

## Evaluation of Causes and Mitigation of Landslide in Harsu Area, Uruga Woreda, Guji Zone, Southern Ethiopia

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### Abstract

*In Ethiopia, the magnitude of landslide occurrence and its resulting damage has been increasing in recent times. The aim was to undertake comprehensive inventory of landslides, evaluate the geological, and engineering geological condition, and state the main factors causing landslides and develop hazard zonation map of study area. Analytical Hierarchy Process method were used to analyse, evaluate and interpret laboratory data's and produce landslide hazard zonation map. The area is classified into four landslide hazard zones; the high hazard zone covers about 22%, moderate hazard zone covers 36 %, the low hazard zone covers 32% and very low hazard zone area covers 20% of the study area. From the inventory data only 6% of the field slopes falls on the very low hazard class, 18% of the landslide falls in low hazard zone, 31% of the landslide falls in the moderate hazard zone and 46% falls High hazard zone. Based on the result analysed, mitigation measure were provision of Gabion retaining structure, drainage improvement, bioengineering using vegetation and develop proper land use plan.*

**Keywords:** *Landslide, Causative factors, Landslide zonation, Mitigation measure*

### 1. Introduction

As defined by Croziers and Glade (2005), landslides are the most significance natural

hazards in many areas of the world. Every year they cause more than 100,000 deaths and injuries and more than one billion USD

in damage (Schuster, 1996). Annual global economic losses due to landslides were estimated to be in the order of two to five billions US Dollars (Schuster, 1992). A landslide can be caused by one or more factors, which are geological, morphological, physical, and human factors are the common (Wieczorek, 2009). According to Wieczorek (2009), landslide trigger refers to an external stimulus, such as intense rainfall, rapid snowmelt, earthquake, volcanic eruption, stream or coastal erosion. These initiate an immediate or near immediate landslide movement by rapidly increasing shear stresses or pore water pressures, by ground acceleration due to seismic activity, by removing lateral support, by reducing the strength of slope materials. According to Cruden and Varnes (1996), different types of slope movement, such as fall, topple, slide, spread and flow, can occur in a variety of materials and degrees of slopes and specific types such as rock fall, earth slump and debris flow, can occur depending upon the types of geological materials and movement. Landslides are causing problems in Ethiopia especially in highlands (most parts of the North, Southern and Western region of the country) and parts of the rift valley escarpments (Ayalew *et al.*, 2014). From

1993 to 1998 alone, about 300 lives have been lost, more than 200 houses demolished, over 100 km long road damaged and in excess of 500 ha of land destroyed (Ayalew, 1999). According to Kefeyalew (2001), heavy rainfall, very steep slope, and unconsolidated weak material or sediment and gully erosion are the most critical factors for the movement of materials from unstable areas. The hillside and mountainous terrains of the Southern part of Ethiopia, Guji Zone, Uruga Woreda, around Harsu village, have been affected by different types of landslides, resulting in damage on agricultural land and forest lands as well as dwelling houses since 2015 and have been reactivated in recent years. Most of the people in study area are living in hilly areas and they use the flat areas for agricultural purposes. As a result of the landslides a total of 201 ha of land was damaged and 112 number of people have been displaced from the area.

## 2. Materials and Methods

### 2.1. Study Area

The study area is located in Guji Zone, Oromia administrative Region, Ethiopia, in a locality called Harsu (Fig.1). It is found within the Geographical location of 663402mN to 677067mN latitude, and

458088mE to 465787mE longitude. The study area covers an area of 56km<sup>2</sup> is located at a distance of 417km from Addis Ababa. The road is asphalt from Addis Ababa to Dilla which is 347km and 70km is gravel from Dilla to Solomo, town of Uruga Woreda, where it is accessible by vehicle during no rainy season and the study area is 20 kilometre far from Solomo Town.

Topographically, it is characterized by rugged topography with steep hills slopes, ridges and small plateau in Harsu Village. The area is characterized by altitudes ranging from 1,850m to 2,350m a.m.s.l. The highest elevation is located at the plateau part of the Village and the lowest elevation is situated in the North part of the gorge towards to the Hawata River. Daniel Gemechu (1977), defined five traditional climatic zones with elevation as: < 800 m Desert (Bereha), from 800m-1500m Tropical (Kola), from 1500-2300m Subtropical (Weyna dega), from 2300-3300m Temperate (Dega) and >3300 m Alpine (Kur). According to this traditional climatic zone classification, the present study area falls from Subtropical (Weynadega) and Temperate (Dega), as the elevation ranges from 1,806 m to 2,392 m.

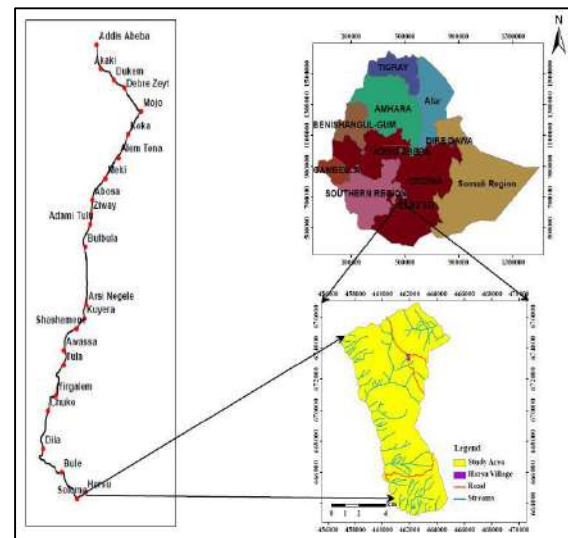


Figure 1. Location and accessibility map of study Area

## 2.2. Samples and Methods

Different methods were used to achieve the aims of the study includes; literature review, field investigations, laboratory works, data analysis and evaluations by Analytical Hierarchy Process (AHP) methods, landslide hazard zonation mapping and development of landslides mitigation practice (Fig. 2).

To evaluate Engineering properties of the representative soil samples collected laboratory test were carried out which include gradational test and Atterberg's limit (liquid limit and plastic limit), and moisture content test. Tests were done at Hawassa University using ASTM standards methods.

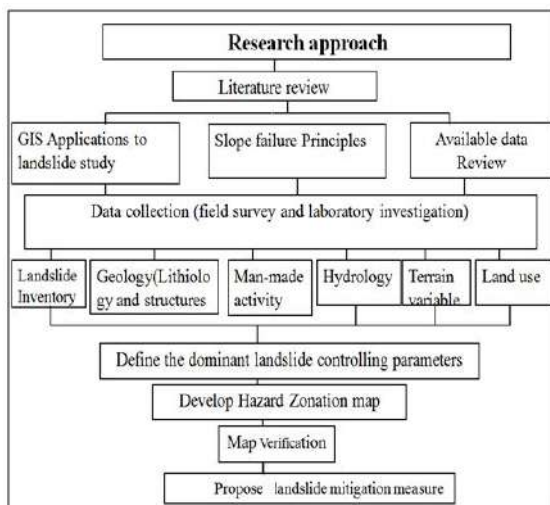


Figure 2. Flow chart showing the research approach

### 2.2.1 Data Analysis and Evaluation by using Analytical Hierarchy Process (AHP) Method

In order to prepare landslide hazard Zonation map of the present study area, six major causative factors parameter were used: lithology, slope gradient, land use /land cover, slope curvature, distance from streams/rivers and ground water condition. After the selection of the causative factors, thematic maps were generated using GIS. The thematic maps corresponding to slope gradient, curvature, distance from streams were obtained directly in raster format from the produced DEM, while the others (lithologies and ground water condition) were produced by the vector format digitization transformed into the raster format by using GIS software and Land use

map was prepared from land sat +ETM satellite (2016) using digital image processing techniques. Each of the factors were grouped into classes, given a weighting depending on its degree of relationship to the landslide hazard and added to give the evaluation of landslide hazard rating for the relative hazard classification.

After computing the weight of each factors and the rate of each class using AHP method, the Landslide Susceptibility Index (LSI) was calculated by summing up each factor's weight multiplied by class weight of every referred factor written as follows.

$$LSI = \sum_{i=1}^n (W_i * R_i)$$

LSI- Landslide susceptibility index of the given pixel,

W<sub>i</sub>- factors weight for factors i and,

R<sub>i</sub>-rating value for factors i

After determination of the total value of landslide susceptibility index parameters (causative factors), Landslide hazard Zonation map was generated.

Finally, the study area was classified into four major classes: High Hazard Zone, Moderately Hazard Zone, Low Hazard Zone and Very Low Hazard Zone.

### 3. Result and Discussion

#### 3.1. Landslide Hazard Zonation of the Study Area

Landslide has caused much hazards and significant economic losses at the study area and over through the district. In the study area different causative factors were evaluated that to promote down slope movement and effective of movement results landslide hazard, which was dangerous to environment and human life. According to Varnes (1984), the term Landslide Hazard Zonation applies to categories the area and arrange them according to the degrees of actual or potential hazard from a landslide or slope instability based on an estimated significance of causative factors inducing that instability.

In the study area Landslide susceptibility hazard Zonation mapping was carried out to identify zone those areas, which have possibly high potential for future hazard, factors causing landslide and where areas necessary to need type of remedial measurement for hazard Zonation.

##### 3.1.1 Landslide Hazard Zonation mapping by Analytical Hierarchy process (AHP) Method

To evaluate the hazard Zonation of the  
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study area, Analytical hierarchy process (AHP) method developed by Saaty (1980), was adopted. In order to prepare landslide hazard Zonation map by using the AHP method for the study area, six major causative factors parameter were combined. The value of the consistency ratio (*CR*) is smaller than 0.1, then the comparison satisfies the consistency requirements. Each of the factors was grouped into classes, given a weighting depending on its degree of relationship to the landslide hazard and added to give the evaluation of landslide hazard rating for the relative hazard classification. The logical assumption made for this purpose is that the risk of occurrence of landslide is a direct consequence of these parameters. After computing the weight of each factors and the rate of each class using AHP method, the Landslide Susceptibility Index (*LSI*) was calculated by summing up each factor's weight multiplied by class weight of every referred factor written as follows (Voogd, 1983).

$$LSI = \sum_{i=1}^n (Wi * Ri)$$

*LSI*- Landslide susceptibility index of the given pixel,

*Wi*- factors weight for factors *i* and,

*Ri*-rating value for factors *i*

### 3.1.2. Weighting the different causative factors

In this study, the analytical hierarchy process (AHP) was applied to develop landslide Hazard zone map for the Harsu area. Six landslide inducing factors were calculated; such as slope gradient, distance from river/ streams, slope curvature, lithology, ground water and land use/land cover (LULC). These factors were evaluated and then factor weight and class weight were assigned to each of the associated factors according to AHP method (Table 1).

Table 1: Pair-wise comparison matrix, factor weightings and CR of the factor

Factors	Slope gradient	Distance from river	Slope curvature	Lithology	Ground water	LULC	Weighting(%)
Slope gradient	1	2	3	5	7	9	0.38
Distance from River/Stream	1/2	1	2	4	3	7	0.26
Slope Curvature	1/3	1/2	1	3	1/3	9	0.17
Lithology	1/5	1/4	1/3	1	2	7	0.10
Ground Water	1/7	1/3	3	1/2	1	5	0.05
LULC	1/9	1/7	1/9	1/7	1/5	1	0.04
CI=0.078, $\lambda^{\max}$ =6.39, n=6, CR=0.062, RI=1.24							

### 3.1.3. Weighting the different class factor

#### 3.1.3.1 Slope Gradient map

Slope gradient defines the inclination of the slope (Anbalagan, 1992). Slope gradient is factor determination of the intensity and character of landslides at the study area. Steeper slopes have greater chance of

landslide, however, at the study area more failures occur on gentle and moderately steep slopes. The slope gradient map is prepared and slope angle is measured by using Arc GIS software from DEM.

The slope gradient Harsu area indicates the steepness of the slope, which are cliff (>45°), steep (35°-45°), moderately steep (25°-35°), gentle slope (15°-25°), and very gentle slope (<15°) were indicated in (Fig.3). These factors were evaluated, and then factor weight and class weight were assigned and rating to each of the associated factors according to AHP method in (Table 2).

Table 2: Relative influence of the different classes' weight and rating of slope gradient area

Slope Gradient	<15	16-25	26-35	36-45	>45	Weight(%)
<15	1	1/5	1/6	1/5	1/2	0.05
16-25	5	1	1/2	1/3	2	0.18
26-35	6	2	1	3	4	0.41
36-45	5	3	1/3	1	3	0.27
>45	2	1/2	1/4	1/3	1	0.09
CI=0.08, n=5, CR=0.07, $\lambda^{\max}$ =5.44, RI=1.12						

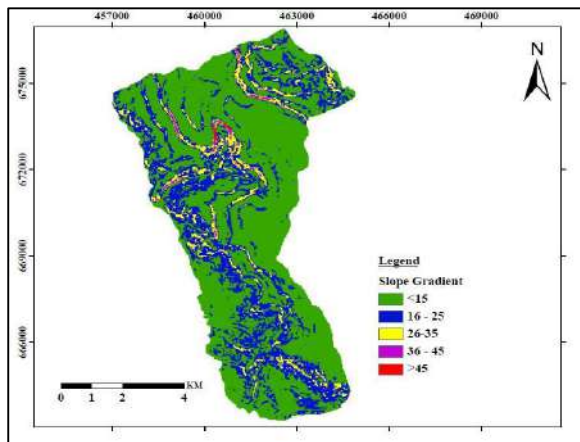


Figure 3: Slope gradient map of the Area

During the field work the various rock types are identified in terms of intact rock and weathering. The soil type is classified based on visual observations and soil depth is assessed from the slope cuts along the road side, stream cuts on surface indications. According to Irfan and Dearman (1978), degree of weathering may affect the relative strength of the rocks. The degree of weathering has been considered as; fresh, slightly weathered, moderately weathered, highly weathered, extremely weathered and rock as soil. The significant impacts of weathering on the rock units of the study area has been verified by observation during the field investigation of the study area.

The lithology of the study areas were, residual soil, Colluvial material, Basalt, Mica schist with amphibolite, Biotite Gneiss and Granite Gneiss indicated on the (Fig. 4). These lithological unit were

### 3.1.3.2 Lithology map

To prepare lithological maps of the study area, pre-existing lithological map of the area can be utilized. Thus, a pre-field map is prepared where the lithologies and soil coverage is transferred over the slope face.

evaluated, and then factor weight and class weight were assigned and rating to each of the associated factors according to AHP method in (Table 3).

Table 3: Relative influence of the different classes' weight and rating of lithology

Lithology	Residual soil	Colluvial Material	Basalt	Mica schist with Amphibolite	Biotite Gneiss	Granite Gneiss	Weight(%)
Residual Soil	1	2	3	5	7	9	0.40
Colluvial Material	1/2	1	2	3	7	7	0.26
Basalt	1/3	1/2	1	2	4	5	0.16
Mica Schist with Amphibolite							
Gneiss	1/5	1/3	1/2	1	3	3	0.10
Biotite Gneiss	1/7	1/7	1/4	1/3	1	2	0.05
Granite Gneiss	1/9	1/7	1/5	1/3	1/2	1	0.03

CI=0.03  $\lambda_{max}$ =6.16, n=6 CR=0.02, RI=1.24

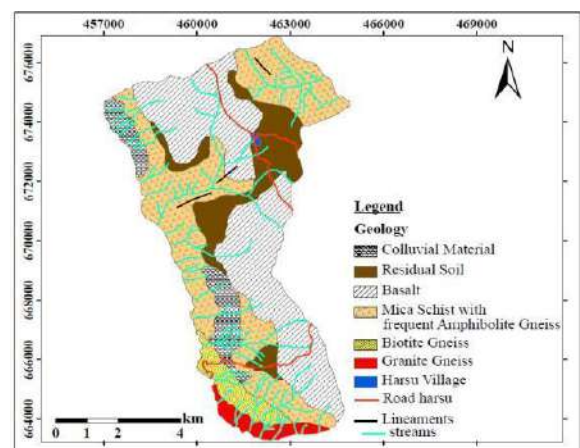


Figure 4: Geological map of the study area

### 3.1.3.3 Groundwater condition map

Ground water is the most important factor in most slope instability problems in the Harsu area. The way ground water flows, its pressure and gradient at any point with in a slope depend on local geology (Abramson, 1996).

The nature of surface indications of the behavior of ground water such as damp, wet, dripping and flowing will provide valuable information on the stability of hill slopes and these are helpful for rating purpose (Anbalagan, 1992).

Groundwater condition map of the study area has been prepared using topographic map as base map and data on groundwater indications like presence of spring on slope face, surface marks of the presence of

Table 4: Relative influence of the different classes' weight and rating of Groundwater

Ground Water	Flowing	Dripping	Wet	Damp	Dry	Weight(%)
Flowing	1	2	3	5	7	0.42
Dripping	1/2	1	3	4	5	0.29
Wet	1/3	1/3	1	2	5	0.15
Damp	1/5	1/4	1/2	1	3	0.09
Dry	1/7	1/5	1/5	1/3	1	0.04

CI=0.06, N=5,  $\lambda_{max}=5.23$ , CR=0.05, RI=1.12

### 3.1.3.4 Distance from river/streams map

Saturation degree of the soil on slopes has been contributing parameter landslide initiation in Harsu area. Water infiltration in soil, runoff and groundwater flows

ground water flow, algal growth in shadow areas and others has been observed.

The observations made on surface water traces were taken using GPS and later were transferred to the map using ArcGIS software.

In Harsu area 60% of the study area was classified as flowing due to the dominant availability of springs with high discharge of water on slope face, about 13% area was classified as dripping, 14 % of area as wet and 6% of area is damp were indicated on (Fig. 5). These Groundwater were evaluated, and then factor weight and class weight were assigned and rating to each of the associated factors according to AHP method in (Table 4).

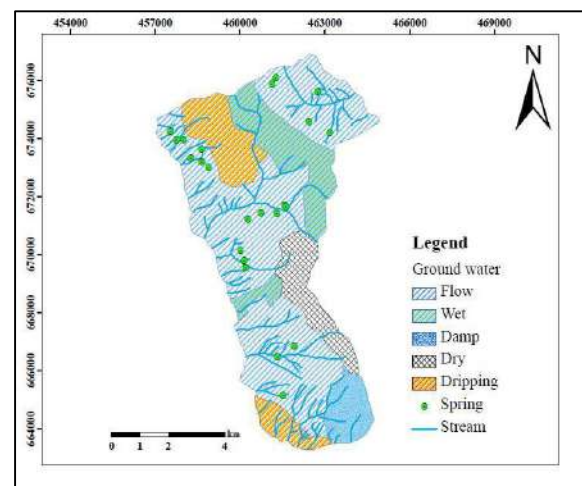


Figure 5: Groundwater condition map of the study area

were all happened under the hydrological circumstance (Thanh & De Smedt, 2011).

Streams may adversely affect stability by eroding the slopes or by saturating the lower part of material until resulting in water level increases (Yalcin, 2005). More of the slope of Harsu area were closes to drainage, stream/ river affect its stability, because the closeness to rivers had been activate the erosion process along the slope of study area.

Five different buffer areas were created with 100 to >500meters interval distance 1:50,000 by using Arc GIS software within the study area to determine the degree to Table 5: Relative influence of the different classes' weight and rating of distance from rivers

Factors	1-100	101-200	201-300	301-400	401-500	>500	Weight %
0-100	1	3	5	6	7	9	0.46
101-200	1/3	1	2	4	5	7	0.23
201-300	1/5	1/2	1	2	3	5	0.13
301-400	1/6	1/4	1/2	1	3	5	0.10
401-500	1/7	1/5	1/3	1/3	1	3	0.05
>500	1/9	1/7	1/5	1/5	1/3	1	0.03

CI=0.032,  $\lambda_{max}$ =6.16, n=6, CR=0.03, RI=1.24

### 3.1.3.5 Slope Curvature map

Curvature values represent the morphology of slopes which plays significant role landslide in the study area. Curvature was the causal factor on the basis that it affects the hydrological condition of the soil cover at the Harsu area. After rainfall, the soil

which the streams affected the slopes (Fig. 6).

Erosion process in Harsu area, water wears away vegetation, sediment, and soil from the riverbed and banks in the study area and down-cutting erosion forms many steep valleys on both sides of river and streams to makes it hazardous. These distance from rivers were evaluated, and then factor weight and class weight were assigned and rating to each of the associated factors according to AHP method in (Table 5).

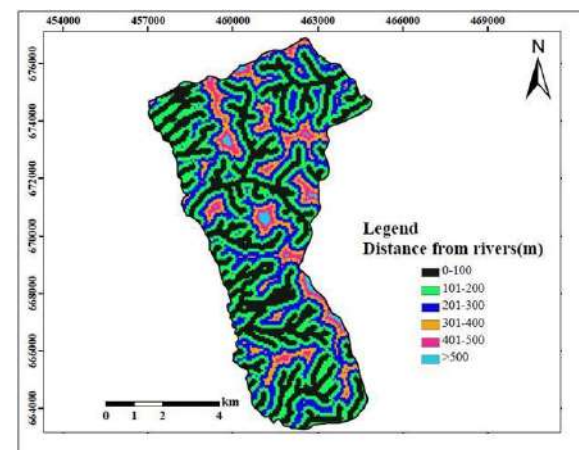


Figure 6: Distance from streams map of the study area

cover on a concave slope contain more water and retain it for a longer period than a convex slope and planar that causes slope instability in Harsu area.

In the curvature raster file the positive curvature values indicate that the surface is convex at those cells, the negative values

indicate that the surface is concave at those cells and the value of zero indicates that the surface is flat. The more negative the value the higher the probability of landslide occurrence, and the more positive the value the lower the probability (Fig. 7).

Table 6: Relative influence of the different classes' weight and rating of Slope curvature

Factors	Concave	planar	Convex	Weight(%)
Concave	1	5	9	0.75
planar	1/5	1	3	0.18
convex	1/9	1/3	1	0.07
CI=0.025, $\lambda_{max}=3.05$ , $n=3$ , CR=0.04, RI=0.58				

### 3.1.3.6 Land use and Land cover map

According to Greenway (1987), the different land use types and land cover control the stability of slopes, and in particular, slope stability is enhanced in terms of mechanical and hydrological characteristics. Land Use/land cover of an area depends on climatic factors, land escapes, land use practice and pasteurized. Land use land cover categories in the area has been interpreted from detail field observation during the study and has been identified as: Agricultural land with populated area, 38%, dense vegetated forest lands, 14%, moderately vegetated areas, 45%, sparsely vegetated areas, 3% sparsely vegetated were respectively indicated on (Fig. 8). These Land use/Land cover were evaluated, and then factor weight and class weight were assigned and rating to each of the associated factors according to AHP method in (Table 7).

These slope curvature were evaluated, then factor weight and class weight were assigned and rating to each of the associated factors according to AHP method in (Table 6).

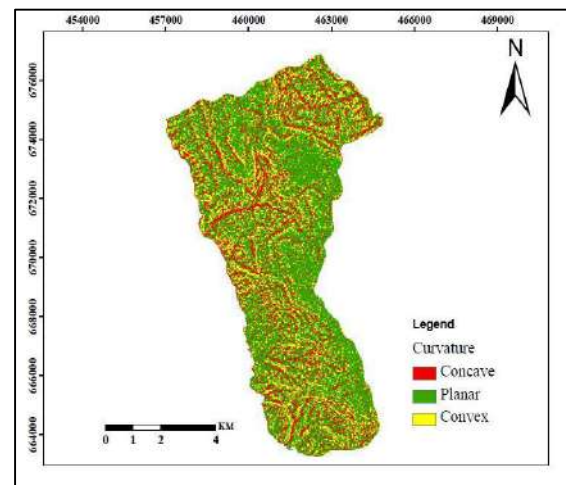


Figure 7: Slope curvature map of the study area

Land use/Land Cover	Sparsely Vegetated	Moderately Vegetated	Forest	Agricultural land with populated	Weight(%)
Sparsely Vegetated	1	3	5	6	0.55
Moderately Vegetated	1/3	1	3	5	0.27
Forest	1/5	1/3	1	3	0.12
Agricultural land with populated	1/6	1/5	1/3	1	0.06

CI=0.07,  $\lambda_{max}$  =4.22, n=4, CR=0.08, RI=0.90

### 3.2.Evaluation of Landslide Hazard Zone of the Study Area

After determination of the total value of landslide susceptibility index parameters which include the causative factors, Landslide hazard Zonation map was generated. The generalized landslide hazard Zonation map of the area was produced to indicate the probable areas where the future landslide activity may take place. Accordingly, the study area has been classified into four major classes; high hazard zone, moderately hazard zone, low hazard zone and Very Low Hazard Zone (Fig. 9).

#### 3.2.1. Very Low Hazard Zone

Very low hazard zone area covers 20% of the study area (Fig. 10). The area is covered with residual soils and represents relatively safe areas for human settlement, and suitable for agricultural development and

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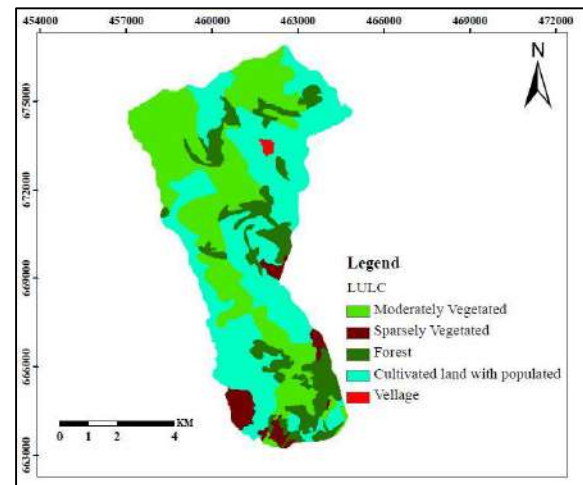


Figure 8: Land use Land cover map of the study area

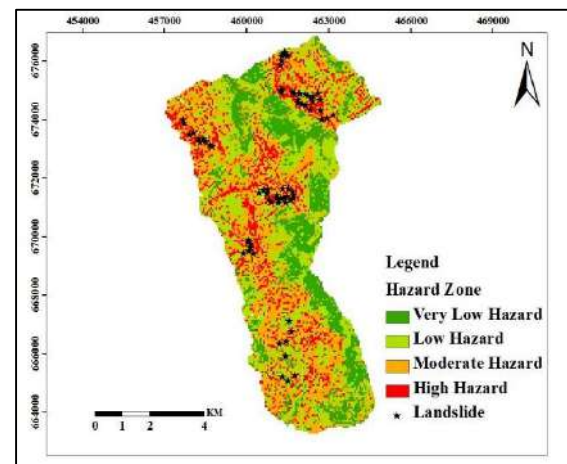


Figure 9: Hazard Zonation map of the study area

dwelling. Local problems may occur along stream gullies and in expansive-soil areas under extremely high rainfall intensity causes flood problem at the area.

### 3.2.2 Low Hazard Zone

The low hazard zones are located in the study area, where populated land, farm lands vegetation and colluvial slopes is located. The Low Hazard Zone covers 32% of the total study area which are mostly gentle area or low relief used for the purpose of agriculture and dwelling (Fig.10).

### 3.2.3 Moderate Hazard Zone

Moderate hazard zone covers 36 % of the study area in which active landslide, crack, soil mass sliding and colluvial materials were deposited. These areas include very gentle slope, where landslide have been triggered mainly by erosion of rain water, particularly where the banks are made up of soil and unconsolidated material and at point of maximum curvatures of streams (Fig.10).

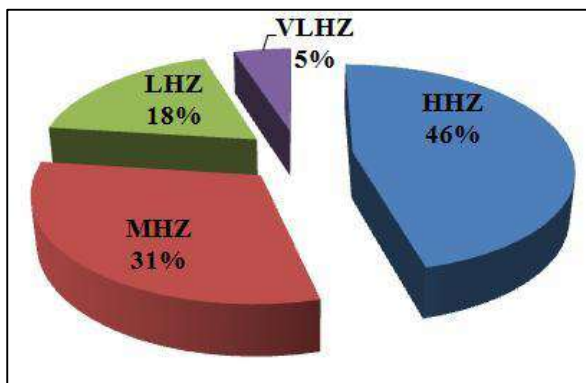


Figure 10: Pie chart percent distribution of landslide in Hazard zone

### 3.3. Validation of landslide Hazard

The verification was performed by  
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### 3.2.4. High Hazard Zone

The high hazard zone covers about 22% of the study area. These areas show clearly recognizable evidence of active landslides or reactivation in parts of the old landslide units with some sliding currently taking place. The high hazard zones are consists of some bolder basalt units, weathered basal and weathered mica schist and interrupted soils, associated with unconsolidated materials in steep slope areas.

The areas are characterized by higher rainfall and greater surface runoff. The interrupted soils and incompetent weathered basaltic rocks and mica schist create favourable conditions for landslide activity when groundwater seeps into these formations (Fig.10).

comparison of existing landslide data (inventory data) with the prepared landslide hazard zone map. From the inventory data only 6% of the field slopes falls on the very low hazard class, 18% of the landslide falls in low hazard zone, 31% of the landslide falls in the Moderate hazard zone and 46% falls High hazard zone. The existing landslide location shows satisfactory agreement with the present landslide hazard map.

### **3.4 Landslide Mitigation Measurement**

In the study area, landslides are extensively damaging agricultural land. It has affected 201 hectare of agricultural lands and 22 households were displaced. Therefore, possible preventive and remedial measures that could be taken for these area affected by landslide.

The main landslide mitigation measures recommended in this study area include;

- Drainage: surface and sub-surface.
- Control structure: Gabion wall
- Slope stabilization by vegetation
- Control Human activity
- Vetiver grass system of slope protection
- Develop proper land use plan

### **4. Conclusion**

The hillside and mountainous terrains of the Southern part of Ethiopia, Guji Zone, Uruga Woreda, around Harsu Village are affected by different types of Landslide and the consequence of these landslide have been damage on agricultural land and forest lands.

Landslides have been caused loss of crop type, 115 hector of Inset, 23.8 hector of Coffee, 36.4 hector of Meaze, 7.2 hector of Bean, and 2.1 of hector of Teff and 6.6 hector of Sugarcane were destroyed.

Moreover, the landslides have affected 201 ha of agricultural land, 22 households were displaced from their settlement.

Types of landslide at the study area were identified as rotational, debris flow slides, creep movement, lateral spread and earth flow. The major factor causing landslide; the type of rock weathering, type of soil, slope morphology, ground water condition, land use, rainfall and man-made activity were identified.

According to the results of the (LSI) obtained, the study area is represented by four Landslide Hazard zones; High Hazard, Moderately Hazard, Low Hazard and Very Low zones. Overall result of the study indicates that about 46 % of the present study area falls within the High Hazard Zone, 31% falls in Moderate hazard zone, 18% falls in low hazard zone and the remaining 5% falls in very low hazard zone. Landslide hazard mitigation of the Harsu area were depended on actions that are carried out before and forecast the disaster occurs generally involving landslide hazard Zonation mapping, construction of control structures Gabion, drainage improvement, slope stabilities using vegetation(vetiver grass system afforestation) and Control human activity were applicable for this

landslide remedial measurement and mitigation.

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