

Remote Sensing and GIS Based Potential Landslide Hazard Zonation in Ambo Woreda: Central Ethiopia

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Abstract:

Landslide hazard is becoming a serious problem in many parts of the world because of its frequent occurrence and related effects it is causing to human and properties. Areas of high altitude and steep slopes were susceptible to landslide hazards depending on their soil type, geology, land use/ land cover, proximity to road and streams, aspects, seismic level and ground water level variation. Even though there are problems related to landslide hazards in the region where Ambo woreda is located, there was significant landslide related scientific studies conducted in the area. The current study was aimed to prepare landslide hazard zonation map for Ambo Woreda based on landslide hazard causal factors including spatial rainfall distribution, local geology, slope, elevation, aspect, soil type, LULC, distance from stream and land slide inventory data based on Geographical Information System and remote sensing techniques. As a result 921 polygons covered an area of 32.9km² (3.43%) of the total study area was found with past landslide hazards. Past landslide hazard areas were studied to investigate the contribution of each landslide causing factors and to map the potential landslide hazard zones of Ambo woreda. Consequently the study area was categorized in to four levels of Potential Landslide Hazard Zones termed as very high, high, moderate, low and very low. The total area of about 959.7km², was classified as 14.7%, 53.28%, 23.43%, 4.99% and 3.6% among the very high, high, moderate, low and very low potential landslide hazard zones respectively. The presence of very high and high potential landslide hazard levels in wider area of Ambo woreda can be used as a warning message for local planners and the community to urgently plan for the reduction of potential landslide disaster risk reduction using various practices such as intensive soil and water conservation works and enhancing landslide disaster preparedness activities.

Keywords: Landslide Hazard, Landslide hazard zonation, Potential landslide hazard

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1. Introduction

Landslides are natural hazards occurring in many parts of the world as a result of geological/geomorphologic processes (Mahler et al., 2012). Landslides can be initiated by numerous natural factors including heavy rainfall, snowmelt, and changes in ground water level, erosion, earthquakes, volcanic activity, and disturbance of natural slopes. Deforestation/ changing vegetation coverage of the landscapes and mining are among many other human caused activities lead to occurrence of landslide hazards (Mandler, 2017; Hamza and Raghuvanshi 2016; Raghuvanshi et al., 2015; Raghuvanshi et al., 2014; Nakamura et al., 2014; Reichenbach et al., 2014).

Geomorphological conditions such as elevation, slopes, aspects, soil infiltration capacity, surface excavations, and rainfall, complex fragile geology with increased manmade activities such as construction of roads on mountains, Land Use/ Land Cover (LULC) change and heavy rain are the major causing factors of past landslides in Ethiopia (Kifle, 2013; Karsli et al., 2008; Kifle et al., 2006 and Girma et al., 2015; Ayalew and Yamagishi, 2004).

Landslide hazards have the potential to cause loss of life and damage to man-made structures and other environmental elements (Gertsema and Highland, 2011). Landslide hazards occurred in different parts of the world during 2004 to 2016 resulted to death of 55,997 people as indicated in various sources. And few studies conducted in several parts of Ethiopia indicated landslides were caused disasters in in areas such as northern highlands (Dessie areas, Shale hill slopes, Tigray, Tekeze areas), Central highlands (Abay basin, Jema basin, West Shoa, Tarmaber and surroundings), Southern regions (Gofa, Gilgel Gibe II, Sodo-Shone area and Wondo Genet) and in several places of Ethiopian rift valley margins (Kifle 2013 and Abebe et al., 2010).

From 1993-1998 losses of 300 people, demolishing of 200 houses, damaging of 100km road and devastating of more than 500 hectares of agricultural land were recorded at different parts of Ethiopia (Ayalew, 1999 and Kifle, 2013). From 1999 - 2008 more than 135 death of human, destruction of 1450 houses, displacement of 6,500 people, damaging of more than 2000 hectare of land and more than 100km asphalt roads and damage of resources estimated to 1.5 million dollars were documented in Ayalew (1999) and Kifle, (2013).

Landslide hazard initiated by the torrential rains during the summer of 2018 caused 23 death and 15 injuries to people, death of more than 30 domestic animals, damaging of 12 homes and more than 6 hectares of land in southern region of Ethiopia. Similarly more than 30 people died in Addis Ababa city as a result of landfills sliding during 2017. According to Kifle (2013) land slide disasters in Ethiopia may exceed beyond what were reported

because many of them were not reported unless they located around the economic routs and derived the communities for critical support from the government.

In Ambo woreda there was no considerable scientific studies conducted concerning the causal factors, distribution and consequences of landslide hazards. But Ambo woreda is characterized by high number of population and various resources exposed to Potential Landslide Hazard (PLSH) that will possibly cause significant injuries and damage of property unless precaution measures will be taken based on the results of scientific studies. The present study was aimed to prepare landslide hazard zonation map for Ambo Woreda based on landslide hazard causal factors including spatial rainfall distribution, local geology, slope, elevation, aspect, soil type, LULC, distance from stream and land slide inventory data.

2. Methodology

2.1. Study Area

The study was conducted in Ambo woreda found in West Shewa Zone part of Oromia regional state in central Ethiopia. The administrative center of this wereda is Ambo town (Figure 1). The geographical location of Ambo Wereda is found between ($8^{\circ} 47'$ - $9^{\circ} 21'$) N and ($37^{\circ} 32'$ - $38^{\circ} 3'$) E (Figure.1). Ambo wereda is located at a distance of 114km from Addis Ababa the capital city of Ethiopia. According to Ethiopian Central Statistical Agency's (ECSA) census data of 2007, the population of Ambo Wereda was 202,655 (99,859 male and 102,796 female) (ECSA, 2010).

According to the data obtained from Ethiopian Metrological Agency (EMA), Ambo Wereda is characterized by mean annual average rainfall of 1036mm while other nearby stations indicated the presence high rainfall reaches 1241mm and its maximum and minimum temperature ranges from 10°C - 28°C respectively. The altitude of the area varies from 1277 - 3225 meter above sea level and it has lowland, midland and highland agro climatic zones.

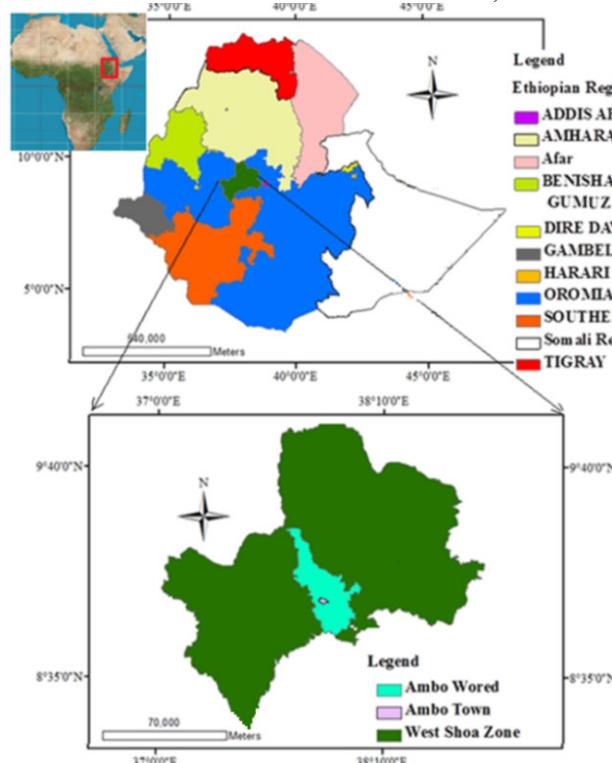


Figure 1 Location map of the study area

2.2. Methods of data collection and Analyses

The methodology followed for landslide hazard zonation of Ambo woreda using GIS and remote sensing techniques, divided into three phases namely: pre-fieldwork, fieldwork and post field work.

2.2.1. Pre-fieldwork

At this phase base map preparation, image downloading, geo referencing and projection, topographic map preparation and secondary data collection were carried out.

Elevation, slope, aspect, soil, geology, and distance from the stream, rainfall, elevation, slope, aspect and distance from the stream map layers were generated from DEM of resolution 90m downloaded from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER). Rain fall data of 7 stations (table 1) were obtained from EMA. Inverse Distance Weighting (IDW) interpolation model was adopted to prepare the layer map

of spatial rainfall distribution of the study area (figure 3H). GIS techniques were applied to prepare all the factor layer maps in Arc Map version 10.2. And all maps used in this study were geo-referenced based on GCS-WGS-1984 and projected to the coordinate system of Universal Transverse Mercator (UTM) zone 37N (WGS, 37N).

2.2.2. Field work

Landslide inventory, ground control points collection was conducted for LULC, soil and geology. GPS instrument was used to collect and recorded locations of past landslides and information of LU/LC types, geological units and nature of soil in the study area were studied and notes were taken during the field work for verification and further analysis at office.

2.2.3. Post field work

Following the field study and literature review, landslide inventory mapping, LULC map preparation, soil map and geological map preparation and assembling and preparation of all raster maps and reclassification of landslide triggering data/factors, analyses of landslide factors in relation to landslide inventory results, factor weighting and potential landslide hazard zonation mapping were conducted. The soil map was prepared from FAO (1974) with minimum modifications based on field investigations. Geology of the study area was modified from existing Ethiopian geology map prepared by Geological survey of Ethiopia (GSE) during 1972 after field investigation. Landsat 8 OLI/TIR image of February 2018 downloaded from USGS was used to classify LU/LC of the study area based on supervised classification techniques.

3. Result and Discussions

3.1. Landslide Hazard Inventory Mapping

Landslide inventory map was prepared based on past landslide data collected from field and Google Earth Image (Figure 2 B) (GEI). Global Positioning System (GPS) instrument was used to collect and record locations of past landslides during field investigations (Figure 2 A). Mapping of landslide polygons were made by importing the data collected from field and GEI to Arc Map. A total of 921 polygons of past landslides covered 32.9Km²(3.43%) of the total area of Ambo woreda were mapped (Figure 2 D). The resulted landslide inventory map was used to evaluate landslide triggering factors and potential landslide hazards.

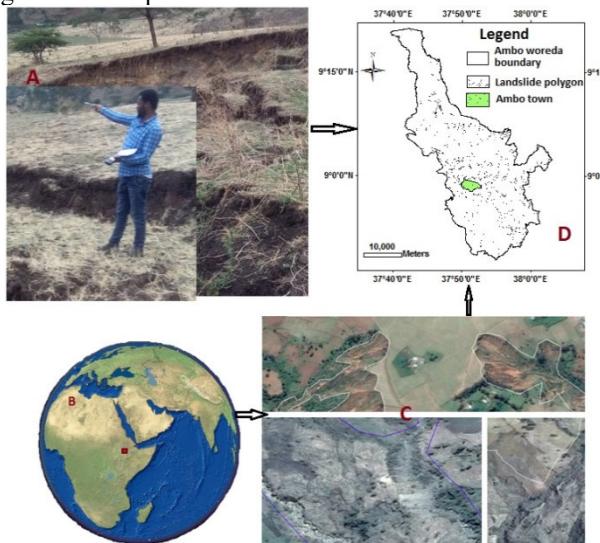


Figure 2 Landslide inventory map of Ambo woreda (D) prepared based on field investigation data (A) and Google Earth Image (B and C)

3.2. Landslide Hazard Causing Factors Generating

Eight landslide hazard triggering factors were identified for the present study following detail field investigation and literature reviews. The eight landslide triggering factors identified as a causal factors for PLSH analyses of Ambo woreda are listed as elevation, slope, aspect, soil, geology, and distance from the stream, rainfall and LULC. The factors were reclassified in to sub factors for further analysis (Table 2).

The reclassified landslide causing factors were weighted (table 3) using the Statistical Index (SI) model approach that was introduced by Van Westen (equation1). The SI model is a bivariate statistical analysis that has been widely used in many studies (Oztekin and Topal, 2005 and Pourghasemi, et.al, 2013). In the SI method, the weighted value for each categorical unit of the factor causing landslide hazard is expressed as the natural logarithm of the area of landslide hazard in any class divided by area of landslide hazard in the entire study area. This method is based on the distribution of landslide hazards across each class. Weighted factors overlay methods of GIS was used to determine the Landslide Hazard Index (LSHI) based on equation 2. The LSHI was used to zone the PLSH

of Ambo woreda (Figure 4) after reclassification of LSHI based on natural breaks system of Arc Map (Table 4). The highest value of LSHI represent the highest degree of potential landslide hazard while the lowest value represent the lowest degree of landslide hazard.

Table 1

Average annual rainfall of 7 different stations

Station	Rainfall	Geographic Coordinate		Station	Rainfall	Geographic Coordinate	
		Easting	Northing			Easting	Northing
Ambo	1036	37.8700	8.9700	Bako	1237	37.0833	9.1167
Ginchi	1135	38.1333	9.0167	Busa	1177	38.1382	8.7725
Jeldu	1241	38.0833	9.2500	Tulu-Bolo	1109	38.2065	8.6545
Weliso	1210	37.9833	8.5500				

Table 2

Reclassified Landslide hazard triggering factors

Landslide triggering factor	Landslide triggering factor class								
Elevation(m)	1277-1706	1706-2093	2093-2372	2372-2674	2674-3225				
Slope	0-5	5-12	12-30	30-38					
Aspect	Flat	North	Northeast	East	Southeast	South west	West	North west	North
Soil	Cambisols	Leptosols	Luvisols	Nitosols	Vertisols				
Geology	Sandstone	Basaltic	lava flow	Limestone	Gypsum				
Distance from Stream	0-50	50-250	250-1000	>1000					
Rainfall(mm)	1036-1077	1077-1118	1118-1159	1159-1200	1200-1241				
Land use/Land cover	Settlement	Rangeland	Shrub	Bare land	Forest	Agriculture			

$$W_{ij} = \ln \left(\frac{(N_{ij}/M_{ij})}{(N/M)} \right) \dots \text{Equation 1}$$

Where:

- W_{ij} is the weight of the i^{th} class of the j^{th} parameter
- N_{ij} is the area with landslide hazard in the i^{th} class of the j^{th} parameter

M_{ij} is the area in the i^{th} class of the j^{th} parameter

- N is the total area with landslide hazards
- M is the total area of Ambo woreda

$$LSHI = \sum W_{ij} \dots \text{Equation 2}$$

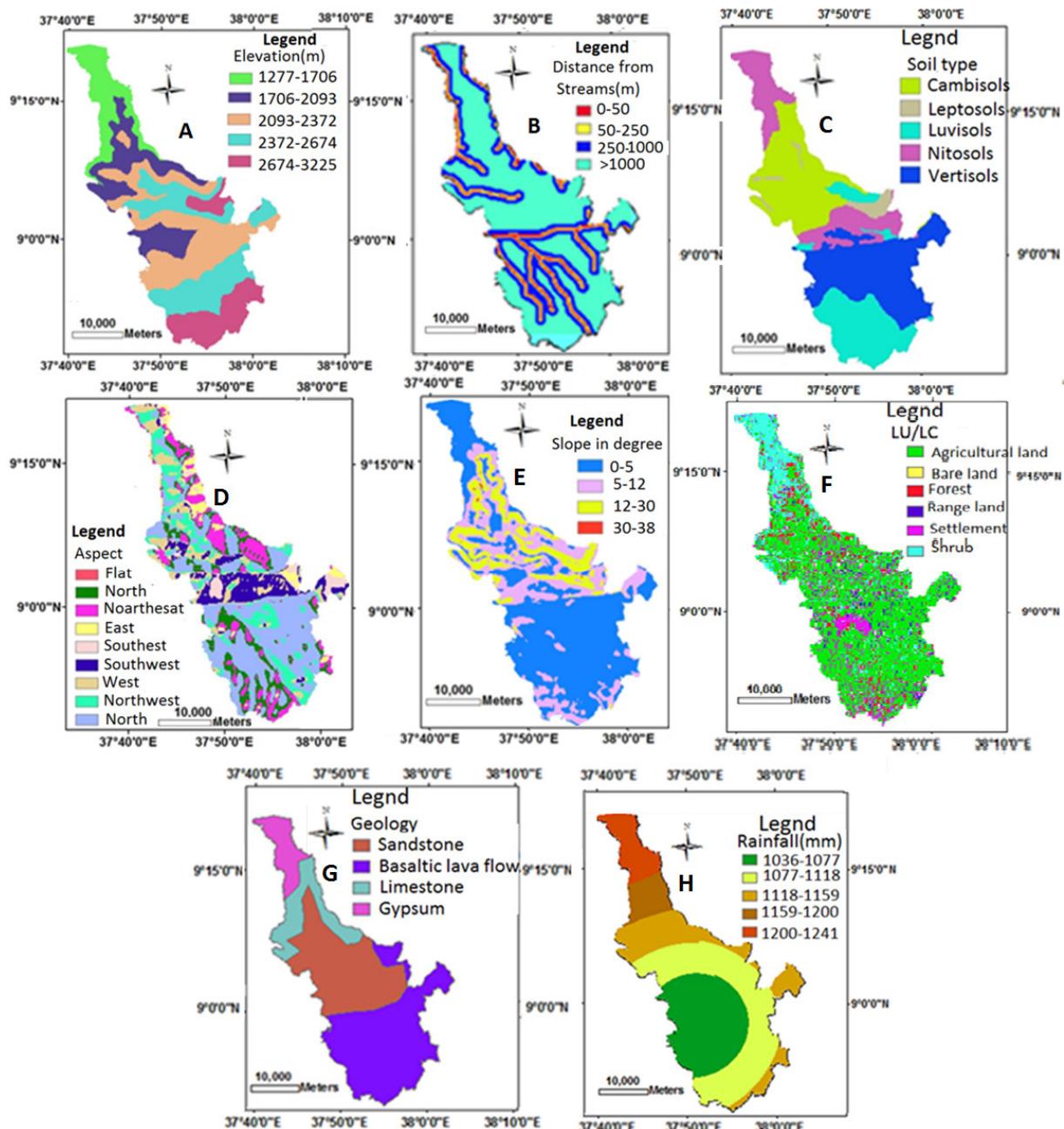


Figure 3 Elevation (A), distance from the stream (B), soil type (C) aspect (D), slope (E), LU/LC (F), geology (G) and rainfall (H) maps of Ambo woreda.

Table 3
 Landslide hazard causing factors reclassified and weight

Factor	Factor class	M _{ij} (Km ²)	N _{ij} (Km ²)	W _{ij}	Factor	Factor class	M _{ij} (Km ²)	N _{ij} (Km ²)	W _{ij}
Elevation(m)	1277-1706	130.1726	0.49	-2.20	Geology	Sandstone	324.2051	11.1961	0.01
	1706-2093	174.2715	8.55	0.36		Basaltic lava	430.3664	8.1195	-
	2093-2372	276.3632	13.74	0.37		Limestone	123.1504	12.9241	0.60
	2372-2674	231.6777	6.62	-0.18		Gypsum	81.9383	0.6507	-
	2674-3225	147.1752	3.47	-0.37		Total	959.6602	32.8905	1.12
	<i>Total</i>	<i>959.6602</i>	<i>32.8905</i>		Distance from Stream	0-50	49.7319	2.3521	1.46
Slope	0-5	544.3440	15.9019	-0.16		50-250	77.6441	5.1383	0.66
	5-12	280.3595	12.8449	0.29		250-1000	252.7519	20.5174	0.86
	12-30	133.7756	4.1383	-0.10		>1000	579.5323	4.8826	-
	30-38	1.1811	0.0054	-2.01		Total	959.6602	32.8905	1.40
	<i>Total</i>	<i>959.6602</i>	<i>32.8905</i>		Rainfall (mm)	1036-1077	285.4021	13.0350	0.29
Aspect	Flat	5.3904	0.1364	-0.30		1077-1118	335.0205	10.3621	-
	North	100.4719	1.6045	-0.76		1118-1159	186.0395	7.2399	0.10
	Northeast	116.2372	2.5594	-0.44		1159-1200	65.7216	1.8411	-
	East	40.7757	1.6099	0.14		1200-1241	87.4765	0.4123	0.20
	Southeast	35.7895	1.7174	0.34		Total	959.6602	32.8905	-
	Southwest	91.3825	6.0465	0.66	Land use/Land cover	Settlement	102.2024	9.3839	0.99
	West	92.4313	3.9136	0.21		Rangeland	30.4550	6.5883	1.84
	Northwest	122.1659	4.5297	0.08		Shrub	150.9230	7.1602	0.33
	North	355.0157	10.7732	-0.12		Bare land	2.4307	0.0878	0.05
	<i>Total</i>	<i>959.6602</i>	<i>32.8905</i>			Forest	71.6279	3.9848	0.48
Soil	Cambisols	171.1436	5.2624	-0.11		Agriculture	602.0213	5.6855	-
	Leptosols	249.3280	8.7473	0.02		Total	959.6602	32.8905	1.29
	Luvisols	206.2401	5.7017	-0.21					
	Nitosols	30.4307	1.4715	0.34					
	Vertisols	302.5177	11.7075	0.12					
	<i>Total</i>	<i>959.6602</i>	<i>32.8905</i>						

3.3. Landslide Hazard Zonation

After factor analyses was made using equation 2, LSH value of between (-9.05) and 4.103 (Table 4) was found. Reclassification of the LSH was made and resulted to very high, high, medium, low and very low potential landslide hazard zones. The percentage of each hazard zones were found as 14.70%, 53.30%, 23.40%, 5% and 3.6% for the very high, high, moderate, low and very low hazard levels respectively while the total area of Ambo woreda is 959.70 km². The landslide hazard zonation map resulted from the methodology of this study (Figure 4) show that the northern parts of the mapped area is found in very low, low and moderate PLSH while high PLSH zones were found widely in the southern parts of the study area. About 53.30% of study area is covered by high PLSH is widely distributed throughout the study area except in the Northern and Southern tips of the study area. Very high PLSH zones were significantly found in the central parts of the mapped area.

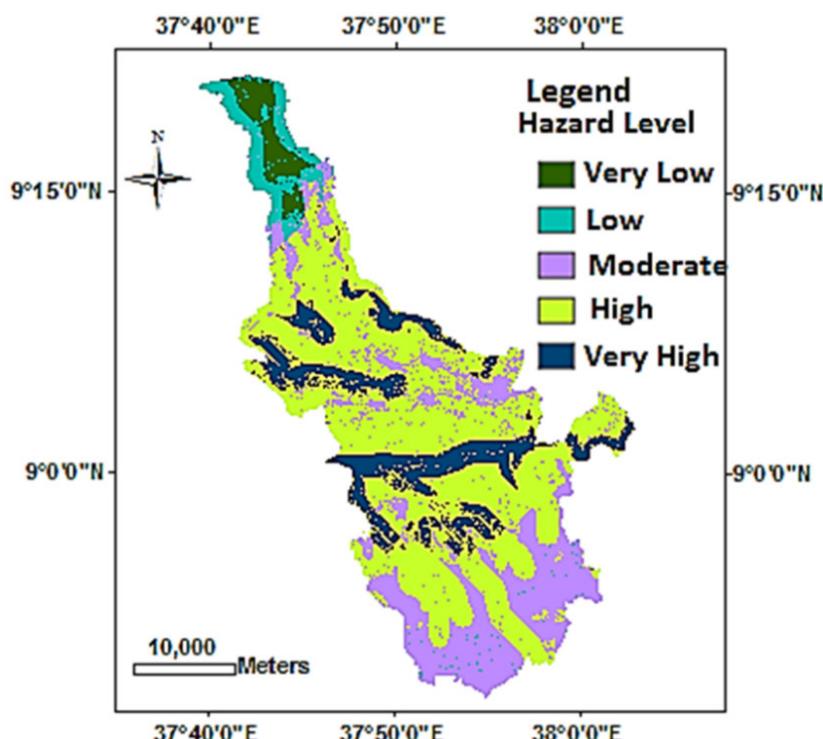


Figure 4 Landslide hazard zonation map of Ambo woreda

Table 4

Landslide Hazard zones and their area coverage

LSHI	Hazard Zone	Area(Km ²)	% of hazard zone
(-9.045185) – (-5.604078)	Very Low	34.60	3.60
(-5.604078) – (-2.984728)	Low	47.90	5.00
(-2.984728) – (- 0.776256)	Moderate	224.80	23.40
(- 0.776256) – (0.969977)	High	511.30	53.30
(0.969977) – (4.102926)	Very High	141.10	14.70
Total		959.70	100.00

4. Validation of Landslide Hazard Map

The LSH map presented in this study was validated using past landslide inventory data and overlay analysis method. The overly analysis result indicated 66.66% of past landslide hazards occurred in high PLSH zone; 19% in very high PLSH zone, 13.83% in moderate PLSH zone; 0.27% in low PLSH zone and 0.25% in very low PLSH zone (Table 5). Thus, the landslide hazard zones map attained in the present study shows that there is concrete agreement between the past landslide hazards distribution and the present result of landslide hazards zonation map.

Table 5

Distribution of past landslide hazards in the PLSH zones

Potential Landslide Hazard zone	Area of Past LSH in Potential LSH zone(km ²)	% of Past LSH in potential LSH zone
Very Low	0.08	0.25
Low	0.09	0.27
Moderate	4.55	13.83
High	21.92	66.66
Very High	6.25	19.00
Total	32.89	100.00

5. Conclusion and Recommendations

The present study was focused on evaluating PLSH distribution of Ambo woreda based on field study and eight landslide hazard causal factors, elevation, slope, aspect, soil type, geology, rainfall, LU/LC and distance from the streams obtained from different sources such as field investigation, DEM and remote sensing and existing maps and finally processed using GIS techniques in ArcGIS software.

Past landslide hazard inventory was made to understand the nature of landslide causal factors in areas of past landslide hazards to realize how they influenced the landslide causal factors in order to get an insight how they will contribute for the future PLSH and contributed in preparing the PLSH map of the study area.

GIS techniques were applied to prepare factor map of each landslide causal factors, to reclassify the factor maps and to overlay the reclassified and weighted maps in order to obtain the final PLSH zonation map for the study area. Accordingly the study area is classified into five PLSH zones as very high, high, moderate, low and very low. The total area of the woreda under consideration was classified as 53.3%, 23.4%, 14.7%, 5%, 3.6% among high, moderate, high, low and very low PLSH zones. The very high and high PLSH zones share majority of the area which is 68%. The existence of wider area coverage of in the study area indicates the need of urgent land use planning, close monitoring of areas with high population and sensitive properties.

Proper land use planning project should include reforestation, and application of structural and biological soil conservation strategies that can help to lessen the level of PLSH and their negative consequences. Landslide disaster risk preparedness and awareness creation for the communities living in high and very high PLSH should also be considered by the woreda Disaster Risk Management office.

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