different phases of basaltic flows separated by randomly exposed reddish palaeosols and sediments. The ignimbrite is very limited in its vertical extent as compared to the aphanitic basalt. It is found at the middle and sometimes on top of the aphanitic basalt with varying thickness at different localities. It is fine to medium grained, bluish gray to gray, friable and composed of small rock fragments.

3.3.1.2 Sela Dengay-Debre Berhan-Gorgo ignimbrite (Tdig)

Sela Dengay-Debre Berhan-Gorgo ignimbrite is exposed mainly at the study area localities; covering 44% of the map (refer Fig.3.1).

It has sharp contacts with the overlying (Tarmaber-Megezez) and underlying (Kesem) basalts. It comprises ignimbrite, rhyolite, Tertiary sediment, tuffaceous sediment, aphanitic basalt, agglomerate and ash. The ignimbrite forms gentle to steep cliffs, elongated ridges and sporadically distributed isolated hills. Plate 3.2 shows ignimbrite in Gora area.

Plate 3. 2 Ignimbrite lithology in Gora

It is medium to coarse grained, light/bluish/brownish gray to gray (fresh color) to dull/dark gray (weathering color), highly consolidated to welded tuff and bedded with columnar joint, vertical joints and fractures. It contains rock fragments of rhyolite and basalt and elongated fibrous glass shards (fiamme), whereas the amount of rock fragments significantly varies from place to place.

The aphanitic basalt is fine grained, black/dark/gray, irregularly fractured, slightly jointed, columnarly jointed and rarely shows a massive appearance that forms a steep morphology.
The Agglomerate contains fragments of ignimbrite and vesicular variety of dark gray porphyritic to aphanitic basalts cemented by white ash. It is loose and highly weathered with angular rock fragments from cobble to pebble size and forming low slope angle than other rocks. The ash is forming mostly gentle slope and flat topography. It is white, light yellow, pink and light brown (fresh color) to red, yellowish gray and black (weathering color). It contains small fragments of basalts and pumice.

3.3.1.3 Tarmaber-Megezez basalt (Ttb)

Tarmaber-Megezez basalt is dominantly exposed on the western part of the study area coverings about 2% of the map (refer Fig.3.1).

Tarmaber-Megezez basalt includes fine, medium to coarse grained, dark gray (fresh color) to light/reddish/dark/yellowish brown (weathering color) and aphanitic to porphyritic basalts. It is characterized by different phases of basaltic flows separated by randomly exposed reddish palaeosols and reddish brown scoriaceous basalts (plate 3.3).

Plate 3. 3 Tarmaber-Megezez basalt in the study area

It is dominantly represented by plagioclase phyric varieties (plagioclase phyric and olivine-plagioclase phyric basalts) together with minor olivine phyric, pyroxene phyric, plagioclase-pyroxene-olivine phyric and aphanitic basalts. Plagioclase phyric basalt shows randomly distributed and faint columnar jointing. It is medium to coarse grained and dark gray, containing plagioclase phenocyrsts in length.

3.3.2 Quaternary Superficial deposits

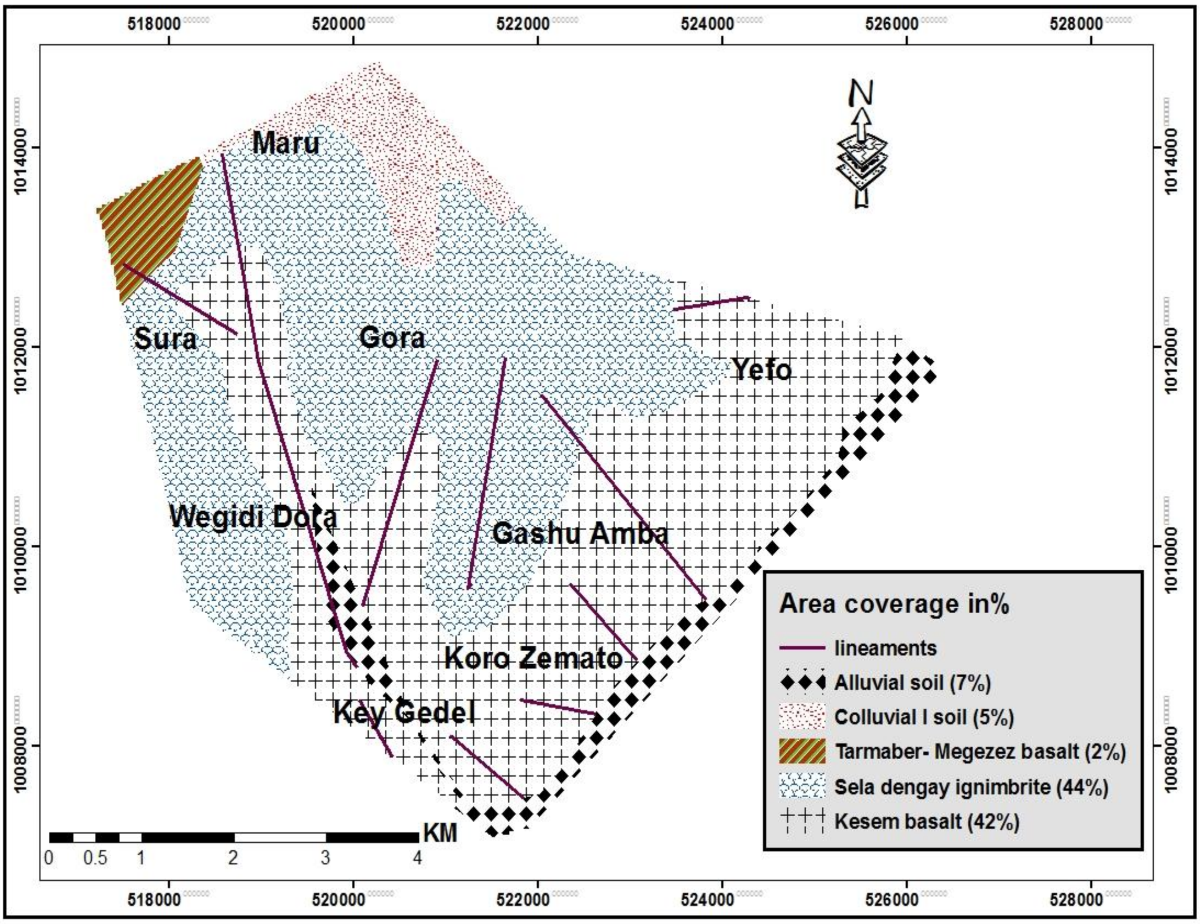
Alluvium soil (Qal)

The alluvium soil is found in the southern part of the study area in the Germame river areas; covering 7% of the map (refer Fig.3.1). It is derived from the weathering, transportation and reworking of different rocks from the plateau and escarpment area. These sediments occur along stream or river channel. The alluvial sediments vary in size from sand, pebble, cobble and boulder. The cobble to boulder size is dominant. It consists of dominantly fine to medium sand, gravel deposits covered by rare bushes. Fine to medium sand and gravel is found in small valleys and gorges areas. Gravel consists of rounded to sub-rounded shaped basaltic boulders (refer plate 3.4).

Plate 3. 4 Alluvium Soil **Plate 3. 5 Colluvium Soil**

Colluvium Soil (Qcol)

The Colluvium soil is mostly found under the rugged and escarpment of the area; occupying topography with 5% coverage of the map and mainly exposed in the central part of the study area (refer Fig.3.1). It is formed by the gradual weathering of the basalt, ignimbrite and rhyolite. There are rock fragments of basalt, ignimbrite and rhyolite within the colluvium soil. It is silt to clay sized, light/dark gray to reddish brown fertile soil.



(Source: Modified after Geological map of Debre Berhan Area (NC 37-11) (Daniel Meshesha et al., 2010))

Fig.3. 1 Local Geology map of the study area

3.3. 3 Structure

The major structural elements within the study area are identified by the combination of results from aerial photo interpretations, Digital Elevation Model (DEM) analysis and field observations. The tectonic structures are associated with the extensional tectonics. They include faults, lineaments, local shear zones, folds, fractures and joints, having variable magnitude and orientations.

Lineaments

Differently oriented lineaments with variable strike directions are recognized. The most abundant and prominent lineament trends are NW-SE and NE-SW directions. Most of the stream or river valleys are controlled by these lineaments.

Joints and Fractures

Differently oriented joint sets and irregular fracture (few mm to cm in width) are observed in the Study area. They are penetrative to non-penetrative joints, having significantly variable strike length.

Mostly in the ignimbrite two sets of joints are encountered, these are horizontal (dipping direction 300 towards SE) and vertical (trending NS and N100E) set of joints. In addition irregularly oriented columnar joint sets (mostly hexagonal faces) are also observed in the ignimbrites and basalts.

3.4 Hydrogeology of the study area

Hydrogeology plays a major role in controlling the occurrence of landslide in the study area. Heavy summer rainfall is the main triggering factor for most of landslides (Bekele Abebe et al., 2009; Tenalem Ayenew and Barbieri, 2004). The major hydro-geological factors are characterized into porous, fissured, permeability and impermeable

3.4.1 Hydrology

The major basin constitute of the study area, is awash basin. There are so many intermittent springs, perennial rivers and high precipitation during rainy season. Rivers like Difo bar, Yefo and Garmama Rivers are tributaries of Mikawa River which is one of the biggest tributary of Awash basin. Drainage characterization is an important factor, which reflects the slope evolution of an area and an indicator of the mass wasting and related erosion aspects. There is a big spring with high potential discharge and a number of low yielding springs common at the base of the slopes throughout the year. The springs form a dendrite pattern in the village and the settlers use the springs for both potable and irrigation purposes (plate 3.6).

Plate 3. 6 Potable spring in the study area

Plate 3. 7 Mikawa river bank failure

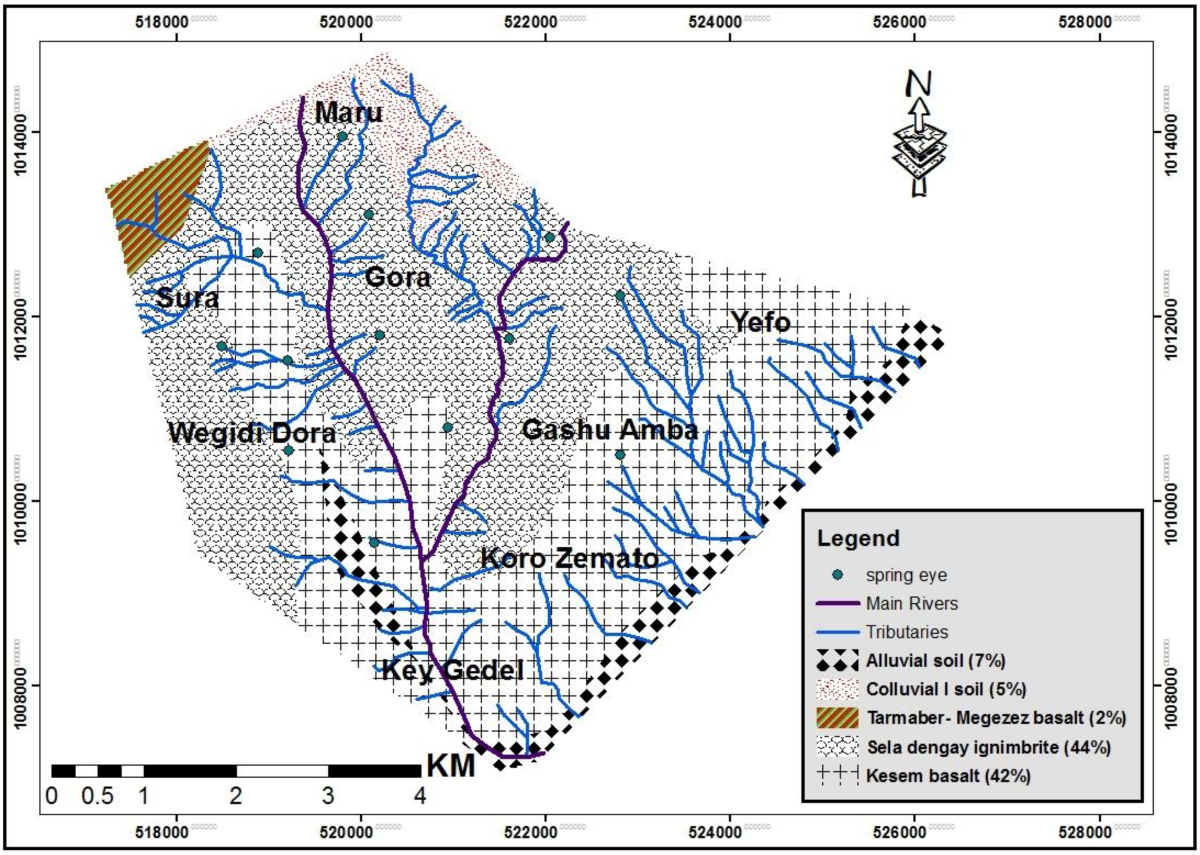
3.4.2 Groundwater Condition

The weathered and fractured surfaces play a significant role in groundwater accumulation and flow. Majority of the tertiary volcanic are highly jointed and fractured but they are filled by secondary filling materials, which are a barrier for groundwater flow.

The occurrence of groundwater is mainly influenced by lithology, geological structures and Geomorphology and climate conditions. Lithology, geological structures and geomorphologic setting of the area strongly influence the quantity, quality and movement of groundwater. Since the climate condition throughout the area seems uniform, it has the same effect through the entire area. The geology of the area provides usable groundwater and good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers.

Fractures, joints and weathering surfaces of different lithological units play a vital role in facilitating the infiltration amount and rate and also groundwater flow. The majority of productive aquifers are characterized by their high degree of weathering and intense fracturing. Fractured volcanic rocks are the major potential rock units for storage and movement of groundwater. Furthermore, inter-granular pore-spaces of alluvium also have significant role in occurrence of groundwater. The main recharge for groundwater of the area is precipitation, surface water, Perennial River and streams.

The correlation of groundwater with landslide of the study area shows that, as the water table rise during rainy season the failure of slope also increases and it is vice versa during dry season. Fig.3.2 and Table 3.1 Show the springs and hydrology of the study area.



(Source: Lithological units modified from Geological map of Debre Berhan Area (NC 37-11))

Fig.3. 2 Hydrological map of the study area

Table 3. 1 Location of springs in the study area

S.No	Name of springs	Location		Discharge Estimated(L/Sec)	Purpose
		Easting	Northing		
1	Lankiso	518461	1011726	1	Potable
2	Bole	520049	1013154	0.7	Potable
3	Chafe	522774	1012281	2	potable and use for irrigation
4	Abanob	519784	1014014	1.5	potable
5	Sindabo	522787	1010508	0.5	Swamp
6	Gomman Agar	520168	1011845	3	For irrigation
7	Goro Zamata	519176	1011593	2	potable
8	Wagidi	518845	1012704	1	For cattle drink
9	Gashoo	519202	1010588	0.5	Useless
10	Sura	522046	1012876	1.5	Washing
11	Zamata	521597	1011765	2.5	potable
12	Kersa	520909	1010839	0.5	potable
13	Game	520115	1009569	0.7	Irrigation

CHAPTER FOUR DATA AND METHODOLOGY

4.1 Introduction

In the present study the methodology adopted is based on bivariate statistical analysis. The weights of different classes are determined by calculating landslide densities. The weights are derived from either landslide abundance or densities in each attribute class within each factor (Gupta and Joshi, 1990; Van Westen et al., 1997; Suzen and Doyuran, 2004). The method is therefore "data-driven". In the statistical modeling of landslides the assumption is based on the rule "the past is the key to the future". This means we can look at the conditions under which landslides have occurred in the past and use the critical combinations for predicting the possible occurrence of landslides where the same conditions prevail, but which are still landslide free.

Landslide prone environments are depicted by factors affecting the occurrence of landslides, such as; rock and soil types, slope angles and landuse etc. (Lee and Min, 2001). For the present study six prominent causative factors are considered for the landslide hazard zonation. These causative factors are i) slope material, iii) slope, iii) elevation, iv) landuse landcover v) groundwater and ii) aspect. The combination of these factors has resulted landslide with triggering factors like rainfall and seismicity in the present study area.

4.2 General Methodology

4.2.1 Pre field activities

The main important works during pre-field involves gathering secondary data from various sources. The secondary data needed and collected for the study includes, topographic map sheet of Debre Berhan with the scale of 1:50,000 and satellite images from Ethiopian Mapping Agency(EMA), Geological, Engineering geological and hydrological map sheet of Debre Berhan(NC37-11), Metrological data and DEM (Digital Elevation Model with 30m x30m resolution Source: Shuttle Radar Topography Mission (SRTM).

Furthermore, the literature review is mainly referred to develop the conceptual frame work about the landslides. This includes understanding on types, factors responsible for landslides and various approaches available for landslide hazard evaluation. As a result, a feasible methodology for the present study was adopted. Different factor maps also prepared based on the secondary data for analysis during field work.

4.2.2 Activities during field work

This field investigation and data collection was performed to obtain information about the past landslide activities and to verify various factor maps prepared during pre-field works.

By using GPS instrument past landslide inventory data was recorded along the border of active landslides. The locations of rivers, springs, streams and geological structures also collected by GPS (Geographical Position System) instruments.

4.2.3 Post Field (Data Processing, Analysis and Compilation)

The inventory map of landslide was prepared from the GPS recorded data using Arc GIS 10.1. Later, it is converted to polygon data by digitizing from satellite images with the help of aerial photos, delineation and creations base maps of the study area from topographic and Geological maps. Further, different factor maps were reclassified to be used for later analysis. All factor maps and inventory map were brought to GIS environment so that further processing can be done to evolve the landslide hazard map.

4.3 Detailed Methodology

In the present study bivariate statistical analysis approach is adopted. In this technique the contribution of each parameter class of causal factors was assessed independently with landslide distribution. This method is considered to determine the density of landslides in different parameter classes, relative to the landslide density over the entire research area. Further, using these density values derived from existing landslide distribution, the landslide susceptibility was predicted for landslide absence areas, by addition of the weights of individual parameter classes.

By using DEM (Digital Elevation Model with 30m x30m resolution Source: Shuttle Radar Topography Mission (SRTM), Aspect, Slope, and Elevation maps were prepared by using Arc GIS 10.1 software. The landuse landcover of the area is prepared by using satellite image, Google earth image and through field observations.

Slope material map was prepared by using lithological map and the soil map. Modifications were made during the field investigation. For each causative factor suitable sub-classes were formed. The groundwater surface traces map is performed from the springs and catchment based condition of the study area.

4.3.1 Causative factor influence on past Landslides

In order to evaluate the relative contribution of a subclass of each causative factor on past landslide, Landslide Susceptibility Index is calculated based on equation 4.1.

$$LSI = \frac{\boldsymbol{Landslide\%\ density}}{\mathbf{100}} \times LSV \quad \ldots\ldots \text{(eq.4.1)}$$

Where 'LSI' is the Landslide Susceptibility Index and 'LSV' is the Landslide susceptibility value which can be assigned to each of the factor, based on the relative importance of that factor in controlling the stability condition of the slope in the given area(Raghuvanshi et al., 2015).

According to Sarkar et al. (1995) Landslide % per km^2 indicates percent of landslide activities per km^2. Thus, they have considered the number of activities which may not account for area coverage of individual landslide activities. For the present study suitable modification as proposed by Raghuvanshi et al. (2015) was made for the LSI computation. In the present case LSI is computed by considering Landslide percentage which represents the ratio between "total pixel counts of a subclass within a Landslide" to the "total pixel count of that subclass in the area of study". The LSI values were calculated for each subclass of all six causative factors. In order to calculate the LSI the first step was to know the total pixel count for the area in which landslides occurred and the total pixel count for each subclass within the landslide area. For this the Raster calculator tool of Spatial Analyst tool in Arc GIS was used.

The distribution of LSV values to respective causative factor class is on a scale of 100 and are assigned based on the relative contribution in inducing instability to the slope. The judgment of general terrain evaluation and information from past landslide activities formed the basis to assign the LSV values to respective causative factor class. The highest value of LSV was in slope material. In the causative factor of slope material there is discontinuity that vulnerable for slope instability. In addition to this the slope material is more sensitive for past landslide. For example during rainy season it simply falls as the local people gave information. On the other hand, the aspect, landuse landcover and groundwater have equal Landslide Susceptibility value as it shows insignificant variation. However, the least causative factors of the present study is Aspect that is assigned based on weight and relative contribution in inducing instability. Table 4.1 presents the LSV values assigned to respective causative factor class.

Table 4. 1 LSV Value given for the different factors

S.No	Factors	LSV Value
1	Slope material	30
2	Slope	20
3	Elevation	20
4	Landuse landcover	10
5	Ground water surface traces	10
6	Aspect	10

For slope material landslide susceptibility value (LSV) is given a maximum value of 30. This indicates the slope material is the most prominent causative factor as compared to other factors. The past landslide occurred for subclasses of slope material had dominant distribution; 40% of past landslide occurred in Sela Dengay-Debre Berhan-Gorgo ignimbrite, 30% in colluvial soil and 26% in Kesem basalt. Therefore, it implies that slope material is the most causative factor in inducing instability to slopes. Slope factor was assigned as the second highest LSV value of 20 similar to elevation. The LSV value for landuse landcover, groundwater surface traces and aspect was assigned as 10.

4.3.1.1 Causative factors classification

As already mentioned above, in the present study area six causative factors namely; slope material, slope, elevation, landuse landcover, groundwater surface traces and aspect were computed.

Reclassification of each causative factor class was done to evolve various feasible subclasses within each causative factor. The Spatial analyst tool of Arc GIS was utilized to reclassify the data for the desired subclasses within each causative factor class. Reclassification allows specific variables to be combined within one class. Table 4.2 show the data sources for causative factors of the present study.

Table 4. 2 Causative factors and their respective data sources

Causative Factors	Sources
Slope material with structures	Geological map of Debre Berhan (NC 37-11) with 1:250,000 and soil map of (FAO) with suitable modifications made in field with visual observations.
Slope	DEM 30m x 30m
Elevation	DEM 30m x 30m
Landuse Landcover	Land Sat7with 30m x 30m and field observations
Groundwater surface traces	GPS location recorded during Field investigations
Aspect	DEM 30m x 30m

From Geological map of Debre Berhan (NC-37-11) with the scale of 1:250,000 and soil map from FAO with suitable modification and field observation is used to delineate and map slope material. This vector map was converted to raster by using vector to raster conversion tool in Arc GIS for raster calculation. As a result, from raster calculation total pixel count was calculated for each subclass within past landslide area and within the total study area.

The geomorphic factors like Slope, Aspect and Elevation were generated from DEM with 30m resolution by using Arc GIS software of extension Spatial Analyst tool. After classification of Slope, Aspect and Elevation; later they reclassified into the desired classes.

The landuse landcover map of the study area is prepared after visualization of satellite images of 1986, 2000, 2011 and 2013 with resolution of 30m x 30m. ERDAS IMAGINE 2014 software is used for the classification of landuse landcover. There was insignificant variation of landuse as observed from satellite images of 1986, 2000, 2011 and 2013; therefore for classification purpose of the present study satellite image of 2013 was utilized by comparing Google earth image and field observation.

Information gathered for springs, exist in the study area was utilized for Groundwater surface trace factor maps. By considering the location of these springs in the study area; three hydro-logical classes were identified. These are: Flow, Wet and Dry traces which cover $16km^2$, $13km^2$ and $9km^2$, of the study area respectively.

In flow traces the perennial springs are very common whereas in wet traces indicate more intermittent springs. However in dry traces the groundwater is low with correlation of landslide occurrence. Finally, the total pixel count was deduced for each subclass within past landslide area and within the total study area.

4.3.1.2 Landslide Susceptibility Index (LSI) Computation

Landslide Susceptibility Index (LSI) value was computed for six causative factors in the present study. For LSI landslide percentage which represents the ratio between "total pixel counts of a subclass within a Landslide" to the "total pixel count of a subclass in the area of study" was computed for each subclass of all six causative factors. Later, this landslide percentage was multiplied with the respective LSV values of the class (Table 4.1) and the resulting value was divided by 100 to get the LSI values. The sum of total weight assigned to each factor has to be equal to 100. For the present case percentage weight assigned to each causative factor was considered equal to LSV value (Table 4.1) which was utilized for the computation of LSI values.

Further, by using the weighted sum in the Overlay tool, found in the spatial Analyst tool in the Arc toolbox, final weighted sum raster was generated. At this stage all LSV Values were assigned to the factor maps in the weighted raster.

Finally, the final weighted sum raster was separated into Five Distinct Hazard Classes using manual breaks, based on judgment and terrain condition. These are very high hazard, high hazard, moderate hazard, low hazard and very low hazard. Table 4.3 represents the computed LSI values for each subclass of all causative factors.

Table 4. 3 Landslide Susceptibility Index (LSI) for causative factor subclasses

Causative Factor Class	Subclass	Pixel count of Subclass in total area	Pixel count of subclass within landslide area	Landslide percentage within subclass	Landslide Susceptibility Index (LSI)
Slope material	Kesem basalt	17066	195	1.143	0.343
	Sela Dengay-Debre Berhan-Gorgo ignimbrite	17931	305	1.701	0.510
	Tarmaber-Megezez basalt	840	0	0.000	0.000
	Alluvium soil	2746	5	0.182	0.055
	Colluvial Soil	2190	28	1.279	0.384
Slope	$0^0 - 5^0$	8457	7	0.083	0.017
	$5^0 - 12^0$	8822	65	0.737	0.147
	$12^0 - 30^0$	19443	344	1.769	0.354
	$30^0 – 45^0$	3932	117	2.976	0.595
	$>45^0$	119	0	0.000	0.000
Aspect	Flat	42	0	0.000	0.000
	North	488	0	0.000	0.000
	Northeast	2874	39	1.357	0.136
	East	9070	158	1.742	0.174
	Southeast	10661	105	0.985	0.098
	South	5955	30	0.504	0.050
	Southwest	5660	91	1.608	0.161
	West	4664	109	2.337	0.234
	Northwest	1092	1	0.092	0.009
	North	267	0	0.000	0.000
Elevation	1820m - 1973m	5078	7	0.138	0.028
	1974m - 2127m	7462	54	0.724	0.145
	2128m - 2281m	8252	193	2.339	0.468
	2282m- 2435m	6709	236	3.518	0.704
	2436m - 2589m	13272	43	0.324	0.065
Landuse/ Landcover	Settlement	4997	35	0.700	0.070
	Bush land	6166	34	0.551	0.060
	Water body	663	0	0.000	0.000
	Bare land	7223	107	1.481	0.150
	Grazing land	6600	38	0.576	0.060
	Cultivated land	15124	319	2.109	0.210
Groundwater Surface traces	Dry	9515	0	0.000	0.000
	Wet	13488	206	1.527	0.153
	Flow	17770	327	1.840	0.184

4.3.1.3 Methodology of the landslide Hazard Mapping and Geo-processing

For the present study, map data were selected based on prominent causative factors and availability of factors that were readily available to be utilized for the development of landslide hazard map. The relationship between the landslide and contributing factors were statistically analyzed. The weight of landslide density is calculated for all causative factors based on equation 4.2.

$$\ln W_i = \ln\left(\frac{\text{DensClass}}{\text{DensMap}}\right) = \ln\left[\frac{\frac{\text{Npix (Si)}}{\text{Npix (Ni)}}}{\frac{\sum \text{Npix (Si)}}{\sum \text{Npix (Ni)}}}\right] \ldots\ldots\ldots \text{(eq.4.2)}$$

Where,

$\boldsymbol{W_i}$: − Is the weight given to a certain parameter class

$\boldsymbol{DensClass}$: − The landslide density within the parameter class

$\boldsymbol{DensMap}$: − The landslide density within the entire map

$\boldsymbol{Npix(Si)}$: − Number of pixels, which contain landslides, in a certain parameter class

$\boldsymbol{Npix(Ni)}$: − Total number of pixels in a certain parameter class

The causative factors were compared separately and the importance of each factor was determined independently over the other factors. The technique is based on the assumption that the important causative factors leading to landslide (Van Westen and Terlien, 1996).

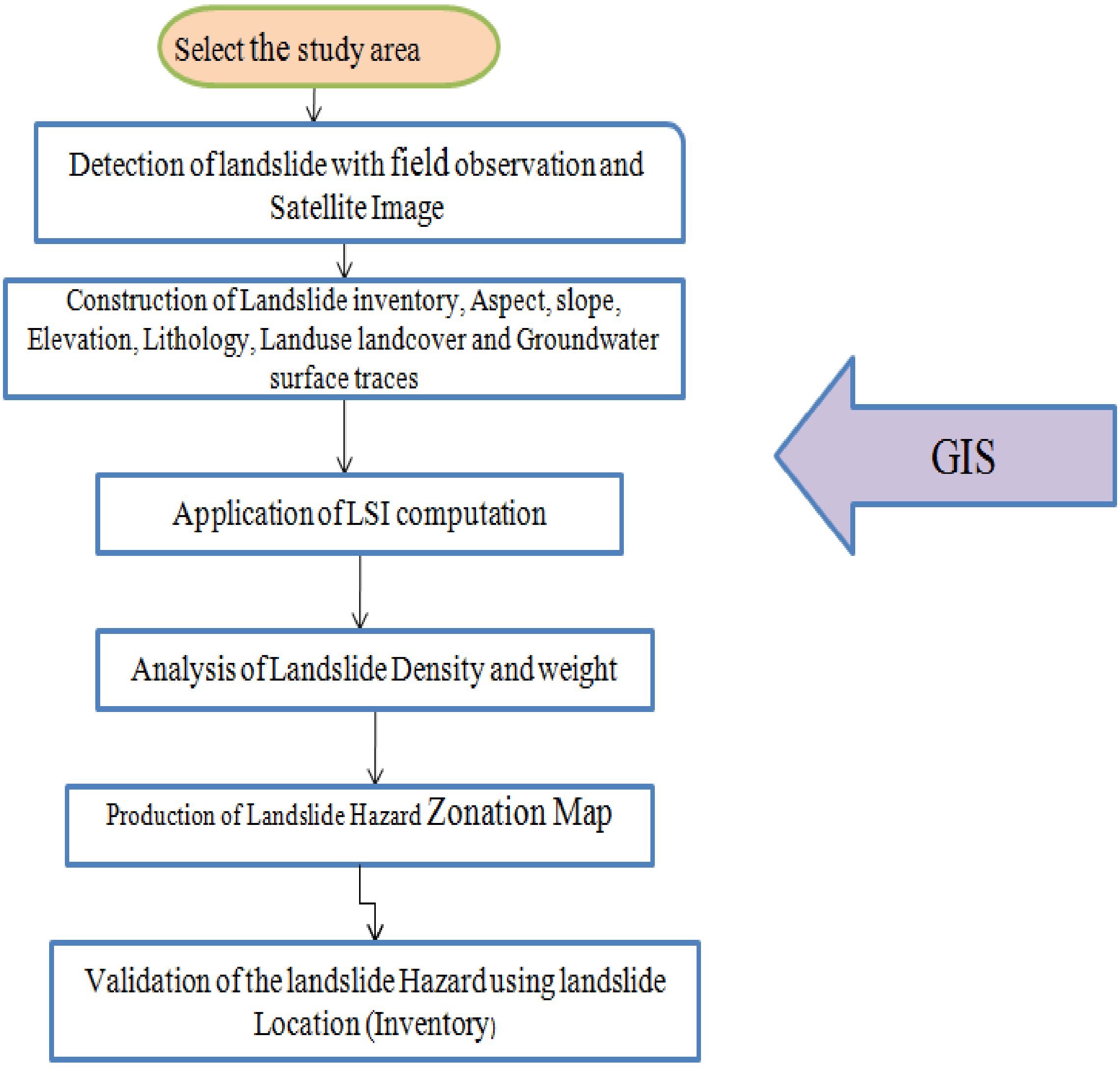
Based on GIS approach the causative factors considered for LHZ map preparation were utilized in the analysis. Thus, the factor maps which were utilized are; slope material, slope, aspect, elevation, groundwater and landuse landcover.

The factor maps which were derived from the DEM Data are; Slope, Aspect and Elevation. These factor maps and landuse landcover maps can automatically be derived into the software. Further, the ‘slope material’ and the ‘Groundwater surface traces’ maps were digitized as vector data. These maps were having different subclasses (as shown in Table 4.3), therefore, as a part of data processing, the subclasses within slope material map and Groundwater surface trace map have to be merged to get the processed vector maps. Later, these vector maps were converted to raster by using conversion tool within spatial analyst tool. Such conversion of vector into raster is a prerequisite for further analysis. Thus, by using the reclassify tool in the spatial analyst tool box all the factor maps were reclassified.

The process entailed combining all six raster data set; slope material, slope, elevation, landuse landcover , groundwater and aspect. The weighted raster also stipulate that each factor raster file be assigned with a percentage weight. This is to give the relative importance of each causative factor in inducing instability of slope. Further, by using the weighted sum in the Overlay tool, found in the spatial Analyst tool in the Arc toolbox, final weighted sum raster was generated. Finally, the final weighted sum raster was separated into Five Distinct Hazard Classes using manual breaks, based on judgment and terrain condition.

In order to verify the past landslide of the study area for hazard classes the inventory data of landslide was overlaid on hazard classes. The percentage of past landslide should be greater than 80% to validate the hazard zonation of the study area that fall on High hazard and Very high hazard zones. Therefore the output (finding) the present study is discussed in chapter six.

Flow chart for Landslide Hazard Zonation in the present study area is presented as below.



CHAPTER FIVE LANDSLIDE HAZARD EVALUATION

5.1 Introduction

The landslide hazard zonation map in short called LHZ map is a rapid technique of hazard assessment of the land surface for slope stability condition over large area (Anbalagan, 1996). Based on an estimated significance of causative factors in inducing instability a landslide hazard zonation map divides the land surface into zones of varying degrees of stability and helps in delineating unstable hazard prone areas.

A landslide hazard zonation is a division of the land surface into areas and the relative ranking of these areas according to degrees of actual or potential hazard from landslides on slopes (Varnes, 1984). This is a method to evaluate the risk where there is the potential for landslides. It is an important tool for designers, field engineers and geologists to classify the land surface into zones of varying degree of hazards based on the estimated significance of causative factors which influence the stability (Anbalagan, 1992).

Slope stability problems can be face on mountainous terrain and along unstable formations due to the developmental activities such as buildings and road construction. These slope stability problems have resulted into damage to engineering structures, agricultural land and also to loss of human life and their properties. Identification of such slope instability problem in the initial stage of planning and investigation may lead to evolve possible remedial measures which may either be adopted to improve the slope stability or such problematic slopes may be avoided if identified during initial planning stage (Anbalagan, 1996)

However, due to constraints of time and financial limitations systematic analytical slope stability analysis are often neglected or carried out too quickly without proper geological or geotechnical inputs. Such inadequate analysis often resulted into slope failures affecting the safe performance of the engineering structures. In order to understand and estimate the landslide hazard in a given area first know that what has happened in past, types of landslides occurred, with what mechanism the landslides were triggered, types of inherent causative factors were involved, what were the possible triggering factors and etc. Much of such information may be gathered by preparing inventory mapping and by investigating the past landslides (Anbalagan and Singh, 1996).

5.2 Inventory of Landslides in the study area

The landslide inventory data for the present study area was collected from engineering geological map of the Debre-Berhan area (Tutan Negash and Ferdawek Legesse, 2014) with modification of scale 1:50,000. In addition to engineering geological map of the study area additional information and data from North Showa Zone Land Administration Office, Alaltu district Disaster Prevention Preparedness office, kebele administration and information from local people were used to prepare landslide inventory map. Furthermore, to verify and validate the data gathered the locations of the landslides in the study area were identified during field investigation with the help of local people and using GPS instrument.

Inventory data of the present study was verified and identified during field investigation using GPS instrument. As a part of this inventory data pertaining to the location, type of failure, material involved in the landslide were collected and presented as in (Annex 3). During field investigation GPS locations were collected along the periphery of landslides wherever it was approachable. By using Arc Map of GIS the collected data locations are converted as a layer for analysis. In addition to this the Spatial Analyst tool was used to convert for analyzes the collected data on Google Earth. Later, with the help of Google earth image polygon data was created to show the boundaries of past landslides. The minimum width measured (estimated) for past landslides was 18m while maximum width was about 123m. Similarly, the minimum length measured (estimated) for past landslides was 25m whereas the maximum was about 105m. The landslide inventory map is presented as (Fig.5.1).

Landslide inventory maps show locations and characteristics of landslides that have moved in the past; however evaluations do not indicate the mechanism(s) that triggered them. The geologic, terrain and climatic conditions that has led to the past slope failures often provide clues to the locations and conditions of future slope failures. Therefore, inventory maps provide useful information about the potential for future landslides. In addition, recognizing the type of landslides can also facilitate the scope and design of site specific geotechnical investigations and guide slope remediation strategies.

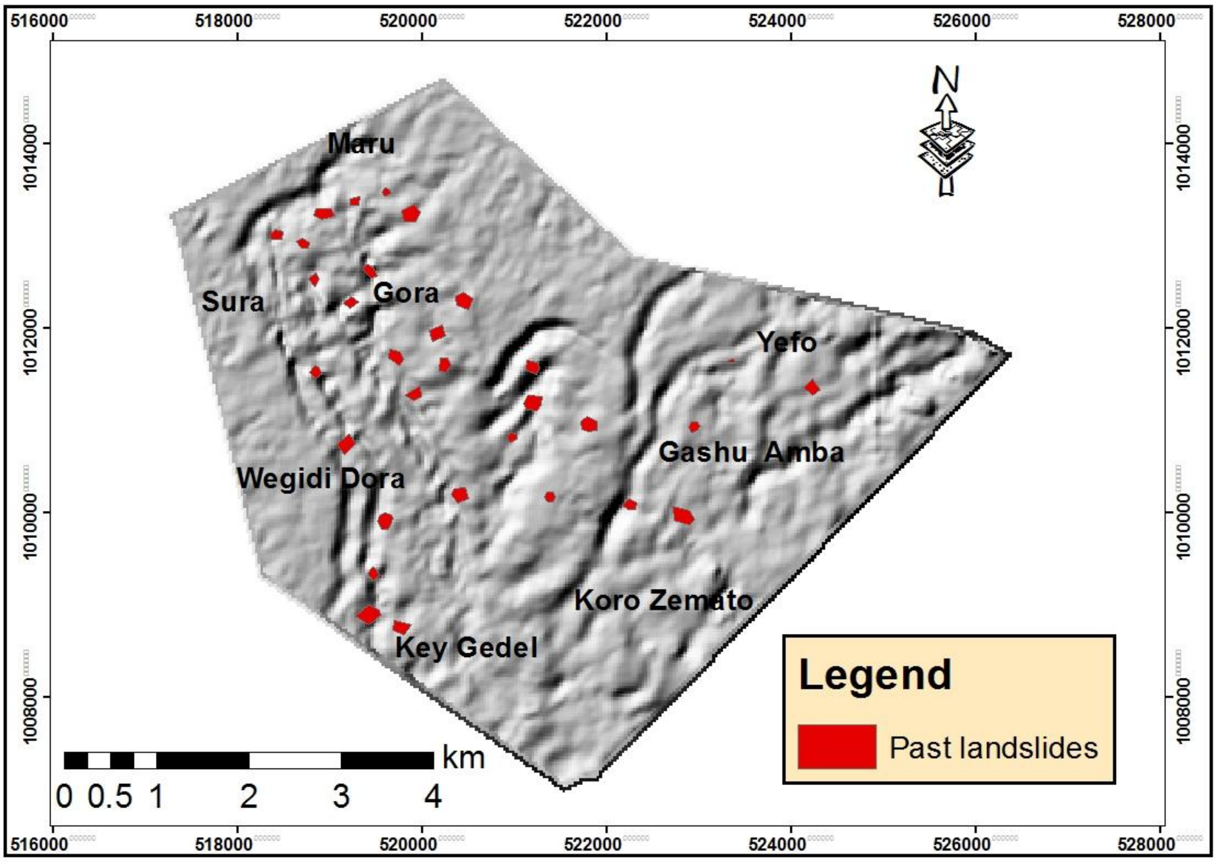


Fig.5. 1 Landslide Inventory map of the study area

5.2.1 Types of Landslides and Mode of failures in the study area

As listed in the (Annex 3) in the present study area there are three types of landslide mode of failures. These modes of failure include fall, Rotational landslides and translational landslides as observed during field investigation.

Fall

Falls are abrupt movements of masses of geological materials that become detached from steep slopes or cliffs. Movement occurs by free-fall, bouncing and rolling. Depending on the type of earth materials involved, the result is rock fall, soil fall, debris fall, earth fall and boulder fall. All types of falls are promoted by undercutting, differential weathering, excavation or stream erosion. In the present study area 'fall' mode of failure was observed mostly in steep slope formed by basalt and ignimbrite. Plate 5.1 and Plate 5.2 show the fall mode of failure in the study area.

Plate 5. 1 Fall of Kesem basalt in the Study area

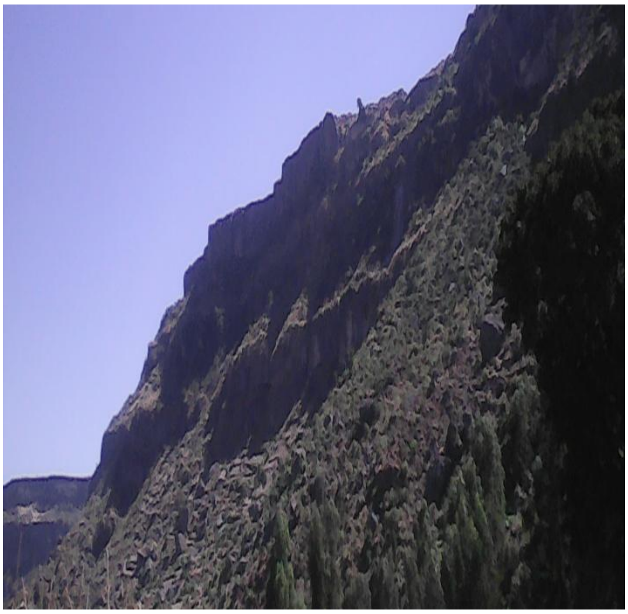


Plate 5. 2 Fall of Ignimbrite lithology

Slide

A slide is a down slope movement of a soil or rock mass occurring on surfaces of rupture or on relatively thin zones of intense shear strain. Movement does not initially occur simultaneously over the whole of what eventually becomes the surface of rupture; the volume of displacing material enlarges from an area of local failure. These slides are generally slow moving and can be deep. Slow moving landslides can occur on relatively gentle slopes and can cause significant property damage, but are far less likely to result in serious injuries than rapidly moving landslides (Varnes, 1996). Slides can be classified into rotational slides and translational slide based on types of movement.

Rotational Landslide

A landslide on which the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope (plate 5.3).

The displaced mass may, under certain circumstances, move as a relatively coherent mass along the rupture surface with little internal deformation.

Plate 5. 3 Rotational mode of failure

The head of the displaced material may move almost vertically downward, and the upper surface of the displaced material may tilt backwards toward the scarp. If the slide is rotational and has several parallel curved planes of movement it is called a slump. In the present study area rotational mode of failure was located in gentle slope and moderately gentle slope as observed in (Plate5.3).

Translational Landslide

The mass in a translational landslide moves out or down, outwards along a relatively planar surface with little rotational movement or backward tilting. This type of slide may progress over considerable distances if the surface of rupture is sufficiently inclined, in contrast to rotational slides, which tend to restore the slide equilibrium. The material in the slide may range from loose, unconsolidated soils to extensive slabs of rock or both. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil. In the present study area translational mode of failure occurred mostly in the colluvium soils where the geomorphology is moderately gentle slope and moderately gentle slope (plate 5.4).

Plate 5. 4 Translational Mode of Failure

5.2.2 Triggering Factors of Landslides

Rainfall and earthquakes is the major landslide triggering factors in the world. Their relationship to the occurrence of landslides can be well addressed when there is a longtime records series of the events. In the present study area both rainfall and seismicity are considered as initiation of landslide.

Rainfall

The frequency and magnitude of rainfall events, together with other factors such as lithology, morphology and landcover, influence on the landslide occurrence. Rainfall has been considered as one of the most frequent triggering factors to natural slope failures. Triggering by rainfall can be defined as a decrease in shear strength due to an increase in pore water pressure on the potential failure surface which finally results in a slope failure (Terlien, 1998).

Keefer (2002) described a real time landslide warning system based primarily on the precipitation intensity duration thresholds developed with consideration also given to seasonal antecedent precipitation. Rainfall intensity duration threshold based methods are empirically developed using previous records for a given region. It has long been recognized that field hydrological and geo-mechanical characteristics are the key elements controlling the stability of a slope under the influence of rainfall.

In the present study area the main triggering factor for the past landslide was heavy rainfall as information gathered from local peoples. In 2007 year in August month after heavy rainfall the failure of land was witnessed by dweller person. At that time there was damage on property such as house, livestock, crops and disappearing of springs that they used for potable. As it continued the 129 people removed from their settlement due to landslide failures (information gathered from settlers and based on rainfall data).

In order to understand the influence of rainfall on this landslide, rainfall data was collected and analyzed. From the data obtained from the metrological agency, the highest rainfall was recorded in the nearest station (Debre-Berhan) with the annual rainfall of 1083.5mm in the year 2007 (Refer Annex 2). Further, for the year 2007 the monthly rainfall data was also analyzed. Analysis showed that the highest average monthly precipitation was in the month of July with average precipitation of 339.1mm (Refer Annex 1).

The precipitation for the month of July as compared to the preceding 15 years of rainfall records was the highest, which affirms the possible cause for the landslide. The above mentioned landslide has actually occurred in end of August and at the beginning of September. As a result, the groundwater by this time must have fully recharged due to the heavy rainfall of July. Thus, it develops destructive driving forces for the failure to occur. Therefore, the heavy rainfall was the main triggering factor for the inventory data of past landslides occurrence validates with the actual rainfall data.

Seismicity

Seismicity can affect the stability of a slope in two ways: earthquake and blasting. These seismic motions are capable of inducing large destabilizing inertial forces. Rock falls, disrupted rock slides and disrupted slides of earth and debris are the most abundant types of earthquake induced landslides, whereas earth flows, debris flows, and avalanches of rock, earth, or debris typically transport material the farthest. There is one type of landslide that is typical for earthquakes, i.e. liquefaction failure which can cause fissuring or subsidence of the ground. Liquefaction involves the temporary loss of strength of sands and silts which behave as viscous fluids rather than as soils. This can have devastating effects during large earthquakes.

For the present study area there is no data recorded regarding to seismicity. However, based on seismic zones of Ethiopia, the estimated horizontal earthquake acceleration comes out to be 0.2g as determined from the Modified Mercali (MM) intensity scale graph (Johnson and Degraff, 1988) (refer Fig.1.6 in chapter 1).

5.2.3 Causative Factors

The causes of landslides are usually related to instabilities in slopes. Causes may be considered to be factors that made the slope vulnerable to failure, that predispose the slope to becoming unstable. The trigger is the single event that finally initiated the landslide. Thus, causes combine to make a slope vulnerable to failure and the trigger finally initiates the movement. The causative factors of landslide in the present study area considered are slope factor, aspect factor, elevation, slope material (geological factors), landuse landcover and Groundwater condition. For each of these causative factors the brief description is presented as below.

Slope factor

The slope is an important factor with regard to landslide initiation. In most studies of landslides, the slope steepness is taken into account as the major causative factor of landslide that means if the slope is steep, there will be an increment in shear stress and the tangential component of the weight of the mass while the perpendicular component of weight will decrease.

Therefore, when the shear stress increases more than the resisting forces the slope mass will acquire tendency to slide down the slope (Shimelis Ahmed, 2009). Thus, more steeper the slope, tendency for failure will be more provided other instability contributing factors also favor sliding. With this consideration, slope of the study area has been prepared from the DEM with resolution 30m x 30m (Source: SRTM) using the Arc GIS10.1.

The minimum slope angle as deduced was 0° along the flat sections while the maximum slope 50.8° was observed for the steep slope. For the present study slope was categorized into five classes; very gentle slope (0-5°) which covers 8km^2 (20%) of the study area, gentle slope (5-12°) cover 8km^2 (21%) of the study area, moderately gentle slope (12-30°) covers 18km^2(48%), steep slope (30-45°) covers 3.6km^2 (10%) and very steep slope (>45°) covers 0.4km^2 (1%) of the study area. The raster computation results indicate that 54% of the landslides occurred in the slope class of (30^0 to 45^0).

As observed, lower the slope angle lower is the frequency of the landslides and increases as the slope angle increases. This indicates the chance of failure increases as it becomes escarpment. Besides, almost 86% of the landslide occurred within a slope angle range of greater than 12^{0}and remaining 14% were below 12^0(refer Table5.1) and (Fig. 5.2).

Table 5. 1 Area coverage with various slope classes and percentage of past landslides occurred within a subclass

No.	Slope Factor Class	Pixel count of Subclass in total area	Pixel count of subclass within landslide area	Landslide percentage within subclass	Percentage of Landslide Occurred (%)
1	0^0 - 5^0	8457	7	0.08	1
2	5^0 - 12^0	8822	65	0.74	13
3	12^0 - 30^0	19443	344	1.77	32
4	30^0 – 45^0	3932	117	2.98	54
5	>45^0	119	0	0.00	0
Total		40773	533	5.56	100

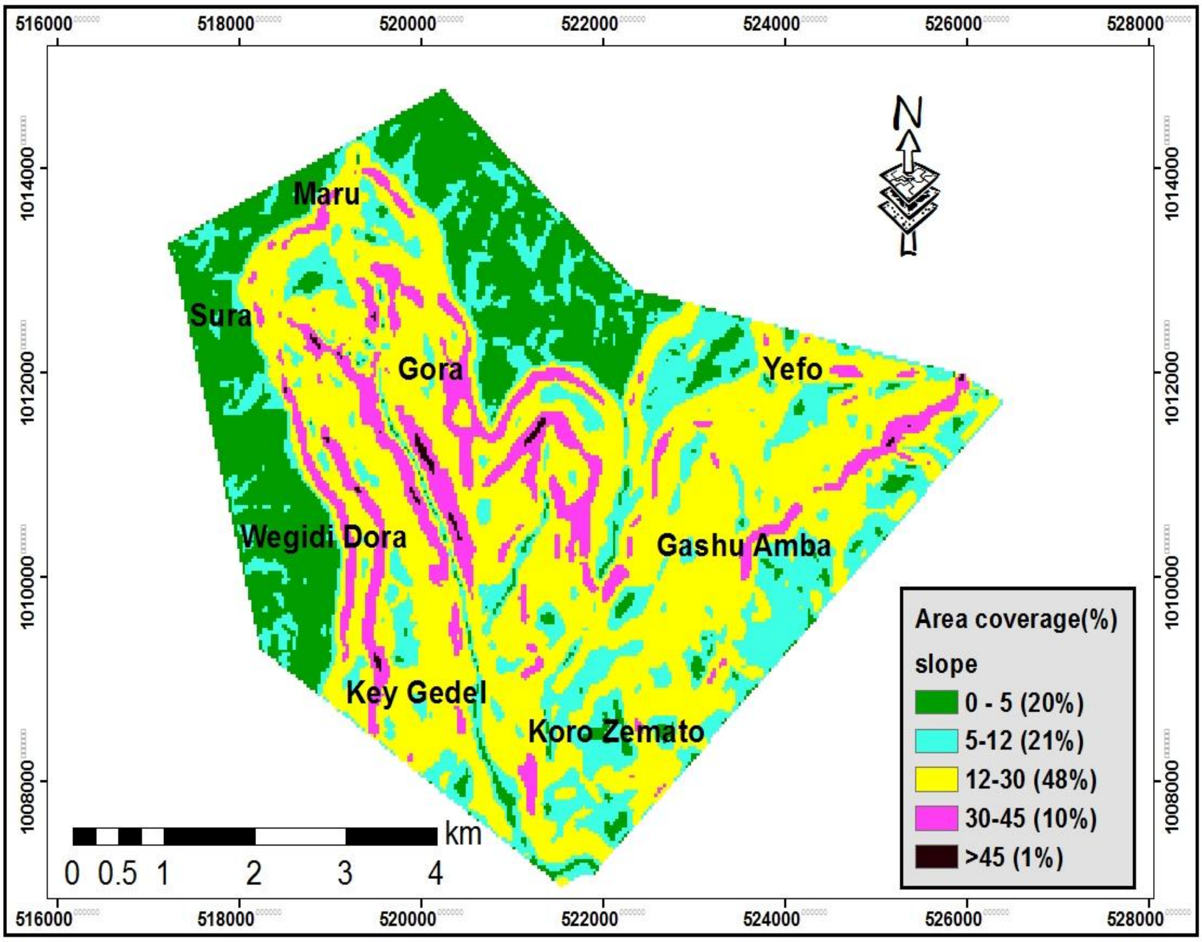


Fig.5. 2 Slope Factor map of the study area

Aspect factor

The aspect factor map of the study area was derived from the DEM of the study area with the resolution of 30m x 30m. During mapping the aspect was grouped into ten main direction of slope facing classes Flat(-1°), North (0°-22.5°), Northeast (22.5°-67.5°), East (67.5°-112.5°), Southeast (112.5°-157.5°), South (157.5°-202.5°), Southwest (202.5°-247.5°), West (247.5°-292.5°), Northwest (292.5°-337.5°) and North (337.5°-360°).

The total area coverage and their percentage in the study area is; 0.04km^2 (0.1%), 0.5km^2(1%), 3km^2(7%), 9km^2(22%), 10km^2(26%), 5.21km^2(15%), 5km^2(13.9%), 4km^2 (11%), 1km^2(3%) and 0.25km^2(1%), respectively.

The results indicate that 27% of the landslide occurred along the West (247.5°-292.5°) facing slopes and 20% were towards East (67.5°-112.5°) facing while 19% Southwest (202.5°-247.5°) facing. This shows that slopes facing to the West (247.5°-292.5°), East (67.5°-112.5°) and Southwest (202.5°-247.5°) have more relationship with landslides.
The landslide which occurred along Northwest (292.5°-337.5°), South (157.5°-202.5°) and Southeastern (112.5°-157.5°) facing slopes account to 1%, 6% and 11%, respectively with having less impact for the slope failure of the area.

Mainly, the slope aspect is related to the general physiographic trend of the area and/or the main precipitation direction. Slope aspect can influence the distribution and density of landslides by controlling the concentration of soil moisture (Wieczorek et al., 1997) or the orientation of tectonic fractures. Refer (Fig.5.3) and (Table 5.2) about the aspect factor of the present study.

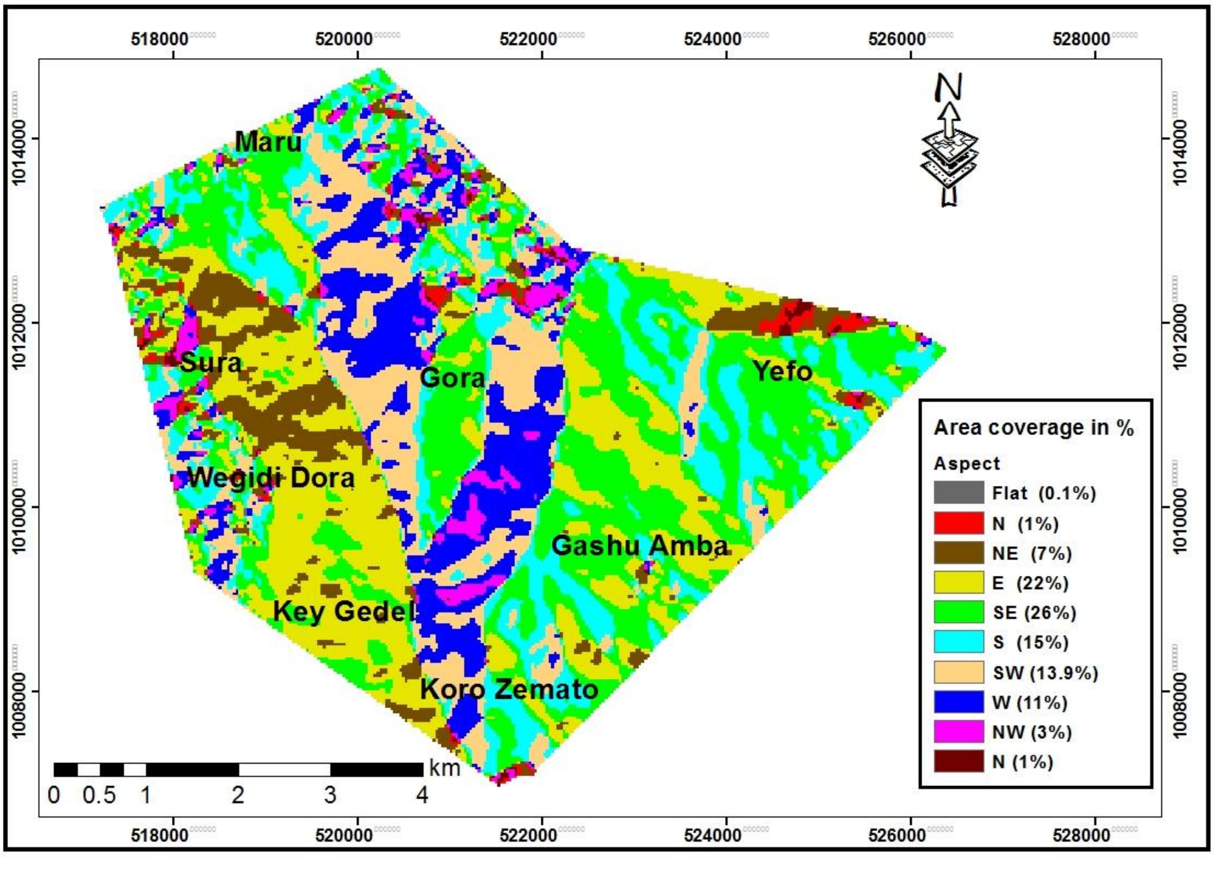


Fig.5. 3 Aspect factor map of the study area

Table 5. 2 Area coverage with various Aspect class and percentage of landslide occurred within a subclass

No.	Aspect factor Class	Pixel count of Sub class in total area	Pixel count of subclass within landslide area	Landslide percentage within subclass	Percentage of Landslide Occurred (%)
1	Flat(-1°)	42	0	0.00	0
2	North(0°-22.5°)	488	0	0.00	0
3	Northeast(22.5°-67.5°)	2874	39	1.36	16
4	East(67.5°-112.5°)	9070	158	1.74	20
5	Southeast(112.5°-157.5°)	10661	105	0.98	11
6	South(157.5°-202.5°)	5955	30	0.50	6
7	Southwest(202.5°-247.5°)	5660	91	1.61	19
8	West(247.5°-292.5°)	4664	109	2.34	27
9	Northwest(292.5°-337.5°)	1092	1	0.09	1
10	North(337.5°-360°)	267	0	0.00	0
Total		40773	533	8.62	100

Elevation

Elevation is one of the factors that can cause landslides. The role of elevation in inducing instability of slope can be related by indirect measures. The influence of elevation may be attributed in terms of degree of weathering, variation in humidity, rate of hydrate reaction, erosion process and depth of weathering. Therefore, elevation is considered as one of the causative factor for controlling landslide process (Shimelis Ahmed, 2009).

The elevation map of the study area was obtained from DEM with resolution 30m x30m by using Arc GIS. The elevation map of the study area was categorized into 5 class ranges. The minimum elevation is 1820m, while the maximum is 2589m. The classified elevation for landslide analysis were (1820m - 1973m) which covers 5km^2 (12%) of the study area, (1974m - 2127m) covers 7km^2(18%), (2128m-2281m) covers 8km^2(20%), (2282m-2435m) covers 6km^2(17%) and (2436m -2589m) covers 12km^2 (33%) of the study area.

From the results obtained by raster calculation 50% of the landslide occurred in the elevation class of (2282m - 2435m) while 33% within (2128m - 2281m) class. However, 2% of the landslides occurred within the elevation class of 1820m - 1973m. When the elevation decreases the landslide distribution in the study area also decreases. Especially for class (1974m - 2127m) and (1820m - 1973m) the landslide distribution percentage shows 10 % and 2%, respectively.

Furthermore, the elevation range 2436m - 2589m shows the lower distribution of landslides and the reason is that at this elevation range the landscapes of topography become flatten. The elevation classes are described in (Table 5.3 and Fig.5.4).

Table 5. 3 Area coverage with various Elevation class and percentage of landslide occurred within a subclass

No.	Elevation (m) Class	Pixel count of Subclass in total area	Pixel count of subclass within landslide area	Landslide percentage within subclass	Percentage of Landslide Occurred (%)
1	1820m - 1973m	5078	7	0.14	2
2	1974m - 2127m	7462	54	0.72	10
3	2128m - 2281m	8252	193	2.34	33
4	2282m- 2435m	6709	236	3.52	50
5	2436m - 2589m	13272	43	0.32	5
Total		40773	533	7.04	100

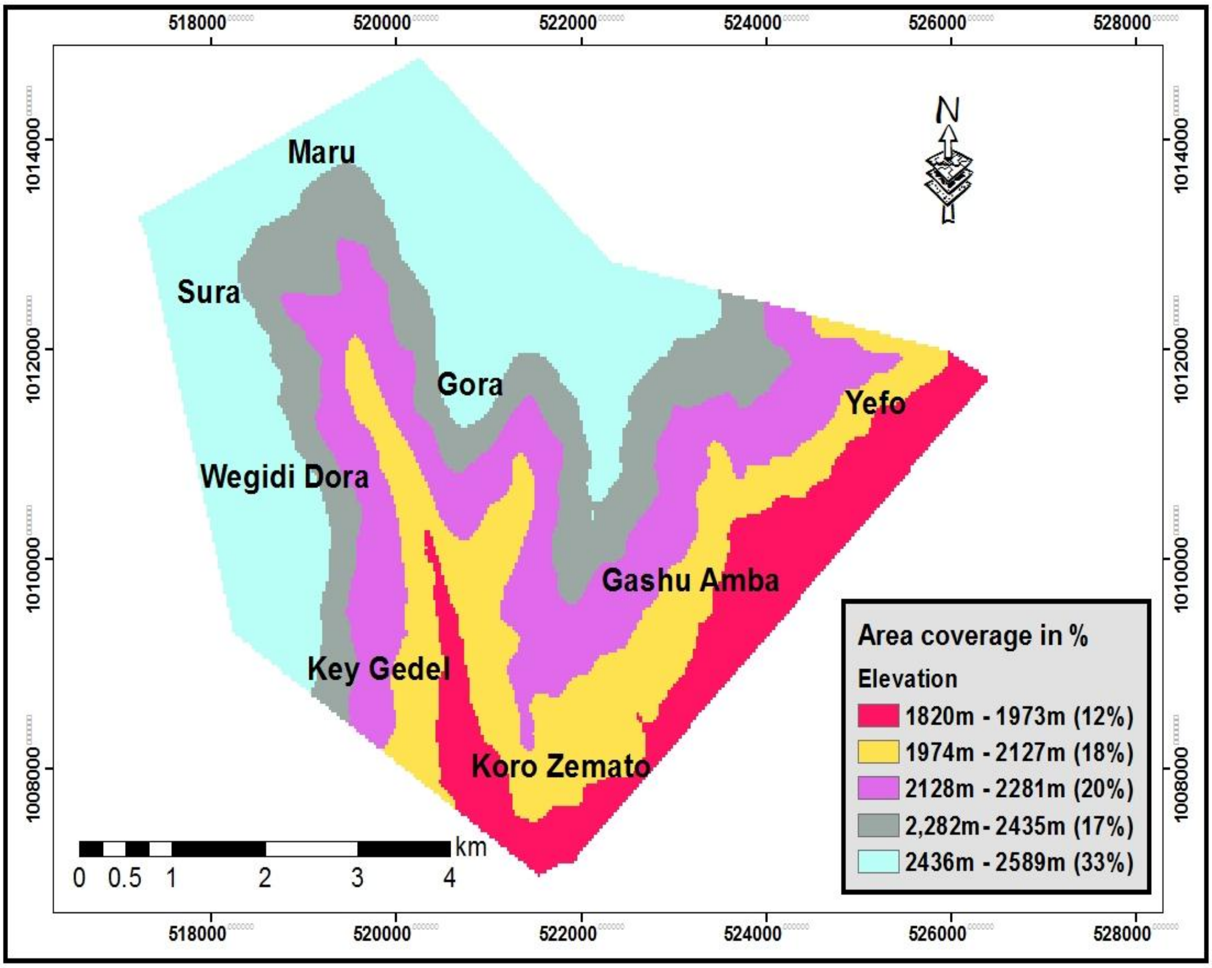


Fig.5. 4 Elevation map of the study area

Geological Factors

Landslide events are strongly controlled by the nature of the regolith material. The various mechanical properties influencing the stability of the slope such as; shear strength, unit weight and the water forces are entirely dependent on the rock formations and the type of soil that constitutes the slope.

Lithology

The lithology includes the composition, fabric, texture or other attributes that influence the physical or chemical behavior of rocks and soils. These attributes are very important in determining the shear strength, permeability, susceptibility to chemical and physical weathering, and other characteristics of soil and rock materials which in turn affect slope stability.

For the present study lithology and soil material deposits were considered as basic contributing factors. The exposed rock units in the study area are kesem basalt, Sela Dengay-Debre Berhan-Gorgo ignimbrite, Tarmaber-Megezez basalt, Alluvium Soil and Colluvium soil.
The quaternary deposit consists of colluvium material mainly with basalt fragments and alluvial deposits. Most of the landslides were observed within the Sela Dengay-Debre Berhan-Gorgo ignimbrite, colluvium soil and kesem basalt lithology.

The area coverage in square kilometers and their percentage for Kesem basalt, Sela Dengay Debre Berhan Gorgo ignimbrite, Tarmaber-Megezez basalt, Alluvium soil and Colluvium soil are:- 16(42%), 16.5(44%), 1(2%), 2.5(7%) and 2(5%), respectively.

The results, as calculated from the raster calculator, show that 40% of the landslides occurred in the Sela-Dengay-Gorgo ignimbrite while in Colluvium soil shows 30% of past landslide occurrence. This indicates that in ignimbrite there is more discontinuity that make susceptible for sliding or mass movement. Further, colluvium soil is formed by disintegration of weak geologic units; in the form of mass movements. The correlation of landslide occurrence in the Kesem basalt cover about 26%, which denotes that in Kesem lithology unit high vulnerability of landslides; since the occurrence of lineaments which enhance landslide is distributed in this formation. However, in Alluvium soil and Tarmaber-Megezez basalt the landslide occurrence is 4% and 0%, respectively. This relation shows that in alluvium soils there was very gentle slope morphology which has low magnitude of landslides.

In the Tarmaber-Megezez basalt the strength of rock unit is higher so it is more stable and not active for landslide occurrence in the study area. Table 5.4 and Fig.5.5 show the detail of slope material of the present study area.

Table 5. 4 Area coverage with various slope material classes and percentage of landslides occurred within a subclass

No.	Slope material Class	Pixel count of Subclass in total area	Pixel count of subclass within landslide area	Landslide percentage within subclass	Percentage of Landslide Occurred (%)
1	Kesem basalt	17066	195	1.14	26
2	Sela Dengay-Debre Berhan-Gorgo ignimbrite	17931	305	1.70	40
3	Tarmaber-Megezez basalt	840	0	0.00	0
4	Alluvium soil	2746	5	0.18	4
5	Colluvial Soil	2190	28	1.28	30
Total		40773	533	4.30	100

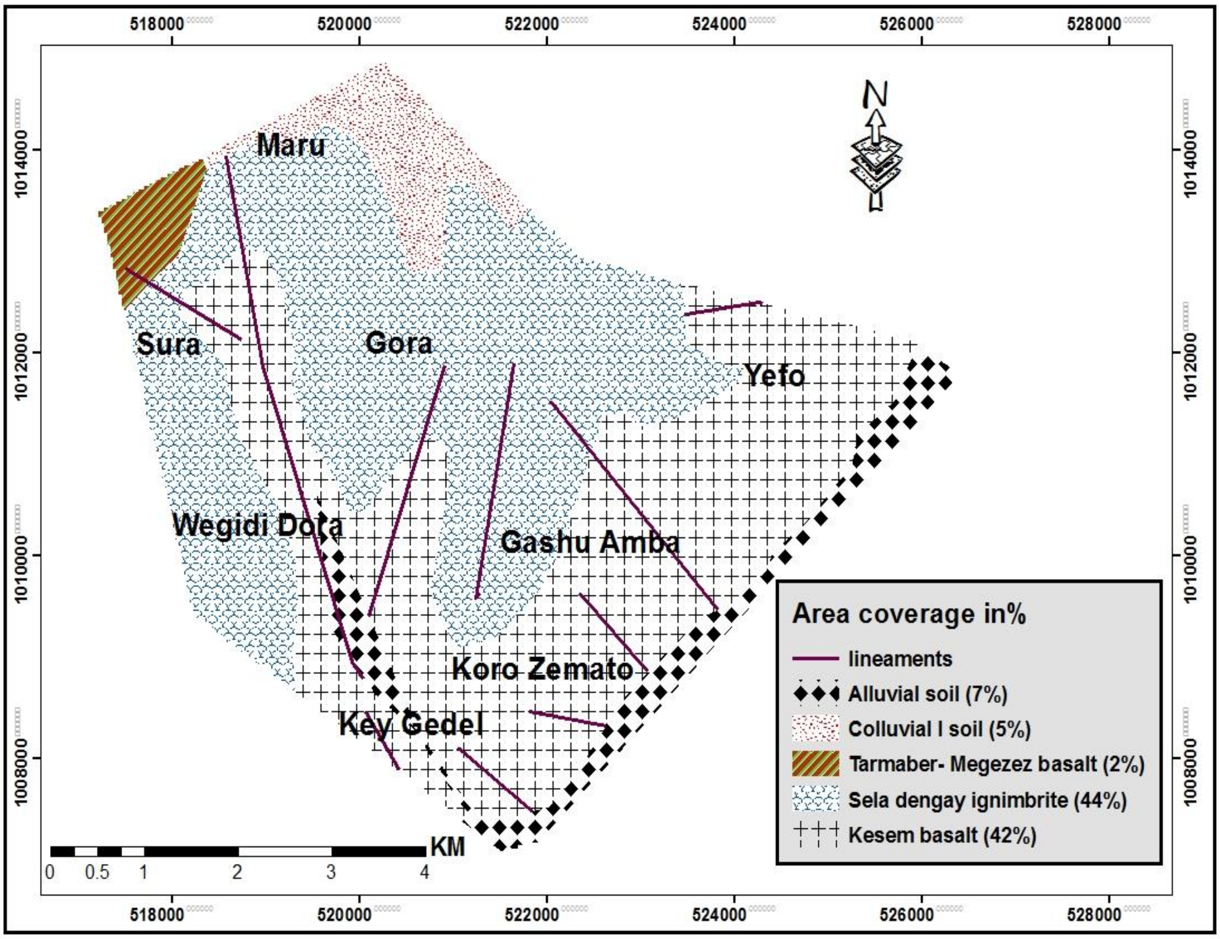


Fig.5. 5 Slope material map of the study area

Groundwater

The instability of the slope is influenced by surface as well as subsurface water. The rating for surface water was awarded on the basis of geomorphologic significance. The groundwater (subsurface water) is generally controlled by the structural condition of the bed rocks and manifested in the form of springs.

Water is the most important factor in most of the slope stability analysis. Pore water in soil can strongly influence the physical interaction among soil grains. Changes in pore pressures can directly impact the effective stresses, which in turn affect both the shear strength and consolidation behavior of soil (Tenalem Ayenew and Barbieri, 2004). Therefore, analysis of pore fluid seepage plays an important role in the solution of many geotechnical problems, especially those concerning the stability analysis of slopes and retaining structures. Therefore hydrology plays an important role in landslide initiation.

For the present study the locations of 13 springs were mapped during the field investigation and correlated with landslide occurrence failure probability (refer Table 3.1 in chapter three). The groundwater surface traces were classified into three; based on groundwater conditions or indicators such as dry, wet and flow. In addition to this the distribution of springs that characterized as perennial and intermittent was observed during field work to map groundwater surface traces as dry, wet and flow.

The result obtained from raster computation indicated that the probability of landslide occurrence was higher in flow with 55% whereas in wet traces 45%. The reason for high correlation of landslide occurrence in Flow and Wet is that the existence of perennial springs that shows shallow groundwater which induces slope instability. However, in Dry traces the probability of landslide occurrence correlation was low with percentage of 0%. This demonstrates that groundwater affects lower on landslide and the landslide occurrence also low and the intermittent springs are higher in Dry traces. The area coverage in square kilometers and the percentage for Flow, Wet and Dry is: 16(44%), 13(33%) and 9(23%), respectively.

Generally, many of the springs were emerged after the landslide and some of the springs were also disappeared after the landslide in the area as local peoples gave me on landslide affect information in the study area.

That means springs had the contribution for landslide to occur and the landslides itself had the effect to make disappear and at the same time to emerge new springs in the study area. Table 5.5 and Fig.5.6 shows the groundwater surface traces with landslide occurrences in the present study area

Table 5. 5 Groundwater Surface traces and percentage of landslide occurred within a subclass

No.	Groundwater Surface Trace Zones class	Pixel count of Sub class in total area	Pixel count of sub-class within landslide area	Landslide percentage within subclass	Percentage of Landslide Occurred (%)
1	Dry	9515	0	0.00	0
2	Wet	13488	206	1.53	45
3	Flow	17770	327	1.84	55
Total		40773	533	3.37	100

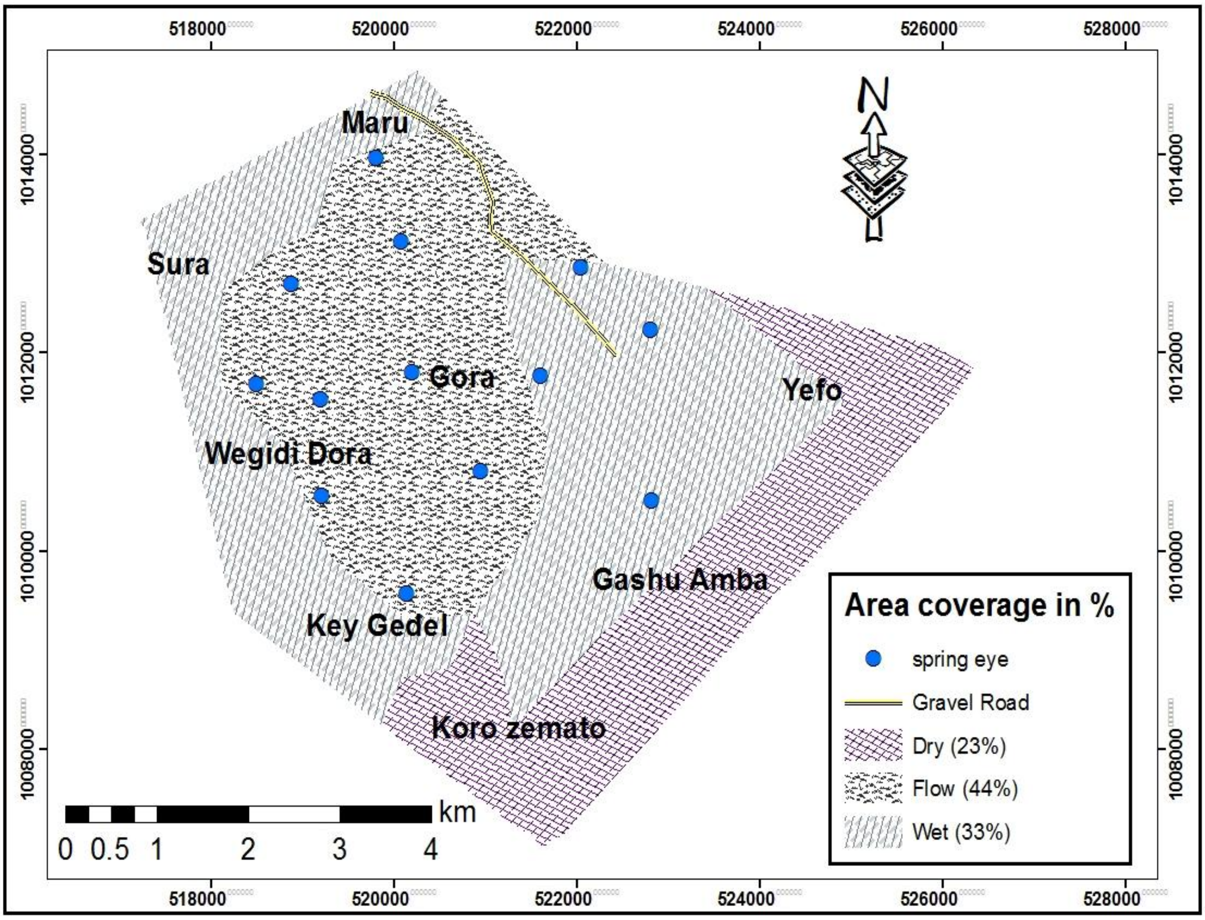


Fig.5. 6 Groundwater map of the study area

Landuse Landcover

The landuse landcover has an important bearing for landslide hazard zonation and mitigation measures. Landcover is an indirect indication of the stability of hill slopes. Barren and sparsely vegetated areas show faster erosion and greater instability as compared to reserve or protected forests, which are thickly vegetated and generally less prone to mass wasting or landslide processes. The vegetation cover has an influence on the hydrological process of relatively shallow potential landslide mass. Vegetation cover may intercept the precipitation, soil moisture reduction and may check hydraulic conductivity (Van Beek, 2002).

For the present study landuse landcover map was prepared from satellite image of (2013) by using ERDAS IMAGINE 2014 software. First the satellite image of the study area with 30m x 30m resolution of four different years:-1986, 2000, 2011 and 2013 was selected to compare the landcover of the study area. Finally, since the landcover variation was insignificant, satellite image of 2013 was assigned to perform landuse landcover of the present study area.

The area coverage in square kilometer and their percentage in bracket for settlement, bush land, water body, bare land, grazing land and cultivated land are:- 4.5(12%), 6(15%), 0.5(2%), 7(18%), 6(16%) and 14(37%), respectively. The result indicates that 39% of land is covered by cultivated land, 27% is bare land, 13% is settlement, 11% is grazing land and the rest 10% is bush land (Fig.5.7). Table 5.6 shows the correlation and coverage of landuse landcover with landslide distribution.

Table 5. 6 Area coverage with various landuse landcover and percentage of landslides occurred within a subclass

No.	Landuse/ Landcover Class	Pixel count of Subclass in total area	Pixel count of sub-class within landslide area	Landslide percentage within subclass	Percentage of Landslide Occurred (%)
1	Settlement	4997	35	0.70	13
2	Bush land	6166	34	0.55	10
3	Water body	663	0	0.00	0
4	Bare land	7223	107	1.48	27
5	Grazing land	6600	38	0.58	11
6	Cultivated land	15124	319	2.11	39
Total		40773	533	5.42	100

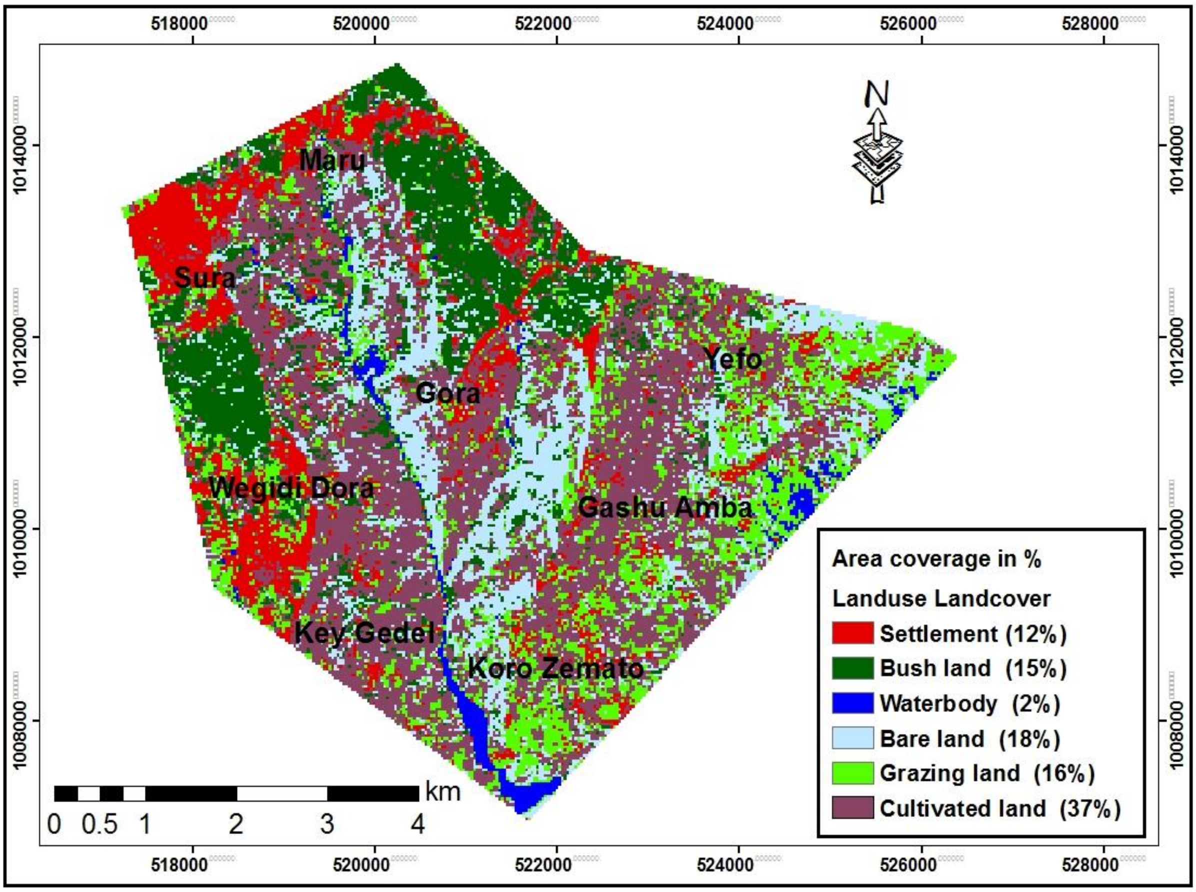


Fig.5. 7 Landuse Landcover map of the study area

5.2.4 Summary on Landslide Hazard Evaluation of the study area

In the present study area the past landslide occurred was 31 as observed from landslide inventory data and during field investigation (refer annex 3). The prominent mode of failures was 3 types; fall, translational and rotational. The landslide coverage in Sela Dengay Debre Berhan Gorgo ignimbrite, Colluvium soil and kesem basalt percentage was 40%, 30% and 26%, respectively. However,in alluvium soil shows low correlation of landslide occurrence while in Termaber Megezez basalt show insignificant.

The probability of landslide occurred in elevation class 2282m- 2435m and 2128m - 2281m was 50% and 33% as observed from inventory of landslide data. However, when the elevation decreases the landslide distribution in the study area also decrease particularly for class (1974m - 2127m) and (1820m - 1973m) the landslide distribution is 10% and 2%, respectively.

Cultivated land and Bare land correlation with the landslide occurrence in the study area shows that 39% and 27%, respectively. This may be resulted from lack of vegetation cover that reduces instability of slope.

Furthermore, it was observed that the concentration of landslides is 27% and 20% in slopes facing towards West (247.5° - 292.5°) facing slopes and East (67.5°-112.5°) directions, respectively. The possible reason for this may be related with the groundwater flow direction.

About 54% of landslides were occurred within $30^0 – 45^0$ slopes in the present study area. The reason is that rock exposed has higher discontinuities or lineament structures that vulnerable the instability of slopes. In addition to this the probability of failure increases as slope increases. The frequency of landslide was low in gentle slope because the morphology of the landform was nearly flat which is not susceptible for landslides. Based on groundwater the landslide occurrence in the present study area in flow surface traces indicates 55% landslide occurrence. This shows that the groundwater interaction with other causative factors of past landslide.

CHAPTER SIX LANDSLIDE HAZARD ZONATION

6.1 General

Landslide hazard zonation (LHZ) refers to a division of the land surfaces into varying degrees of stability based on an expected significance of causative factors in inducing instability. The landslide hazard zonation maps have an important role in planning and development schemes in mountainous regions (Anbalagan, 1996). These maps are useful for identification of unstable zones. The landslide hazard maps are useful for the following purposes: 1) they identify and delineate unstable hazard prone areas; so that environmental regeneration can be initiated by adopting suitable mitigation measures. 2) The maps help planners to choose favorable locations for site developmental schemes, such as building and road constructions.

The methodology followed for the present study was based on analysis of past landslide activates where the relative influence of causative factors was assessed by computing Landslide Susceptibility Index (LSI). For the present study 6 causative factors namely; slope material, slope, elevation, landuse landcover, groundwater and aspect are considered for landslide hazard evaluation and zonation. Based on the density of landslide the entire study area was delineated into various zones of landslide hazard susceptibility. For the preparation of landslide hazard zonation map the approach followed was weight calculation by using landslide density and Landslide Susceptibility Index (LSI) for each classes and parameters based on GIS approach. After the calculation of weight the identified factors: slope material, slope, aspect, landuse landcover, elevation, groundwater surface traces maps were converted to grid cells 30m x 30m to overlay and each grid cell was geo-processed to depict various subclasses of each causative factor. Finally the causative factors of the study area maps were overlaid and the weight overlay in spatial analyst tool was performed. Finally based on weight calculated the hazard class values determined.

6.2 Landslide Hazard Zonation

In bivariate statistical method various weight estimation methods have been employed: information value method, weight of evidence modeling, frequency ratio and landslide nominal susceptibility factor (LNSF) are examples (Gupta and Joshi, 1990).

For the present study to prepare landslide hazard zonation two approaches were followed: weight evidence modeling and Landslide Susceptibility Index (LSI) using GIS methods.

6.2.1 Weight Evidence Modeling Approach

As already discussed in chapter four this method was based on the calculation of the weight using the equation (6.1).

$$lnW_i = ln\left(\frac{DensClass}{DensMap}\right) = ln\left[\frac{\frac{Npix\ (Si)}{Npix\ (Ni)}}{\frac{\sum Npix\ (Si)}{\sum Npix\ (Ni)}}\right] \ldots\ldots \text{(eq.6.1)}$$

Where,

$\boldsymbol{W_i}$: − Is the weight given to a certain parameter class

$\boldsymbol{DensClass}$: − The landslide density within the parameter class

$\boldsymbol{DensMap}$: − The landslide density within the entire map

$\boldsymbol{Npix}(\boldsymbol{Si})$: − Number of pixels, which contain landslides, in a certain parameter class

$\boldsymbol{Npix}(\boldsymbol{Ni})$: − Total number of pixels in a certain parameter class

The method is based on map crossing of a landslide map with a parameter map which can be used to calculate the density of landslides per parameter class. A standardization of these density values can be obtained by relating them to the overall density in the entire area. By combining two or more maps of weight values a hazard map can be created. The hazard map value is obtained by simply adding the separate weight values (Van westen et al., 1997). In the present study the six causative factors were considered and the density of landslide for each thematic map of the causative factor was performed for landslide hazard evaluation and zonation.

To evaluate the landslide susceptibility of the study areas, a bivariate statistical method in Arc GIS environment was followed. In order to evaluate the contribution of each factor towards landslide susceptibility, thematic factor maps separately overlaid with landslide inventory. The number of landslide pixels falling on each class of the thematic factor map was recorded and weights calculated based on the weight evidence modeling method using equation (6.1). The weights were directly assigned to the respective thematic layers to produce the weighted thematic maps. The weighted thematic maps were summed up to produce a landslide hazard zonation map. Based on the density of landslide in subclass of causative factors the weight is computed in (Table 6.1).

Table 6. 1 Weight of landslide computed for causative parameters

Causative Factor Class	Subclass	Pixel count of Subclass in total area =[Npix(Ni)] or(A)	Pixel count of subclass within landslide area =[Npix(Si)]or (B)	$\frac{NPix(Si)}{Npix(Ni)}$ =B/A=C	$\frac{\sum NPix(Si)}{\sum Npix(Ni)}$ =533/40773 =D	Weight=E	Landslide % within subclass=F	LSI=F*LSV/100
Slope material	Kesem basalt	17066	195	1.1430	0.0131	0.87	1.143	0.343
	Sela Dengay-Debre Berhan-Gorgo ignimbrite	17931	305	1.7010	0.0131	1.30	1.701	0.510
	Tarmaber-Megezez basalt	840	0	0.0000	0.0131	0.00	0.000	0.000
	Alluvium soil	2746	5	0.1820	0.0131	0.14	0.182	0.055
	Colluvial Soil	2190	28	1.2790	0.0131	0.98	1.279	0.384
Slope	0^0 - 5^0	8457	7	0.0008	0.0131	0.06	0.083	0.017
	5^0 - 12^0	8822	65	0.0074	0.0131	0.56	0.737	0.147
	12^0 - 30^0	19443	344	0.0177	0.0131	1.35	1.769	0.354
	30^0 – 45^0	3932	117	0.0298	0.0131	2.27	2.976	0.595
	>45^0	119	0	0.0000	0.0131	0.00	0.000	0.000
Aspect	Flat	42	0	0.0000	0.0131	0.00	0.000	0.000
	North	488	0	0.0000	0.0131	0.00	0.000	0.000
	Northeast	2874	39	0.0136	0.0131	1.04	1.357	0.136
	East	9070	158	0.0174	0.0131	1.33	1.742	0.174
	Southeast	10661	105	0.0098	0.0131	0.75	0.985	0.098
	South	5955	30	0.0050	0.0131	0.38	0.504	0.050
	Southwest	5660	91	0.0161	0.0131	1.23	1.608	0.161
	West	4664	109	0.0234	0.0131	1.79	2.337	0.234
	Northwest	1092	1	0.0009	0.0131	0.07	0.092	0.009
	North	267	0	0.0000	0.0131	0.00	0.000	0.000
Elevation	1820m - 1973m	5078	7	0.0014	0.0131	0.11	0.138	0.028
	1974m - 2127m	7462	54	0.0072	0.0131	0.55	0.724	0.145
	2128m - 2281m	8252	193	0.0234	0.0131	1.79	2.339	0.468
	2282m- 2435m	6709	236	0.0352	0.0131	2.69	3.518	0.704
	2436m - 2589m	13272	43	0.0032	0.0131	0.25	0.324	0.065
Landuse Landcover	Settlement	4997	35	0.0070	0.0131	0.54	0.700	0.070
	Bush land	6166	34	0.0055	0.0131	0.42	0.551	0.060
	Water body	663	0	0.0000	0.0131	0.00	0.000	0.000
	Bare land	7223	107	0.0148	0.0131	1.13	1.481	0.150
	Grazing land	6600	38	0.0058	0.0131	0.44	0.576	0.060
	Cultivated land	15124	319	0.0211	0.0131	1.61	2.109	0.210
Groundwater Surface Traces	Dry	9515	0	0.0000	0.0131	0.00	0.000	0.000
	Wet	13488	206	0.0153	0.0131	1.17	1.527	0.153
	Flow	17770	327	0.0184	0.0131	1.41	1.840	0.184

The correlation ratings are calculated from relation analysis between landslides and the relevant factors. Therefore, the rating of each factors type or ranges was assigned at the relationship between landslide and each factors type or ranges, that is ratio of the number of the cells where landslide were occurred to the number of cells where Landslides did not occurred.

6.2.1.1 Discussion on the result of weight computed

As already presented (in table 6.1) the weight for all parameters of causative factors was performed. The weighting values calculated, for each class of the six causative factors, using the weight evidence modeling method (WEM). The weighting values are calculated on the basis of the landslide density within each class.

Among the slope material in the study area, the highest weight (Wi =1.30) has been obtained for the Sela Dengay-Debre Berhan-Gorgo ignimbrite. On the contrary, the landslide density is particularly low where the alluvium soil, as highlighted by the very low (Wi =0.14). In Tarmaber Megezez basalt the weight is zero, which is the lowest one among those calculated for all the slope material and this denotes no landslide occurs within these formations.

In the case of slope factor classes, the calculated weight does not regularly increases with slope angle. In fact, the value calculated for the slope angle class > 45^0(wi = 0) is lower than the one obtained for the 0^0 - 5^0class (wi = 0.06). Relatively high weighting values have been obtained for both the classes 30^0 – 45^0 (wi = 2.27) and 12^0 - 30^0 (wi = 1.35).

The weight (Wi) obtained for the aspect classes by computing based on landslide densities. The higher values have been obtained for both the slopes facing to West (Wi = 1.79) and to East (Wi = 1.33). However, the weight obtained for flat land surfaces shows no landslide occurrence.

The weight (Wi) of elevation factor classes denote that higher in class 2282m- 2435m (wi=2.69) and 2128m - 2281m (wi = 1.79). For the class 1820m - 1973m denotes low weight (wi = 0.11).For the landuse landcover classes the highest weight or indicative of the highest landslide density, have been obtained for the Cultivated land (wi = 1.61) and Bare land (wi=1.13). Landslides are relatively frequent in areas covered by settlement (wi = 0.54), while they are very rare in areas occupied by bush land (wi = 42) and absent in water body areas (wi=0). In the case of groundwater surface traces the weight obtained was highest in Flow (wi=1.41) and in Wet (wi=1.17). However, in Dry it denotes no landslide occurrence.

Based on (Gupta and Joshi, 1990) landslide hazard class classification the value of weight obtained for the present study was reclassified as the (Table 6.2). This classification shows for weight evidence modeling (WEM) approach.

Table 6. 2 Hazard index classifications for five classes

Hazard class	Hazard class classification	Hazard class name
1	0 – 0.381	Very low hazard
2	0.382 – 0.761	Low hazard
3	0.762 – 1.142	Moderate hazard
4	1.143 - 1.523	High hazard
5	>1.524	Very high hazard

The combination of the causative factor maps were carried out from major to least order of importance (influence) for hazard zonation. Therefore, in Fig.6.1 the hazard map was produced by combining the causative factors with the order of slope material, slope, elevation, landuse landcover, groundwater and aspect, respectively. The result shows that, the area coverage with its percentage for very low hazard 10km^2(27%), for low hazard 9km^2(24%), for moderate hazard 5km^2 (13%), for high hazard 7km^2(19%) and for very high hazard 7km^2(17%) in the study area.

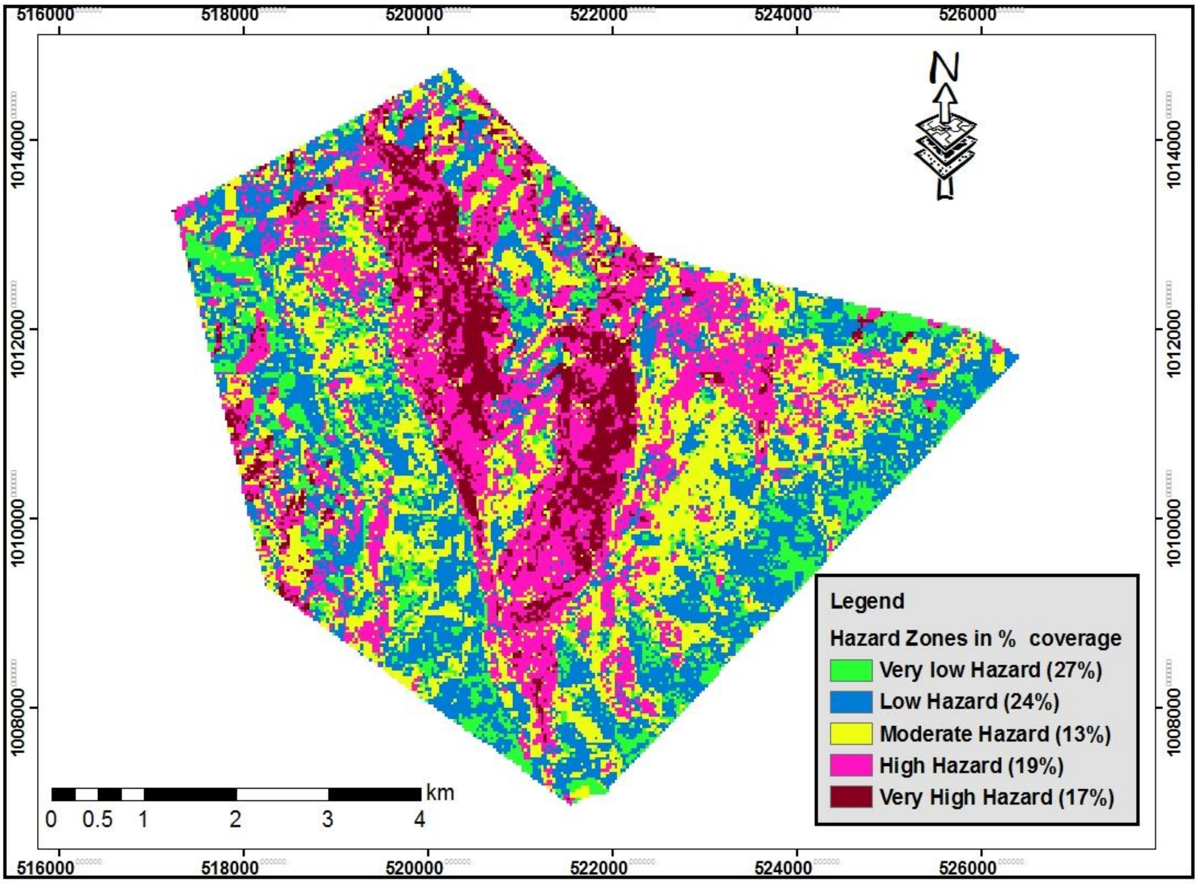


Fig.6. 1 Landslide hazard zonation map of the study area Based on weight evidence modeling

6.2.1.2 Validation of LHZ map prepared by weight evidence modeling (WEM) approach

To validate the landslide hazard zone map prepared by (WEM) the past landslide vector data was overlaid over the prepared hazard zone map. This is useful to see and to verify the number of the past landslide activities fall within very high hazard and high hazard zones. From this, the result shows 16% error when verified with the landslide inventory data (from 31 only 5) with which 6% falls in low hazard zone and 10% in moderate hazard. That means 84% of the inventory data falls in the high and very high hazard zone which shows validity of the Hazard zonation. Table 6.3 and Fig.6.2 Shows the validation of LHZ map prepared by WEM approach.

Table 6. 3 Validation data for LHZ map prepared by (WEM) and past landslide activities

Land Slide Hazard Zone	Number of Landslide falling within Hazard Zone	Percent of Landslide falling within Hazard Zone	
Very High Hazard	10	32%	**84%**
High Hazard	16	52%	
Moderate Hazard	3	10%	**16%**
Low Hazard	2	6%	
Very Low Hazard	0	0.00%	
Total Past Landslides	**31**	**100%**	

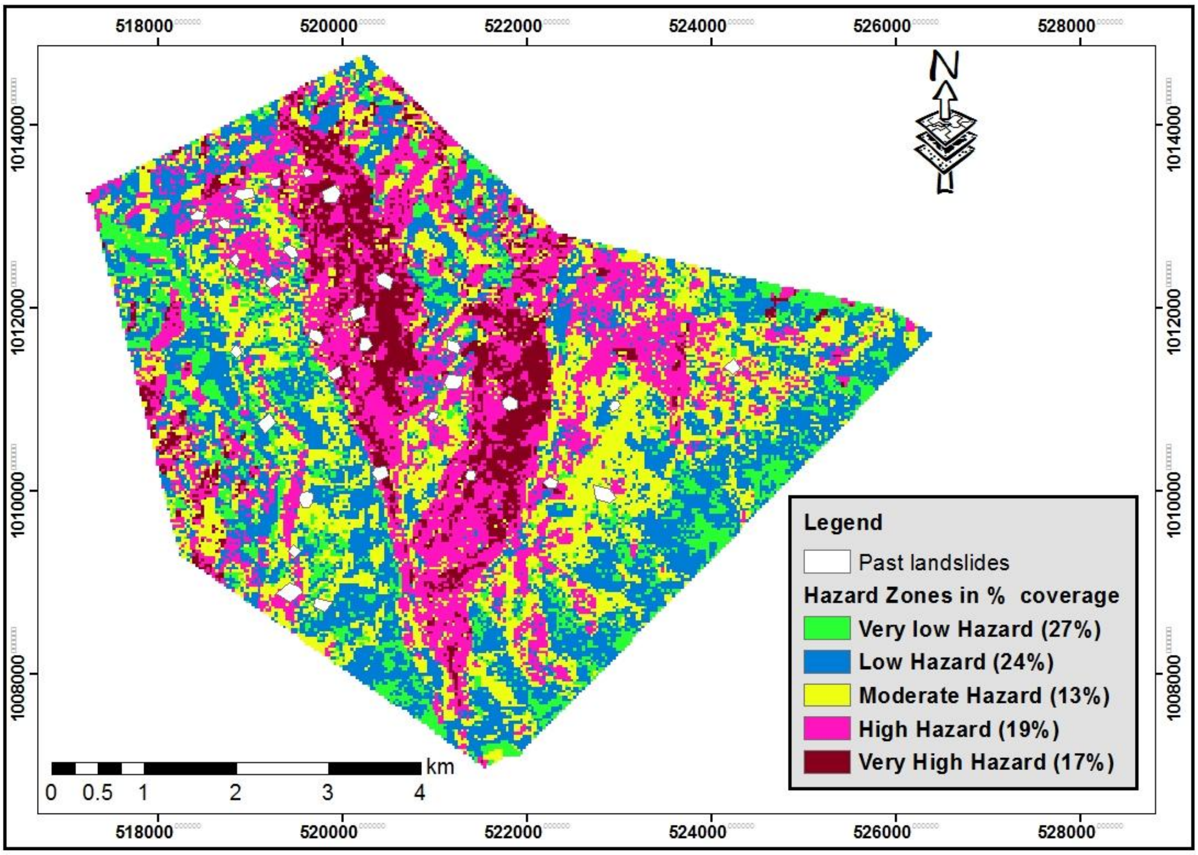


Fig.6. 2 Validated Map of Landslide Hazard Zonation by Weight evidence modeling approach

6.2.2 Landslide Hazard Zonation based on LSI value Using GIS Approach

The spatial relationship among landslide occurrence location and each landslide related factors was driven using GIS method. The main causative factors are slope, aspect, elevation derived from the DEM with resolution 30m x 30m (source: STRM) and landuse landcover extracted from satellite image 2013. These factor maps can automatically be derived into the model builder by the software. The causative factors like slope material derived from the geology database, groundwater surface trace from field data of springs were digitized as vector data that are merged into the model builder to get the processed vector maps. Later, these vector maps were converted to raster by using conversion tool within spatial analyst. The factors were converted to a 30m x 30m grid for use in statistical package. The total cell number is 40733 in the study area while the landslide occurrence cell number is 533.

For causative factor parameter the modeling of specific rating was assigned to different factor subclasses. Therefore, respective LSI values are utilized as ratings for various causative factor subclasses. The percentage weight is assigned to each causative factor class for the requirement of modeling. Thus, the sum of total weight assigned to each factor has to be equal to 100. For the present case percentage weight assigned to each causative factor was considered equal to LSV value (Table 4.1 in chapter 4), which was utilized for the computation of LSI values. After the LSI Values were assigned to all causative factors subclasses the final stage was to generate the final weighted sum raster. The process entailed combining all six raster data set; Slope material, slope, aspect, elevation, landuse landcover and groundwater. The weighted raster also stipulate that each factor raster file be assigned with a percentage weight. Further, by using the weighted sum in the Overlay tool, found in the spatial Analyst tool in the Arc toolbox, final weighted sum raster was generated. At this stage all LSV Values were assigned to the factor maps in the weighted raster.

The total landslide susceptibility index (TLSI) was obtained from the summation of all six causative factors landslide susceptibility index (LSI) of subclasses. It was computed by using model builder in Arc tool and weight overlay for the reclassified factors data sets.

The range of TLSI values obtained was classified into zones based on the landslide detected during the field work observed. The total distribution of TLSI values falls within a range of 0.16 to 1.37. As the result indicates, 0.16 value of TLSI represents the least hazard and the value 1.37 indicates a very high hazard.

Finally, based on the field evidence, judgment and logical consideration the landslide hazard zones were classified as: very high hazard, high hazard, moderate hazard, low hazard and very low hazard. Table 6.3 shows the Landslide hazard zones and corresponding TLSI values.

Table 6. 4 Landslide hazard zones and corresponding TLSI values

Landslide Hazard Zone	Total Landslide Susceptibility Index (TLSI)
Very low hazard	0.16 – 0.34
Low Hazard	0.35 – 0.68
Moderate Hazard	0.69 – 1.03
High Hazard	1.04 – 1.37
Very High Hazard	>1.37

The final weighted sum raster was separated into five distinct hazard classes using manual breaks, which was done based on judgment and terrain condition. The area coverage of the five distinct zones of hazard is: 6km^2(16%) for very low hazard, 9km^2(23%) for low hazard, 5km^2 (12%) for moderate hazard, 9km^2 (24%) for high hazard and 9km^2 (25%) for very high hazard zone. The landslide hazard map prepared with the distinct landslide hazard zone is presented as Fig.6.3 for LSI value using GIS approach method.

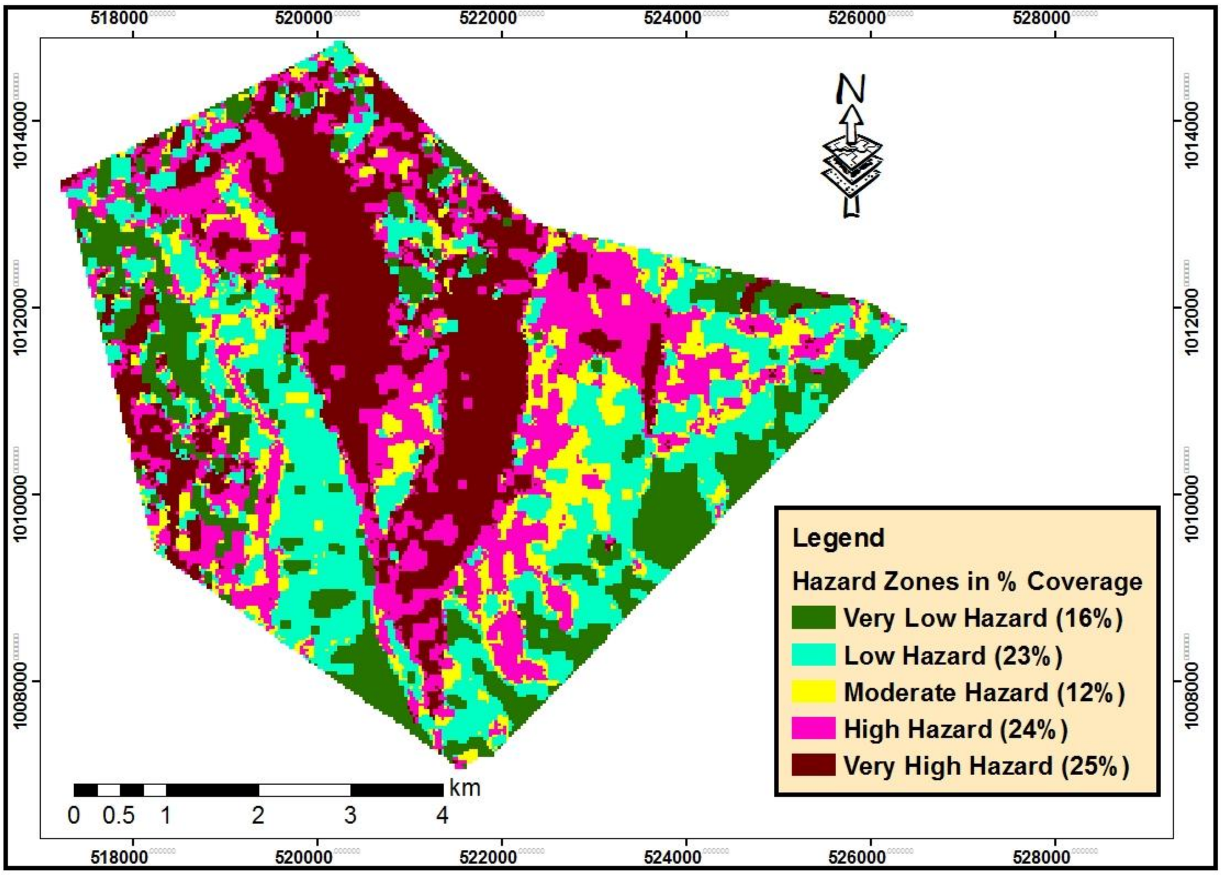


Fig.6. 3 Landslide hazard zonation map of the study area by GIS approach (LSI)

6.2.2.1 Verification of (LHZ) map prepared by LSI value using GIS approach

The verification method is performed by comparison of existing landslide data (inventory data) with the landslide hazard zone map. From the inventory data only 3.23% of the past landslide falls on the low hazard class and 6.45% of the landslide falls in the moderate hazard class. That means only 9.68% of the total inventory landslide shows deviation to Hazard map prepared during the present study. The 35.48% of the inventory landslide location falls in high hazard zone and 54.84% in very high hazard zone. That means 90.32% of the existing landslide location shows satisfactory agreement with the present landslide hazard zonation map. Table 6.5 and Fig.6.4 show the verification of Landslide Hazard Zonation map prepared by LSI value using GIS approach

Table 6. 5 Validation data for LHZ map prepared by LSI value using GIS approach and past landslide activities

<table>
<tr><th>Land Slide Hazard Zone</th><th>Number of Landslide falling within Hazard Zone</th><th colspan="2">Percent of Landslide falling within Hazard Zone</th></tr>
<tr><td>Very High Hazard</td><td>17</td><td>54.84%</td><td rowspan="2">90.32%</td></tr>
<tr><td>High Hazard</td><td>11</td><td>35.48%</td></tr>
<tr><td>Moderate Hazard</td><td>2</td><td>6.45%</td><td rowspan="2">9.68%</td></tr>
<tr><td>Low Hazard</td><td>1</td><td>3.23%</td></tr>
<tr><td>Very Low Hazard</td><td>0</td><td colspan="2">0.00%</td></tr>
<tr><td>Total Past Landslides</td><td>31</td><td colspan="2">100%</td></tr>
</table>

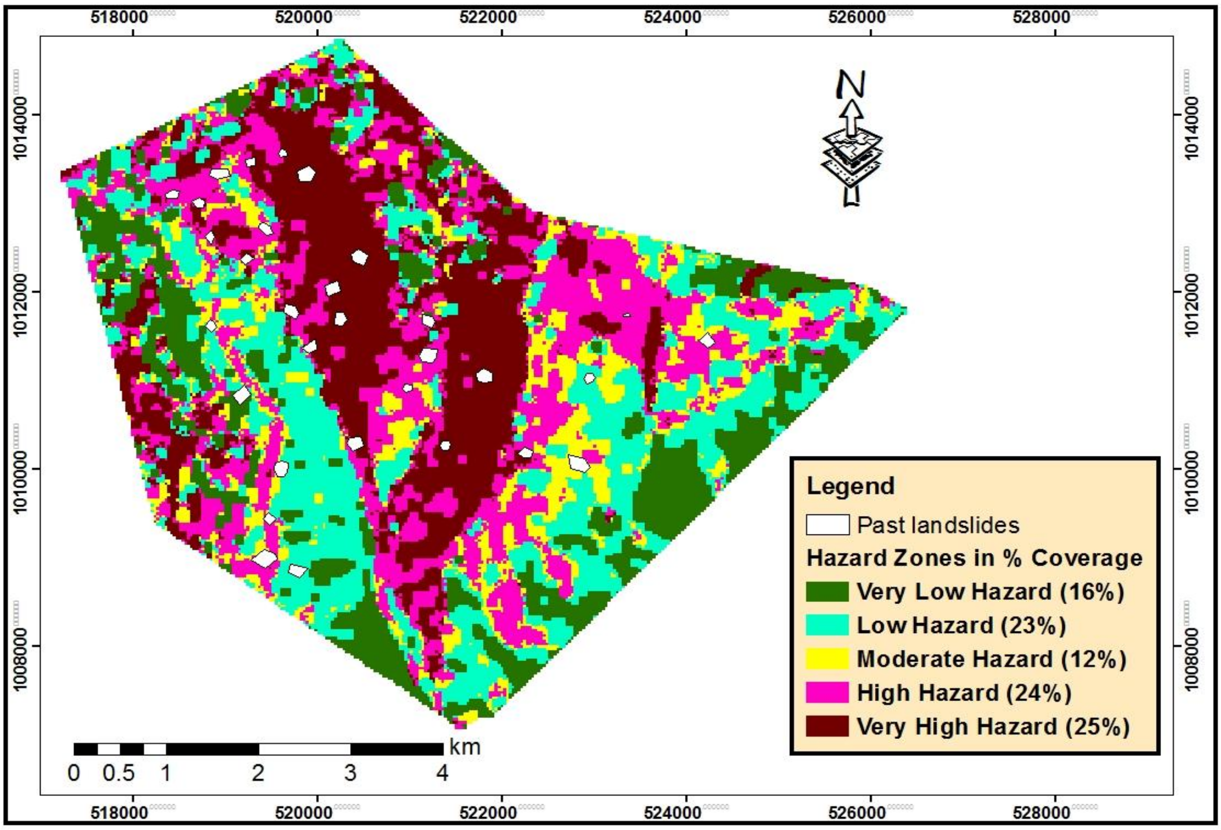


Fig.6. 4 Validation map of Landslide Hazard zonation by LSI value using GIS approach

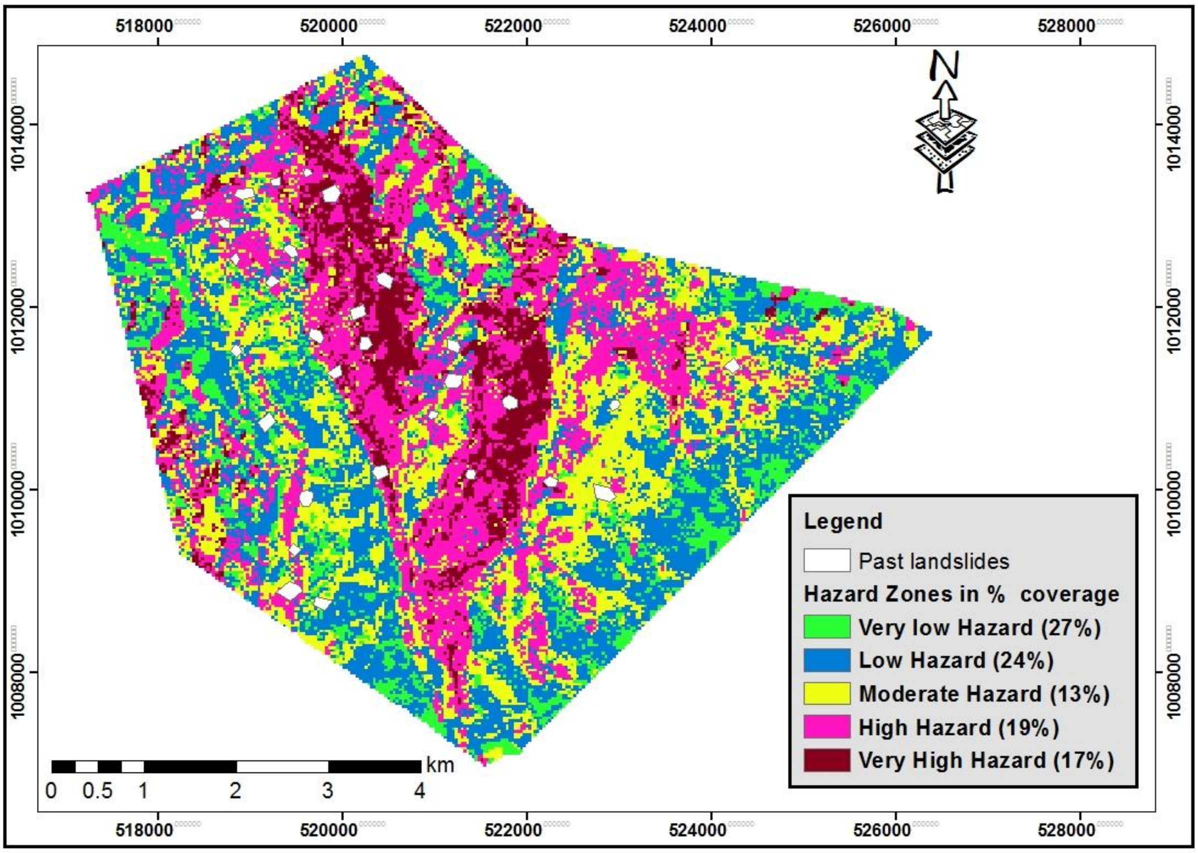
6.3 Comparison of LHZ Maps Prepared by weight evidence modeling (WEM) approach and LSI value using GIS approach

The same causative factors and subclasses are considered for both methods. These causative factors are; slope material, slope, elevation, landuse landcover, groundwater surface traces and aspect. For both methods five distinctive landslide hazard classes were performed. These are: very low hazard, low hazard, moderate hazard, high hazard and very high hazard. The validation of landslide hazard zonation maps were performed for both approaches. It was validated with past landslide activities and shows that LSI value using GIS approach gave better agreement than weight evidence modeling(WEM) method (Table 6.6).

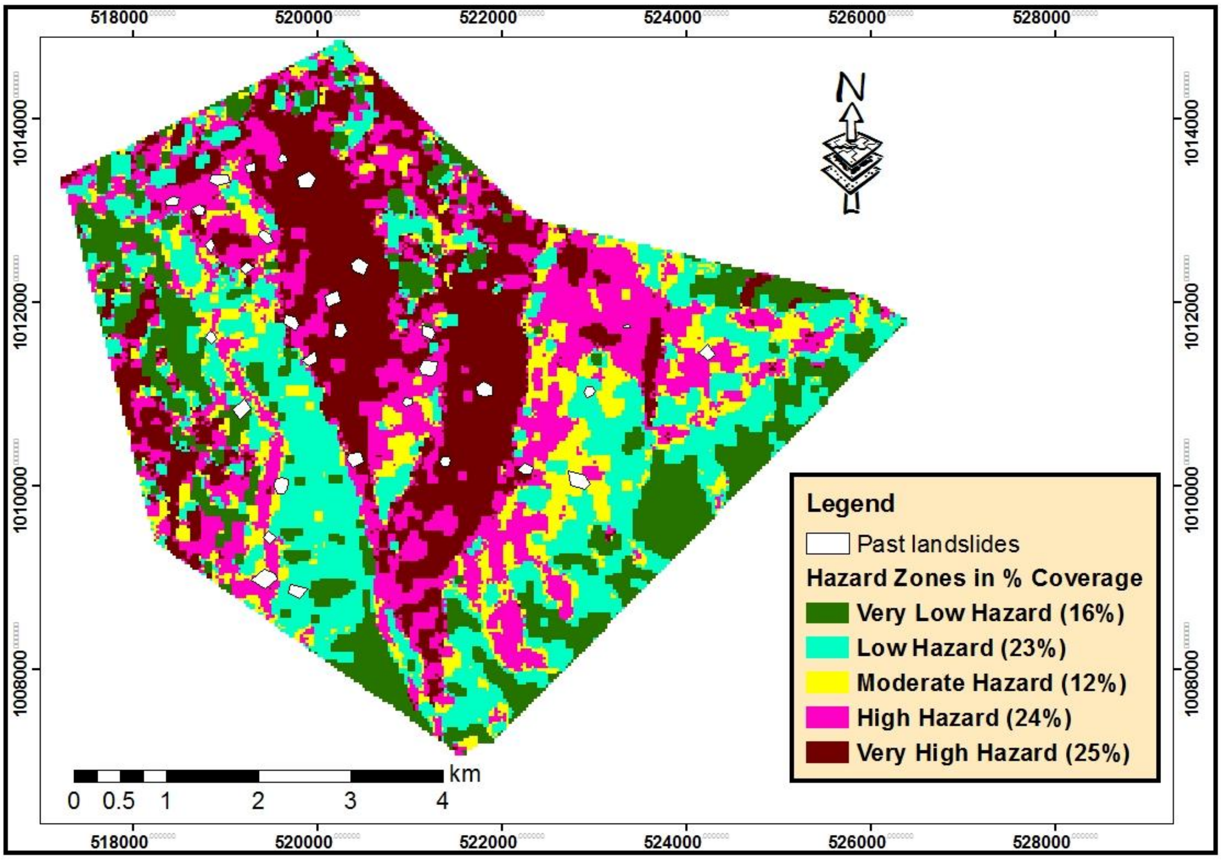
Table 6. 6 Comparison of Validation data for LHZ map prepared by (WEM) approach and LSI value using GIS approach

<table>
<tr><th rowspan="2">Land Slide Hazard Zone</th><th colspan="2">Number of Landslide falling within Hazard Zone</th><th colspan="4">Percent of Landslide falling within Hazard Zone</th></tr>
<tr><th>Weight Evidence Modeling</th><th>LSI value using GIS approach</th><th colspan="2">Weight Evidence Modeling</th><th colspan="2">LSI value using GIS approach</th></tr>
<tr><td>Very High Hazard</td><td>10</td><td>17</td><td>32%</td><td rowspan="2">84%</td><td>54.84%</td><td rowspan="2">90.32%</td></tr>
<tr><td>High Hazard</td><td>16</td><td>11</td><td>52%</td><td>35.48%</td></tr>
<tr><td>Moderate Hazard</td><td>3</td><td>2</td><td>10%</td><td rowspan="2">16%</td><td>6.45%</td><td rowspan="2">9.68%</td></tr>
<tr><td>Low Hazard</td><td>2</td><td>1</td><td>6%</td><td>3.23%</td></tr>
<tr><td>Very Low Hazard</td><td>0</td><td>0</td><td colspan="2">0.00%</td><td colspan="2">0.00%</td></tr>
<tr><td>Total Past Landslides</td><td>31</td><td>31</td><td colspan="2">100%</td><td colspan="2">100%</td></tr>
</table>

The LHZ map prepared by weight evidence modeling approach validate 84% of past landslides fall within very high hazard or high hazard whereas in the case of LSI value using GIS approach shows 90.32% of past landslides fall within very high hazard or high hazard. Therefore, both approaches produced the results, which validates with past landslide data. However, in case of LSI value using GIS approach has given better validation with past landslide activities. In general, both methods are considered for bivariate statistical analysis approach to prepare landslide hazard zonation with the same scale in the present study (Fig.6.5).



LHZ map prepared by WEM approach



LHZ map prepared by LSI value using GIS approach

Fig.6. 5 Comparison of LHZ map prepared by (WEM) approach and LSI value using GIS approac

CHAPTER SEVEN CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Landslides are among the great geo-environmental hazard in the present study area. The present study area is located in Oromiya Regional State, North Showa Zone in the eastern part of Alaltu District, Central Ethiopia. Its topography is highland and rift margin which is prone areas for landslide occurrence. Furthermore, it is characterized by rugged topography with maximum elevation 2589m and minimum1820m above sea level. Its climate condition is temperate and subtropical zones with 10^0C to 20^0C. The economic activity of the settlers is based on cultivation and animal breeding. The geology of the study area is characterized by Tertiary volcanic rocks and Quaternary deposits.

The main objective of the present study is to map landslide hazard zone by evaluating the causative factors of the landslide in the study area. In addition, the study aims at landslide risk assessment for hazard mitigation and management. The Landslide Hazard Zonation map prepared for the area will help to conduct further study on the detailed slope stability analyses on the future. In addition to this, it serves as a guide for residents to protect from loss of life and property caused by landslides. It will also help in adopting proper remedial measures by giving much attention to the event.

For the present study, bivariate statistical analysis approach was adopted to derive a landslide Hazard map of the area. Weight evidence modeling and Landslide Susceptibility Index (LSI) are used to perform hazard map. Based on the methodology evolved the secondary and primary data were collected. Different factor map also prepared based on the secondary data for analysis during field work. These map includes landuse landcover map from satellite image (2013) and Google earth image, slope map, elevation map and aspect map from DEM with 30m x 30m resolution (source: SRTM), slope material map from geological map of Debre Berhan 2010 with scale of 1:250,000 and soil map from FAO and Groundwater surface traces from topographic map of 1:50,000 scales and Location of springs during field investigation of the study area.

The prominent causative factors considered during the present study are six: These are slope material, slope, elevation, landuse landcover, groundwater and aspect. For landslide conditioning factors, a landslide inventory was analyzed within a GIS environment. In the present study area the past landslide occurred was 31 as observed from landslide inventory data and field investigation.

The modes of failure for these landslides were; fall, translational and rotational modes failure. The causative factors parameter were classified as subclasses and for each subclass, based on landslide inventory the pixel count were calculated. By using the Landslide Susceptibility Value (LSV) the Landslide Susceptibility Index (LSI) was computed for causative factor parameter. Based on the LSI value the causative factors were reclassified and later by using the weight sum in spatial analyst tool the six prominent causative factors maps; Slope material, slope, elevation, landuse landcover, groundwater surface traces and aspect maps were combined to give one raster data set. Finally it was classified into five distinctive classes based on manual breaks and its terrain conditions as Very Low Hazard, Low Hazard, Moderate Hazard, High Hazard and Very High Hazard. On the other hand, Landslide Hazard Zonation was performed based on weight evidence modeling approach. In this method the landslide density pixel count of subclasses computed for entire classes and the weight of landslide was calculated for all parameters. Finally, the weight sum map was prepared and classified into five Landslide Hazard Zones.

The result of the present study shows that five distinctive class of Landslide Hazard Zonation (LHZ) map was identified for the study area. These are Very Low Hazard (16%), Low Hazard (23%), Moderate Hazard(12%), High Hazard(24%) and Very High Hazard(25%). The area coverage for Very Low Hazard, Low Hazard, Moderate Hazard, High Hazard and Very High Hazard is 6km^2, 9km^2, 5km^2, 9km^2 and 9km^2, respectively.

The verification of Landslide Hazard Zonation was performed using inventory data of past landslides. The result of validation shows that for weight evidence modeling approach map was low verification than Landslide Susceptibility Index (LSI) based on GIS approach Map.

7.2 Recommendation

Several landslides have occurred in the last eight years in the study area. People have been permanently displaced from their residences, as they lost their houses, cattle and farm plots. To reduce this problem the present study focused on remedial measures on planning for settlement and constructions.

Individuals can reduce their exposure to hazards by educating themselves on past hazard area and by making inquiries to planning of local governments. Avoiding the landslide prone areas for settlement, agricultural and any other activities on the critical slope sections, especially that has been identified as very high hazard zones.

In additional, possible mitigation measurements recommended by Bekele Abebe et al., (2009) like gully recovering and control, planting of trees and avoiding construction on unstable slopes and intensive cultivation at the foot of steep rocky slope or escarpments to reduce landslide damage on human and animal life, property and agricultural land can be performed.

Finally, the present study was focused to map landslide hazard zonation using bivariate statistical approach; however, it is possible to study slope stability analysis for construction of roads and other infrastructures in the future for scientific study.

7.3 Limitation of the study

The constraints during this study were the resource materials such as lack of the previous work on this area and absence of long year statistical data. The other limitation that occurred was the absence of well documented data of landslides because recording of such type of disaster was unfocused earlier.

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Annex 1. Average monthly precipitation of Debre Berhan station from 2000 to 2014

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.0	0.0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8
2001	0.0	33.8	71.2	-	64.6	34.9	406.7	260.4	32.2	4.1	0.0	.4
2002	18.1	28.0	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	0.0	8.4
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.1	288.7	74.2	-	0.0	7.4
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0.0
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0.0
2006	17.3	24.4	61.0	38.3	19.8	35.2	432.6	224.2	59.8	8.6	-	26.3
2007	2.0	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	0.0
2008	0.3	1.7	0.0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2
2009	47.2	0.0	8.1	31.4	14.9	13.7	423.4	273.1	31.4	36.6	1.2	25.3
2010	47.2	21.6	55.7	119.3	42.2	35.4	242.3	312.2	53.8	0.3	8.5	3.9
2011	0.3	7.0	76.8	38.6	111.2	73.4	357.4	312.3	79.0	0.0	4.3	0.0
2012	0.0	0.0	5.2	93.3	57.9	56.0	351.6	394.5	92.4	0.0	0.0	0.0
2013	0.8	0.0	48.8	54.2	23.9	40.1	358.5	204.4	79.6	63.1	11.5	0.0
2014	0.0	16.0	67.7	44.1	46.9	16.8	260.3	291.0	110.0	55.9	0.0	0.0
sum monthly	207.5	213.4	608.4	867.5	605.2	830.3	5086.7	4352.1	1217.5	229.8	117.9	82.7
Mean monthly	**13.8**	**14.2**	**40.6**	**57.8**	**40.3**	**55.4**	**339.1**	**290.1**	**81.2**	**15.3**	**7.9**	**5.5**

Annex 2. Annual precipitation of Debre Berhan station from 2000 to 2014 year

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual pp(mm)
2000	0.0	0.0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8	**985.3**
2001	0.0	33.8	71.2	0.0	64.6	34.9	406.7	260.4	32.2	4.1	_	3.4	**911.3**
2002	18.1	28.0	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	_	8.4	**830.1**
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.1	288.7	74.2	_	_	7.4	**1005.5**
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0.0	**1023.2**
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0.0	**932.4**
2006	17.3	24.4	61.0	38.3	19.8	35.2	432.6	224.2	59.8	8.6	_	26.3	**947.5**
2007	2.0	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	0.0	**1083.5**
2008	0.3	1.7	0.0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2	**946.7**
2009	47.2	0.0	8.1	31.4	14.9	13.7	423.4	273.1	31.4	36.6	1.2	25.3	**906.3**
2010	47.2	21.6	55.7	119.3	42.2	35.4	242.3	312.2	53.8	0.3	8.5	3.9	**942.4**
2011	0.3	7.0	76.8	38.6	111.2	73.4	357.4	312.3	79.0	0.0	4.3	0.0	**1060.3**
2012	0.0	0.0	5.2	93.3	57.9	56.0	351.6	394.5	92.4	0.0	0.0	0.0	**1050.9**
2013	0.8	0.0	48.8	54.2	23.9	40.1	358.5	204.4	79.6	63.1	11.5	0.0	**884.9**
2014	0.0	16.0	67.7	44.1	46.9	16.8	260.3	291.0	110.0	55.9	0.0	0.0	**908.7**

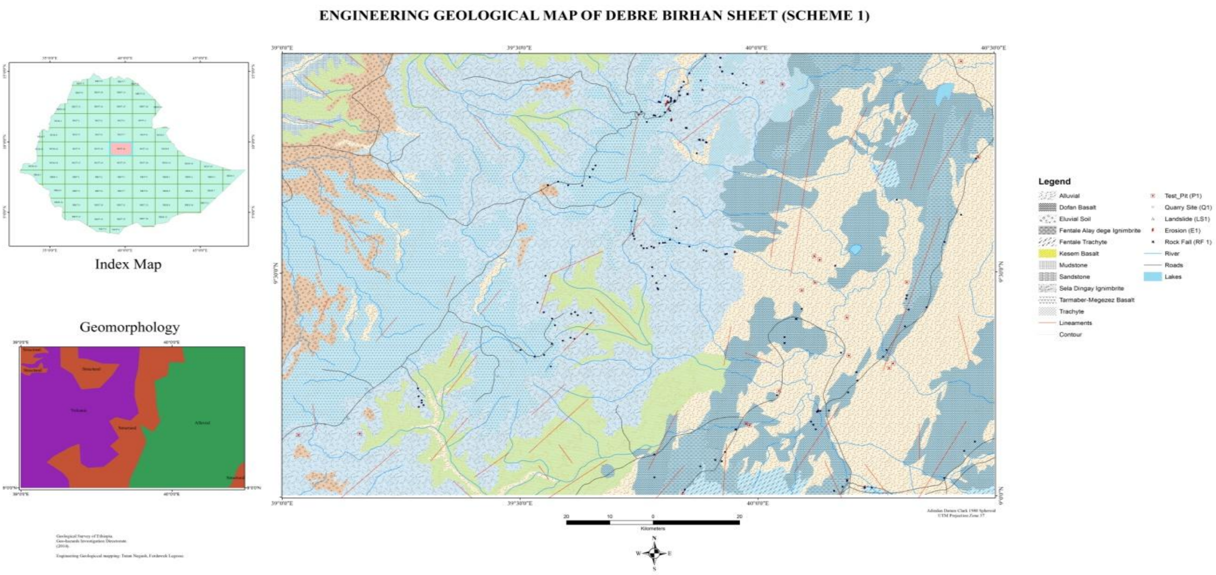
Annex 3. Inventory of Landslide Types and Their Characteristics in the study area

Id	UTM x	UTM Y	Area (in m^2)	slope material	Mode of failure	Estimated width(m)	Estimated length(m)	Land use/land cover	slope
1	519593	1013527	5774	Colluvium soil	Translational Landslide	19	62	Bare Land	Moderately Gentle Slope
	519568	1013564							
	519593	1013615							
	519640	1013605							
	519675	1013552							
2	519355	1012728	1461	Colluvium soil	Rotational Landslide	45	77	Cultivated land	Gentle slope
	519369	1012775							
	519421	1012783							
	519481	1012743							
	519520	1012663							
	519503	1012648							
3	518907	1013268	2122	Kesem Basalt	Fall	35	87	Bare Land	Steep slope
	518818	1013319							
	518851	1013388							
	519018	1013397							
	519051	1013307							
4	518694	1012958	1054	Colluvium soil	Translational Landslide	71	59	Grazing Land	Moderately Gentle Slope
	518632	1013027							
	518707	1013069							
	518777	1013023							
	518766	1012958							
5	519215	1012309	1100	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Rotational Landslide	60	47	Bush land	Moderately Gentle Slope
	519155	1012368							
	519225	1012447							
	519304	1012392							
6	519626	1011769	1900	Alluvium soil	Rotational Landslide	18	56	Cultivated land	Gentle slope
	519642	1011869							
	519747	1011847							
	519803	1011758							
	519755	1011691							
7	519818	1011376	1500	Colluvium soil	Translational Landslide	27	40	Bare Land	Moderately Gentle Slope
	519972	1011471							
	519988	1011356							
	519909	1011300							
8	518484	1012418	1165	Kesem Basalt	Fall	41	54	Bush land	Steep slope
	518557	1012467							
	518637	1012449							
	518617	1012367							
	518505	1012365							
9	519153	1010717	2287	Kesem Basalt	Fall	39	72	Bush land	Escarpment
	519075	1010833							
	519197	1010938							
	519275	1010843							
10	520315	1010278	2043	Kesem Basalt	Rotational Landslide	51	57	Cultivated land	Moderately Gentle Slope
	520344	1010352							
	520448	1010355							
	520503	1010249							
	520395	1010191							

11	519409	1009440	1027	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Translational Landslide	33	60	Bare Land	Gentle slope
	519465	1009510							
	519543	1009434							
	519470	1009362							
12	519668	1008835	1848	Colluvium	Translational Landslide	59	43	Grazing Land	Moderately Gentle Slope
	519702	1008919							
	519882	1008869							
	519787	1008771							
13	519887	1009688	3025	Alluvium soil	Rotational Landslide	52	69	Cultivated land	Gentle slope
	520030	1009783							
	520165	1009696							
	520030	1009589							
14	519222	1013422	8375	Colluvium soil	Translational Landslide	40	75	Settlement	Gentle slope
	519217	1013497							
	519317	1013518							
	519311	1013427							
15	518769	1012625	9022	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Rotational Landslide	30	65	Settlement	Gentle slope
	518839	1012699							
	518881	1012625							
	518835	1012546							
16	519796	1013249	2662	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Translational Landslide	123	57	Settlement	Gentle slope
	519780	1013360							
	519910	1013423							
	519978	1013360							
	519931	1013249							
17	518771	1011615	9935	Colluvium soil	Rotational Landslide	50	63	Settlement	Gentle slope
	518834	1011682							
	518898	1011608							
	518845	1011543							
18	520376	1012338	2228	Kesem Basalt	Fall	25	105	Bare Land	Escarpment
	250349	1012427							
	520432	1012477							
	520538	1012401							
	520511	1012301							
19	520207	1012123	1976	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Fall	57	89	Bare Land	Steep slope
	520243	1012014							
	520101	1011934							
	520114	1011958							
20	521098	1011272	2485	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Rotational Landslide	60	97	Cultivated land	Moderately Gentle Slope
	521148	1011361							
	521296	1011344							
	521291	1011250							
	521242	1011199							
	521134	1011203							
21	519331	1009976	1121	Kesem Basalt	Fall	36	50	Settlement	Moderately Gentle Slope
	519390	1010039							
	519471	1010022							
	519484	1009965							
	519405	1009933							
22	520174	1011630	1549	Alluvium soil	Translational Landslide	55	75	Cultivated land	Moderately Gentle Slope
	520255	1011616							
	520320	1011683							
	520275	1011767							
	520195	1011760							

23	521353	1010212	1009	Kesem Basalt	Rotational Landslide	20	71	Bare Land	Moderately gentle slope
	521326	1010256							
	521355	1010318							
	521423	1010319							
	521439	1010278							
	521419	1010214							
24	522171	1010178	1275	Kesem Basalt	Fall	42	39	Bush land	Steep slope
	522238	1010251							
	522335	1010201							
	522310	1010121							
	522229	1010128							
25	521728	1010992	2122	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Rotational Landslide	97	25	Settlement	Gentle slope
	521723	1011077							
	521805	1011140							
	521898	1011074							
	521892	1010995							
	521816	1010960							
26	520956	1010862	8556	Colluvium	Translational Landslide	34	46	Bush land	Moderately Gentle Slope
	520918	1010894							
	520946	1010963							
	521033	1010948							
	521030	1010885							
27	524223	1011365	1632	Kesem Basalt	Rotational Landslide	70	25	Grazing Land	moderately Gentle Slope
	524133	1011445							
	524237	1011539							
	524316	1011428							
28	522918	1010960	1001	Kesem Basalt	Fall	82	45	Bush land	Steep slope
	522887	1011024							
	522926	1011076							
	522985	1011080							
	523015	1011037							
29	523315	1011724	2235	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Rotational Landslide	77	30	Bare Land	Moderately Gentle Slope
	523310	1011750							
	523369	1011757							
	523385	1011751							
	523397	1011730							
30	523062	1010362	3049	Colluvium	Translational Landslide	69	52	Bare Land	Gentle Slope
	523042	1010506							
	523224	1010462							
	523284	1010372							
	523218	1010310							
31	521244	1011596	1548	Sela Dengay-Debre Berhan-Gorgo ignimbrite	Rotational Landslide	98	25	Cultivated land	Gentle slope
	521278	1011668							
	521244	1011596							
	521128	1011647							

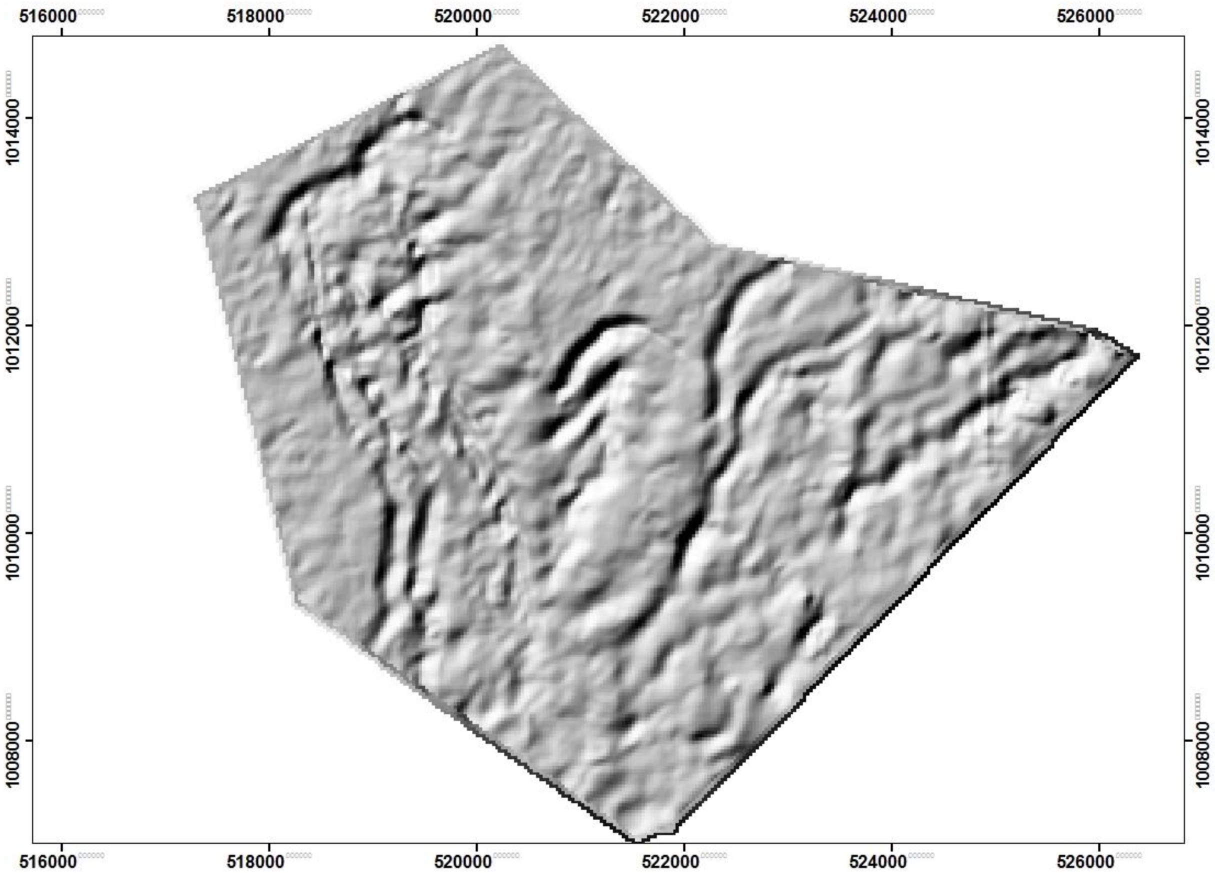
Annex 4. Engineering Geological map of Debre Berhan



Genetic Soil Class	USCS	Consistancy	Density	Plasticity	Index UCS (kg/cm2)
Alluvial Soil	SM,MH,ML	Stiff	x	15-32	between 1 and 14
Eluvial Soil	SM,MH,ML	Stiff	x	15-32	between 4 and 14
Rock Mass Strength Units	Point Load IS 50 range	Schmidt Hammer Strength Range	Weathering Grade	Discontinuity Spacing	Lithological Units
Highly Strong Rock Mass (HRMS)	1-3 Mpa	16-35 Mpa	SW - MW	Moderate	Tkb, Mmst, Msst, Tdig
Very Strong Rock Mass (VRMS)	3-10 Mpa	16-44 Mpa	SW - MW	Moderate	Ttb
Extremly Strong Rock Mass (ERMS)	> 10 Mpa	14-68 Mpa	SW - MW	Moderate	Qdb, Qfig, Qft, Tt

Annex 5. DEM (Digital Elevation Model) of the study area 30m x 30m Resolution

Source: Shuttle Radar Topography Mission (SRTM)



Annex 6. Data collected from North showa zone disaster prevention and preparedness

Lakk G17/574/17/61

Guyyaa 22/3/2007

Ragaa Sigigoo Lafa Bara 2003-2007

Aanaa	Baay'ina Gandoota Balaan irra gahe	Namoota Baalaan Sigigoo irra gahe	Lafa Miidhan irra gahe	Beeyilada Balaa kanaan miidhaman	Mana Jireenya barbada'e	Bu'uraale Misooma balaan irra gahe	Dhaabilee Tajajila Hawasa balaan irra gahe	Kan biroo	Bara balaan kun qaqabe
Alaltu	2	129	45	21	25	4	2		2003 fi 2004

Ragaa Ibsa Sigigoo Lafa Bara 2003-2007

Aanaa	Baay'ina Gandoota Balaan irra gahe	Namoota Baalaan Sigigoo irra gahe	Lafa Miidhan irra gahe	Beeyilada Balaa kanaan miidhaman	Mana Jireenya barbada'e	Bu'uraale Misooma balaan irra gahe	Dhaabilee Tajajila Hawasa balaan irra gahe	Kan biroo	Bara balaan kun qaqabe
Alaltu	2 Goraa fi Surra	129	Goraa=32 Surra=13,Id=45	Horii gaafa =5,Hoola fi Re'ee=16,Id=21	Qorqorro=5,Qaca=20	Burqaa =3 fi Daandii miila=1	MLBarumsa =1 fi Bataskaana=1		2003 fi 2004

Ragaa Kan Qopheesse:-

Maqaa

Mallattoo

Annex 7. Data collected from North showa zone office of Land administrator

Unkaa Ragaa Itiifayadama Lafaa walitti qabame (existing major land use types)

Godina __Sh/Kaabaa____________________ bara 2007

lak	Maqaa Aanaa	Balina Aanaa (Ha)	Balina gosa itti Fayadama Lafaa Hektaaran													
			Qonnaa			Bosona			Micireen kan qabame (bush &	Lafa Dhedicha (grezing land)	Lafa margaa (grass land)	Lafa ijaarsaa (settlment)	Paarkii/dawo	Lafa caffe(Marsh area)	Lafa Dhagaa (Rocky area)	Kan biraa(yaaibsamu)
			Roban	*Jalisiin*	*Ida'ama*	Kan umamaa	Kan namaan dhabate	Ida'ama								
1	W/Jarso	119835	39847	1512	41359	2330	0	2330	11567	30479	0	32657	0	0	1443	0
2	Kuyyu	94575	48084.84	6609.6	54694.44	2833.649	0	2833.649	3838	13467.71	0	7260.68	0	0	3168.11	931[illegible]
3	Deraa	160315	127700.6	302	128002.6	13725.3	1054.5	14779.8	2020	2303.5	0	2100	0	1500	4578	[illegible]030.62
4	H/Abote	50382	30831.54	4950	35781.54	2334.5	679	3013.5	5638	3734.96	0	1166	0	0	96[illegible]	[illegible]8
5	Dagam	71517	36370	7729	44099	1340	0	1340	0	12197.64	0	7372.85	0	0	0	6507.11
6	G/Jarso	49435	36461	545	37006	547	194	741	0	6466	1443	813	0	0	0	2966
7	Y/Gulale	33649	18226	5638.05	23864.05	1407.02	678.1	2085.12	514.09	3004.1	900.7	1389.59		214.05	641.25	1036.61
8	D/Libanos	29408	10909	*7805*	18714	713.4	155	868.4	28.09	5882.116	2529.937	1384.797	0	0	0	0
9	Wechale	90227	59691.51	4158	63849.51	0	720.49	720.49	451	15855.93	0	8964.68	0	0	0	385.395
10	Jida	48804.9	19214.3	1900	21114.3	20	556.25	576.25	0	24602.04	0	2087.99	0	0	0	424.32
11	Aleltu	49217	22531	5856	28387	2516	1500	4016	2750	5535	3391.25	2625	0	500	2013.71	0
12	Qimbibit	67993	*45000*	*7084*	52084	130	900	1030	20	11016	1422	1037	0	45	16	1323
13	A/Nya'a	70208	28751	5284	34035	105	856	961	0	22929	0	11843	0	0	0	440
		935565.9	523617.79	*59372.65*	582990.44	28001.869	7293.34	35295.209	26826.18	157472.996	9686.887	80701.587	0	2259.05	12820.07	27513.465

Hubachisa hanga danda'ameti kaartaan haadegaramu

Kan qphese__________ kan mirkanese Tibebu Asefa

Maqaa ______________ Maqaa______________

Malatoo____________ malatoo____________