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Landslide Hazard Zonation (LHZ) around Alemketema Town, North Showa Zone, Central Ethiopia - A GIS based Expert Evaluation Approach

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Abstract: *In the present study landslide hazard zonation (LHZ) was carried out in an area around Alemketema town, central Ethiopia, about 120 km north of Addis Ababa. For LHZ map preparation, GIS based expert evaluation technique was followed. The parameters considered are; slope geometry, slope material, structural discontinuities, landuse and landcover, groundwater, seismicity, rainfall and manmade activities. For landslide hazard evaluation the study area was divided into 273 slope facets and thematic layers on slope facets and intrinsic parameters were prepared in GIS environment from secondary data, topographical map and satellite images. Later, primary data on various parameters was collected facet wise from the field and as per actual observations suitable modifications were made to the thematic maps. Further, geo-processing in GIS environment was done to know the type of parameter classes that fall within each slope facet. Based on the presence of various intrinsic and triggering parameters class within a slope facet, appropriate ratings were assigned to the parameters as per expert evaluation. Later, sum total of all ratings for various parameters form the basis to prepare the LHZ map in GIS. As per prepared LHZ map, 66.9% of the area falls into 'high hazard zone' and 33.1% falls into 'moderate hazard zone'. Validation of this LHZ map revealed that about 80% of past landslides fall within 'high hazard zone'. This reasonably confirms the rationality of adopted methodology, considered parameters and their evaluation in producing LHZ map.*

Keywords: *Landslide, Slope susceptibility, Landslide hazard zonation, Evaluated landslide hazard*

1. Introduction

The highlands in Ethiopia are prone for landslides. As a result the general public and infrastructure are being seriously affected during the rainy season (Girma et al. [1]; Raghuvanshi et al. [2]; Ayele et al. [3]; Woldearegay [4]; Mulatu et al. [5]; Ayenew and Barbieri [6]; Ayalew and Yamagishi [7]). The present study area is located in North-eastern part of Jemma River basin around Alemketema town in central highlands. The area is highly affected by variety of active landslides mostly in superficial materials and the people and infrastructure in the region are at risk. Thus, for effective strategic mitigation planning it is necessary to evaluate and zone the active and potential landslides zones in the area (Raghuvanshi et al. [8]; Pan et al [9]; Anbalagan [10]).

For the purpose of landslide hazard zonation (LHZ) various techniques are available which may be placed into three main groups; expert evaluation, statistical methods and deterministic approaches (Kanungo et al. [11]; Fall et al. [12]; Casagli et al. [13]; Guzzetti et al. [14]; Leroi [15]; Ramakrishnan [16]). Selection of a technique for landslide hazard zonation depends on the scale at which the study has to be carried out (Fall et al. [12]), the total coverage area, experience and skill set of evaluator (Carrara et al. [17]), geologic or geomorphic parameters or the methods by which parameter data has to be generated (Carrara et al. [17]). Thus, owing to these requirements every technique has its own merits and demerits (Fall et al. [12]; Kanungo et al [11]).

The main objective of the present study was to prepare LHZ map of the study area. Thus, for the preparation of LHZ map an integrated GIS based expert evaluation technique proposed by Raghuvanshi et al. [8] was followed.

2. Overview of the study area

2.1 Location

The present study area is located around Alemketema town in Amhara regional state in north Showa zone, central Ethiopia, about 120 km north of Addis Ababa. The study area is bounded by geographic co-ordinates $10^0 15'$N - $10^0 00'$N and $39^0 15'$E - $39^0 00'$E and the total coverage of the study area is about 756 km^2 (Fig.1).

2.2 Physiography and climate

The study area forms a part in highlands of the north-central Ethiopian plateau. The topography is generally rugged with elevation difference from 1340 m to 2650 m (Fig. 2). The study area forms a part in Blue Nile (Abay) basin and the drainage in the area has a parallel, sub-parallel and dendritic pattern. The long-term average annual precipitation (years 1992 –

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2013) of the area is 913 mm/year. The long term temperature of the study area varies from 12^{o} C to 28^{o} C.

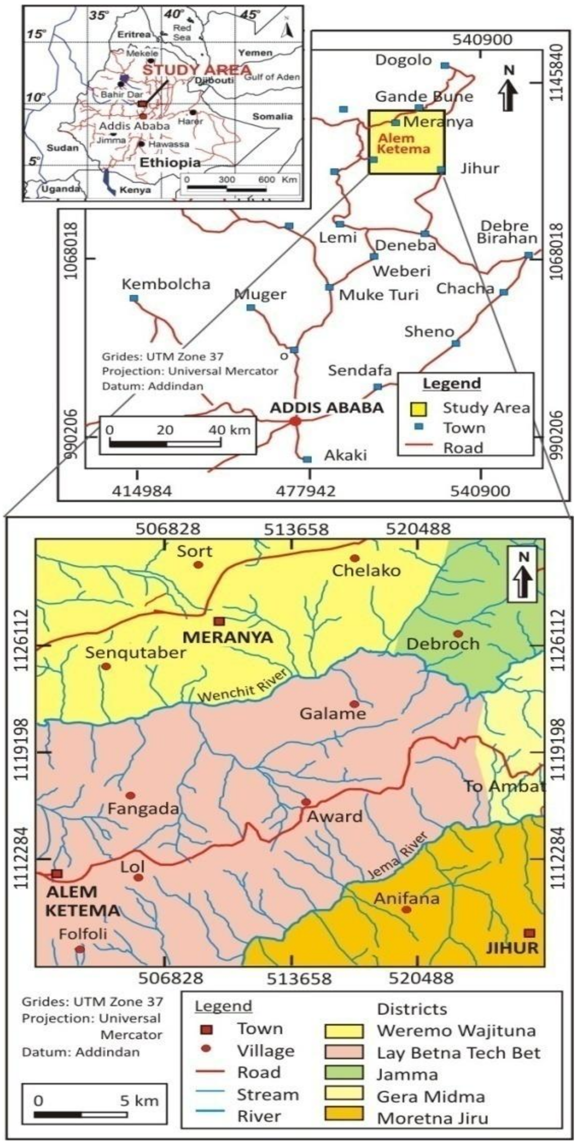

***Figure 1** The study area*

2.3 Geology

The main litho-stratigraphic units present in the study area are; Mesozoic sedimentary rocks, Cenozoic volcanic rocks and Quaternary superficial deposits.

Sandstone is the main rock unit which belongs to Mesozoic sedimentary Formation. This sandstone is referred to as Upper sandstone or Amabradom Formation (Tefera et. al [19]). This unit is exposed mainly along the banks of Wenchit and Jema Rivers in the study area (Fig. 3). The unit has unconformable contact with the overlying Ashangi basalt (Belay et al [20]).

The Cenozoic volcanic rocks present in the study area are Ashange Basalt, Alajae Basalt, and Molale Ignimbrites. The Ashangi basalt is mainly present in the central, north-eastern and south-western parts of the study area (Fig. 3). It lies unconformably above the Mesozoic Upper sandstone Formation (Belay et al [20], Tefera et. al [19]). Alajae Basalt Formation comprise of aphyric flood basalt with rhyolites (ignimbrites) and subordinate trachytes. In the present study area it forms flat topped topography on the plateau, and cliff along the escarpment (Fig. 3). The Molale ignimbrite Formation comprises ignimbrite associated with minor rhyolitic tuff and rhyolitic obsidian (Belay et al [20]). In the present study area rocks belonging to this formation are exposed along the ridges in northern and southern region of the study area (Fig.3).

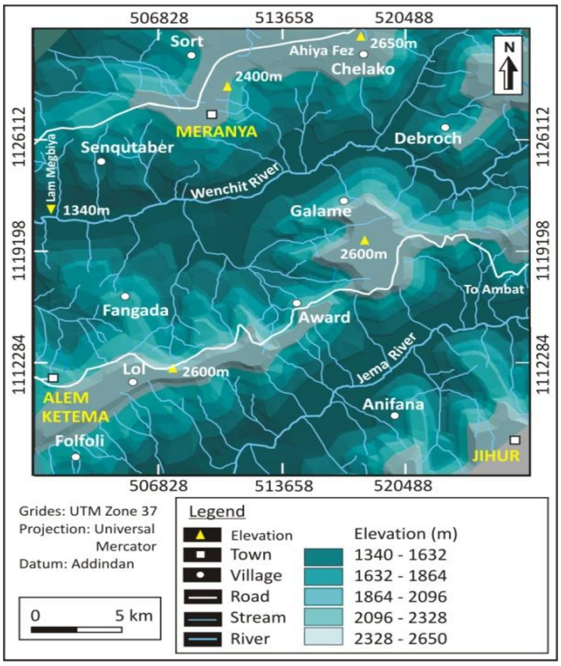

***Figure 2** Physiography of the study area*

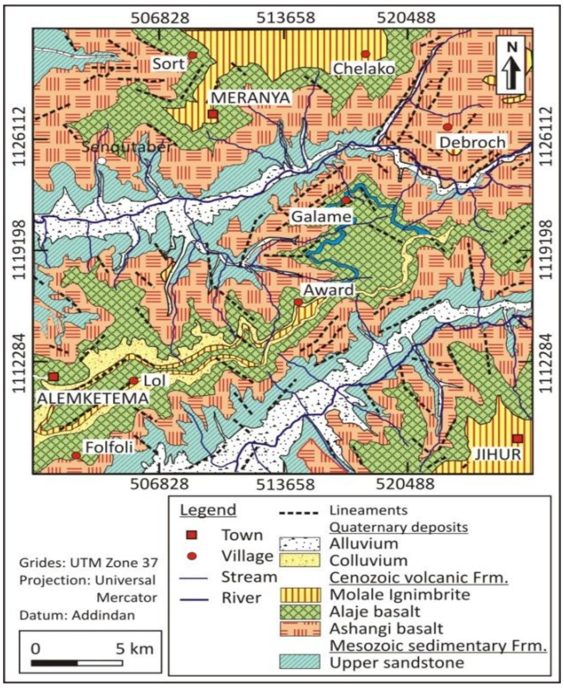

***Figure 3** Geology of the study area*

The Quaternary superficial deposits in the study area mainly comprise of colluvial and alluvial soils. The colluvial soils are mainly distributed on gentle slopes whereas alluvial soils are present along banks of rivers in deep gorges (Fig.3).

The main geological structures identified in the present study area are lineaments and joints. The lineaments mainly trend in NW-SE, NE-SW and E-W directions (Fig.3) (Belay et al [20]). The main joints type is columnar, however tectonically induced irregular vertical and horizontal joints are also observed.

3. Methodology

The general methodology followed for the present study is GIS based ‘slope susceptibility evaluation parameter (SSEP) rating scheme, an expert evaluation technique proposed by Raghuvanshi et al. [8].

The SSEP technique is based on the evaluation of intrinsic and external triggering parameters that may possibly be responsible for the landslides in the area. The intrinsic parameters that were considered are; slope geometry, slope material, structural discontinuities, land use and land cover and groundwater. Further, the external triggering parameters that were considered are; rainfall, seismicity and manmade activities. The intrinsic and external triggering parameters, based on their evaluation were assigned with numerical ratings which are based on their relative impact in inducing instability to the slopes. Further, summation of ratings for all intrinsic and external triggering parameters formed the basis to evaluate landslide hazard in the study area. The SSEP technique is versatile and uses realistic field data. Further, this technique provides landslide hazard for anticipated adverse conditions such as; during heavy rainfall, seismic loading or for slope alterations due to manmade activities (Raghuvanshi et al [8]). Therefore, for this reason, the SSEP technique was adopted to prepare a LHZ map for the present study area.

3.1 Data collection

For landslide hazard evaluation both primary and secondary data was collected from different sources. Table 1 presents the data source used during the present research study. Under desk study the topographical map (1:50,000 scale) was used in GIS environment to delineate slope facets, relative relief and slope morphometric thematic layers. Besides, thematic layers on slope material and land use/ land cover were also prepared from the secondary data and satellite images. Later, during field work, primary data on various intrinsic and triggering parameters was collected facet wise and suitable modifications were made for these thematic maps as per the variations observed in the field. Further, appropriate ratings were assigned facet wise to each of the parameters as per SSEP rating scheme. Thus, finally sum total of all ratings for causative intrinsic parameters and external triggering parameters provided evaluated landslide hazard (ELH), this was further utilized to prepare the LHZ map.

For the present study landslide inventory was prepared from the field mapping. In total 137 past landslides were recorded in the present study area. For, all identified past landslides in the area representative GPS point coordinates were recorded along the boundaries of these landslides. Later, with the help of Google Earth image polygon data along the periphery of all past landslides was delineated by using Arc-GIS 9.3 (Fig.4).

3.2 Data preparation and computation

3.2.1Delineation of slope facet

In order to prepare LHZ map by SSEP rating scheme (Raghuvanshi et al. [8]) the first requirement was to prepare a slope facet map. The slope facet is a land unit which has more or less uniform slope inclination and slope direction (Sharma [28]; Anbalagan [10]). These slope facets can be delineated on topographical maps with the help of streams, spurs, gulleys, ridges and other topographical undulations (Raghuvanshi et al. [8]; Anbalagan [10]).

For the preparation of slope facets for the present study area topographical map at 1:50,000 scale was used in Arc- GIS 9.3. Accordingly, a total of 273 slope facets were delineated as a polygon data layer (Fig.5). Further, this slope facet map served as a base map for the preparation of other thematic maps on various intrinsic and external triggering factors.

Table 1: *Data source and data layers used for the present study*

[1] Classification	[2] Sub classification	[3] GIS Data	[4] Scale	[5] Source
[6] Landslide	[7] Past Landslides	[8] Polygon	[9] 1:50,000	[10] Google Earth image, Ethio Infra [20], Field observations during present study
[11] Topography	[12] Facet map	[13] Polygon	[14] 1:50,000	[15] Topographical map Ethiopia Survey Agency
[16]	[19] Relative relief	[20] Polygon	[21] 1:50,000	[22] Topographical map Ethiopia Survey Agency
[17] [18] Inherent	[23] Slope morphometry	[24] Polygon	[25] 1:50,000	[26] Topographical map Ethiopia Survey Agency

factors	[27] Rock type	[28] Polygon	[29] 1:50,000	[30] Geological map (Belay et al [20]), GSE [22] Field observations during present study
	[31] Soil mass	[32] Polygon	[33] 1:50,000	[34] Google Earth image, Field observations during present study
	[35] Slope discontinuity data	[36] -	[37] -	[38] Field observations during present study
	[39] Landuse and landcover	[40] Grid	[41] 30x30	[42] Sima [23], Google Earth image, Field observations during present study
	[43] Groundwater surface trace	[44] Polygon	[45] 1:50,000	[46] Field observations during present study
[47] External triggering factors	[48] Rainfall data	[49] -	[50] -	[51] National Meteorological Agency of Ethiopia for 3 stations Alem Ketem, Jihur, and Meragna (1990 – 2013)
	[52] Seismicity	[53]	[54]	[55] Seismic Risk Map (Asfaw [24])
	[56] Manmade activities	[57] Polygon	[58] 1:50,000	[59] Google Earth image, Field observations during present study

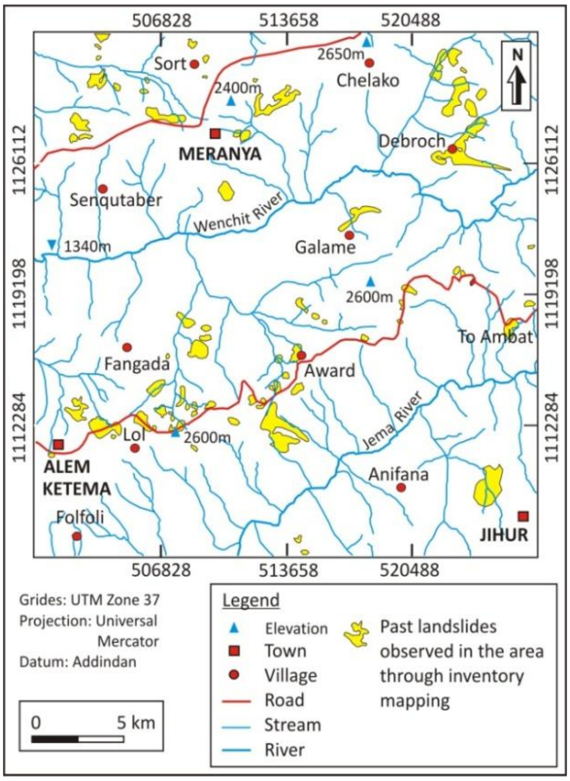

Figure 4 Landslide inventory map

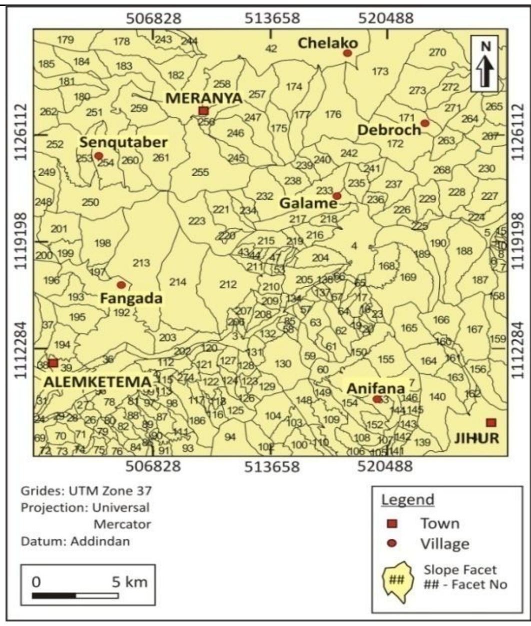

Figure 5 Slope facet map of the study area

3.2.2Intrinsic Factors

The slope stability is basically governed by various intrinsic factors (Raghuvanshi et al. [8]; Ayalew et al. [29]; Wang and Niu [30]; Anbalagan [10]). These intrinsic factors individually or in combination may provide favorable condition for slope failure to occur (Raghuvanshi et al. [2]). As per SSEP rating scheme the intrinsic parameters to be considered are; slope geometry, slope material, structural discontinuity, landuse and landcover and groundwater. Accordingly, thematic layers on all these intrinsic factors were prepared.

3.2.2.1 Slope geometry

Slope geometry comprises slope morphometry and relative relief.

S*lope morphometry* is defined as the inclination of the slope. The main driving force to which slopes are subjected is gravitational pull which is directly proportional to the slope inclination (Raghuvanshi et al. [8]; Anbalagan [10]; Singh [31]). For the present study the slope morphometry was computed for each individual slope facet in GIS environment by utilizing topographical maps. Slope morphometric classes of the study area are categorized as per the SSEP rating scheme (Raghuvanshi et al. [8]) into; escarpment/cliff (> 45°), steep slope (36°-45°), moderately steep slope (26°-35°), gentle slope (16°-25°) and very gentle slope (< 15°). Thus, by considering slope morphometric classes, each of the slope facets was assigned with an appropriate slope morphometry class (Fig. 6(A)).

Relative relief is the elevation difference between the least elevation and the highest elevation within an individual facet (Raghuvanshi et al. [8]; Anbalagan [10]). The instability in slope increases as the height of the slope increases (Hoek and Bray [32]). In the present study relative relief was computed by overlaying the facet layer over the topographic layer and the maximum and minimum elevations within the facet provided relative relief for each slope facet. Further, relative relief of the present study area was categorized as per SSEP rating scheme (Raghuvanshi et al. [8]) into five classes; low (< 50 m), moderate (51-100 m), medium (101-200 m), high (201-300 m) and very high (>301 m). Later, with these classes relative relief map of the study area was prepared (Fig. 6(B)).

3.2.2.2 Slope material

In general, slope material controls the stability of a slope (Raghuvanshi et al. [2]; Girma et al. [1]). Slopes composed of weaker material such as soils will be more prone for instability as compared to competent rocks (Anbalagan [10]). Similarly, slopes composed of different soil types and its thickness may have varied potential for instability (Raghuvanshi et al. [2]). Weathering also plays an important role in controlling stability of rock slopes (Siddique [33]).

The slope material thematic layer for the present study area was prepared by utilizing secondary data, satellite image interpretation and through field observations (Table 1). The prominent rock types exposed in the study area are; sandstone (very strong rock, 100-250 MPa), Ashangi Basalt (medium strong, 25-50 MPa), Alajae Basalt (very strong, 100-250 MPa) and Molale Ignimbrite (strong rock, 50-100 MPa) (Fig.6(C)). Further, two prominent type of soils were observed in the study area, these are; colluvial and alluvial soils (Fig.6(C)).

3.2.2.3 Structural discontinuities

The stability of rock slopes is greatly affected by the discontinuities and their interrelationship with the slope (Hoek and Bray [32]). The main characteristics of discontinuities that have a control on stability of rock slopes are spacing, orientation, surface characteristics, continuity, separation of discontinuity surface and nature and thickness of material filled in discontinuities (Johnson and Degraff [34]).

During the present study facet wise structural data was collected from the field. Later, its kinematic relation with respect to general slope was determined using stereographic analysis. Further processing and analysis of this structural discontinuity data was made to utilize it later for landslide hazard evaluation.

3.2.2.4 Land use and land cover

Land use and land cover have a significant control over slope stability. Barren lands are more prone for erosion and instability as compared to slopes which have thick vegetation cover. The root system may bind the soil mass which in turn will increase the shear strength of the slope mass (Arora [35]; Turrini and Visintainer [36]). In the present study, land use and land cover of the study area was deduced from the secondary data and satellite image interpretation under desk study (Table 1). Later, during field work, this map was further updated and modified based on the visual field observations within each individual slope facet. The land units as identified in the present study area are barren land, cultivated land, thickly vegetated land, moderately vegetated land and sparsely vegetated land (Fig. 6(D)).

3.2.2.5 Groundwater

Groundwater plays a significant role in facilitating instability in slopes. The water within discontinuities develops water forces which reduce shear strength along the discontinuity surfaces resulting into rock mass sliding (Raghuvanshi et al. [8]; Hoek and Bray [32]). Similarly, in soil slopes presence of groundwater may result into pore water pressure development and reduction in shear strength of the soil mass. (Raghuvanshi et al. [8]; Arora [35]). For LHZ mapping over large areas it is not feasible to have direct observations for groundwater regime. Thus, in the absence of such records indirect observations such as; flowing, dripping, wet or damp can be made on individual slope facets (Anbalagan [10]). For the present study systematic observations were made and facet wise groundwater surface manifestations were recorded. Also, 76 springs and 60 hand pumps were observed in the study area (Fig.6(E)).

3.2.3External triggering factors

The important external triggering factors that were considered for the present study are; rainfall, seismicity and manmade activities.

3.2.3.1 Rainfall

Intensity of rainfall has a direct relation with the slope instability problems. For this reason only most of the landslides occur during rainy season (Ayalew et al. [29]; Collison et al. [37]; Dai and Lee [38]; Dahal et al. [39]). Rainfall can result into surface erosion and also it can recharge groundwater which ultimately saturates the slope material (Raghuvanshi et al. [8]). According to SSEP technique rainfall triggering effect can be incorporated by considering the, ‘mean annual rainfall’ in the area. The mean annual precipitation for the present study area fall in the moderate class (701 - 1100 mm), as per the SSEP rating scheme (Raghuvanshi et al. [8]). Further, during field study facet wise observations were also made to know the rain induced manifestation on slope such as; stream bank erosion, toe erosion, gully formation, etc. Besides, in order to know the impact of rainfall on slope, instability factors such as; type of slope material, discontinuity orientation with respect to slope, slope morphometry has also been considered. Later, all such observations were utilized to prepare themes as rain induced manifestation (Fig. 7 (A)) and slope material as rainfall parameter (Fig.7 (B)) using Arc-GIS 9.3.

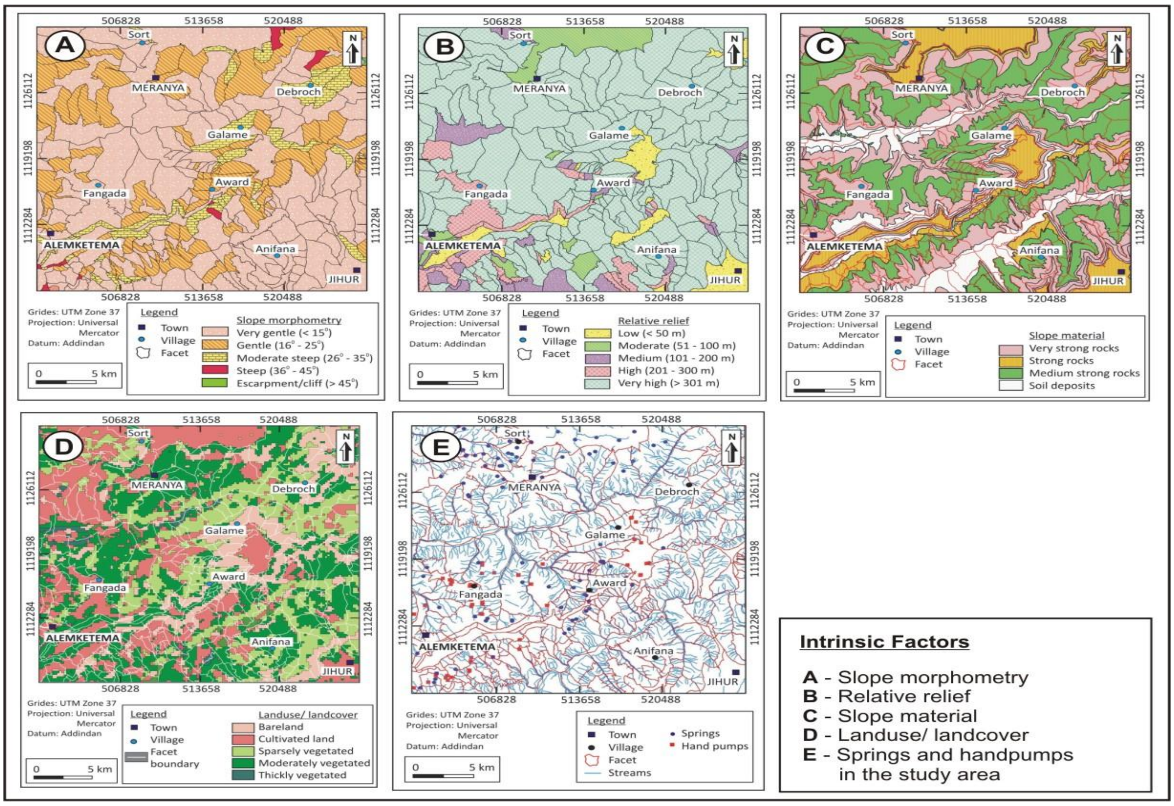

Figure 6 *Intrinsic factor maps*

3.2.3.2 Seismicity

When slope undergo seismic loading, ground accelerations may develop which in turn may trigger landslides (Raghuvanshi et al. [8]; Keefer [40]; Parise and Jibson [41]). According to SSEP rating scheme ground acceleration corresponding to estimated intensity of earthquake (Modified Mercalli intensity scale) may form the basis to incorporate the seismic triggering effect on slopes for landslide hazard evaluation (Raghuvanshi et al. [8]). The present study area as per seismic map of Ethiopia produced by Asfaw [24] lies in a Modified Mercalli intensity scale of 8 and the estimated horizontal earthquake acceleration falls between 0.1 - 0.2g, with an average value 0.15g, the same value was considered for landslide hazard evaluation in the present study.

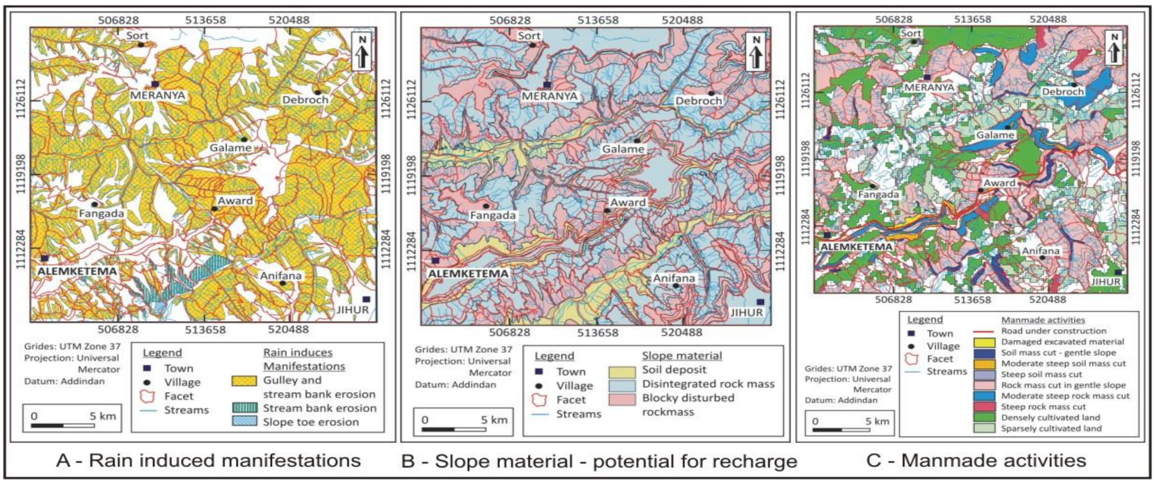

Figure. 7 *External triggering factor maps*

3.2.3.3 Manmade activities

The major manmade activities responsible to destabilize slopes in mountainous terrain are road construction which may have a wide spread effect and the cultivation activities on slopes (Raghuvanshi et al. [8]; Wang and Niu [30]; Vishal [42]). Road construction may involve slope cutting by mechanical means or by blasting, which generally is done in unplanned manner. In addition to this the excavated loose material is generally dumped on down slopes forming unstable slope mass (Raghuvanshi et al. [8]). Other, manmade activity which significantly contributes for slope instability is cultivation practice on hill slopes. For cultivation steep slopes are cut into gentle slopes, thus alteration in natural slope geometry may result into slope instability (Raghuvanshi et al. [2]). For the present study, to assess the contribution of development activity, facet wise observations were made (Fig. 7 (C)).

3.3 Landslide hazard evaluation

As per the general methodology of SSEP technique the first requirement is to know that within each slope facet what parameter sub classes for all intrinsic and external triggering parameters falls. For this overlay analysis between slope facet theme and each individual intrinsic and external triggering parameter in GIS environment was made.

3.3.1Geo-processing of inherent and external triggering parameters

Geo-processing was carried out between each of the inherent and external triggering parameters and the facet map. The inherent parameter themes that were used for geo-processing are; slope morphometry, relative relief, slope material, land use and land cover and groundwater. Whereas external triggering parameters themes that were used for geo-processing are; Rain induced manifestation, slope material as rainfall parameter and manmade activities. Thus, after geo-processing there were 8 individual geo- processed files on above mentioned inherent and external triggering parameters. Further, each of these geo-processed theme files was merged by using 'merge themes' option within geo-processing tool. Finally, a single file was obtained which depicted type of parameter classes that fall within each slope facet. Later, respective ratings to each parameter class were assigned as per SSEP technique.

3.3.2Evaluated landslide hazard (ELH)

As per SSEP rating scheme Evaluated landslide hazard (ELH) is a sum total of all ratings of inherent and causative factors within an individual facet. As stated above all ratings of various parameters were summed up. Thus, each individual facet got an ELH value and according to SSEP based on this ELH value, landslide hazard can be defined into any of the 5 classes, as stated in Table 2. The ELH distribution for the present study area indicates that the study area falls into two landslide hazard classes; landslide hazard Class III (Moderate hazard zone, LHZ) and Class IV (High hazard zone, HHZ), respectively (Table 2).

Table 2: *Evaluated Landslide Hazard (ELH)*

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

3.3.3Landslide hazard zonation (LHZ)

For the purpose of LHZ map preparation, facet wise ELH values were utilized to prepare a map by using Arc-GIS 9.3. Perusal of Fig. 8 clearly indicates that, 66.9% (506 km^2) of the study area fall into 'high hazard zone' and remaining 33.1% (250 km^2) falls into 'moderate hazard zone'.

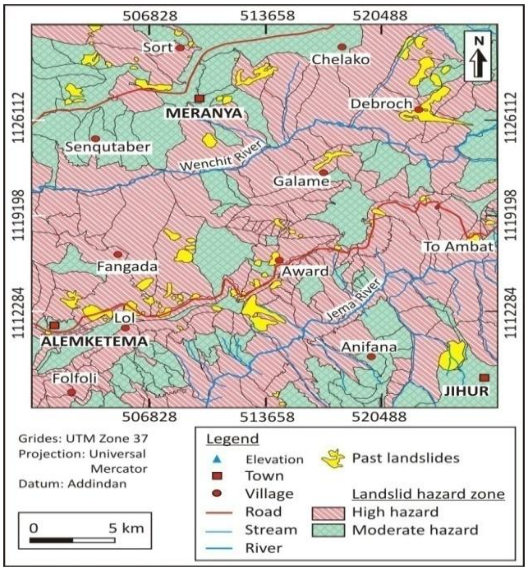

Figure 8 *Landslide hazard zonation map of the study area*

4. Results and discussion

The present study area is highly affected by the landslides with variety of active landslides mostly in superficial materials. In total 137 past landslides were recorded in the present study area. As observed, about 49% of landslides are distributed in the eastern, central, and south-western parts of the study area. However, distribution of landslides in north-eastern, north-western and south-eastern parts of the study area is 21%, 19% and 11%, respectively (Fig. 5). The dominant type of slope failures as observed in the study area are; rock falls, rock slides, soil slides and flows.

4.1 Influence of inherent causative factors on landslides

4.1.1 Slope morphometry

Out of total, 60.68% (458.74 km^2) of the area is covered by very gentle slopes, 30.08 % (227.41 km^2) by gentle slopes, 8.22 % (62.14 km^2) by moderately steep slopes, 1 % (7.56 km^2) by steep slopes and remaining 0.02 % (0.15 km^2) by escarpment cliff (Fig. 6, Table 3). Much of the study area falls into very gentle or gentle slopes. The past landslides in the area, as indicated earlier, are mostly shallow translational and planar landslides and gully erosion. Mostly these are associated with colluvial and alluvial soils which forms very gentle or gentle slopes in the area. It was observed that nature of slope material; colluvial and alluvial soils, and the type of failures; shallow translational and planar landslides and gully erosion have more significance than the slope inclination over instability in the study area.

4.1.2 Relative relief

Relative relief of the area, (Fig.6) clearly shows that 76.8 % (580.62 km^2) of the area falls in very high relief, 6 % (45.36 km^2) in high relief, 6.4 % (48.38 km^2) in medium relief, 5% (37.8 km^2) in moderate relief and remaining 5.8 % (43.84 km^2) of the study area falls into low relief (Table 3). As can been seen, much of the present study area (76.8 %) falls into very high relief which has a strong relationship with instability of slopes in the area.

Table 3: *Distribution of intrinsic and external triggering factors in the study area*

[60] Class		**[61] Area Distribution**	
		[62] (%)	**[63] (km^2)**
[64] (a) Slope morphometry			
[65] Very gentle slopes		[66] 60.68	[67] 458.74
[68] Gentle slopes		[69] 30.08	[70] 227.41
[71] Moderately steep slopes		[72] 8.22	[73] 62.14
[74] Steep slopes		[75] 1	[76] 7.56
[77] Escarpment cliff		[78] 0.02	[79] 0.15
[80] Total		**[81] 100**	**[82] 756**
[83] (b) Relative relief			
[84] Very high relief		[85] 76.8	[86] 580.62
[87] High relief		[88] 6	[89] 45.36
[90] Medium relief		[91] 6.4	[92] 48.38
[93] Moderate relief		[94] 5	[95] 37.8
[96] Low relief		[97] 5.8	[98] 43.84
[99] Total		**[100] 100**	**[101] 756**
[102] (c) Slope material			
[103] Very strong rocks		[104] 36	[105] 272.16
[106] Medium strong rocks		[107] 35	[108] 264.6
[109] Strong rocks		[110] 15	[111] 113.4
[112] Soils – alluvial and colluvial		[113] 14	[114] 105.84
[115] Total		**[116] 100**	**[117] 756**
[118] (d) Landuse/ landcover			
[119] Moderately vegetated land		[120] 33.4	[121] 252.5
[122] Cultivated land		[123] 27.4	[124] 207.14
[125] Sparsely vegetated		[126] 21.9	[127] 165.58
[128] Bare-land		[129] 15.5	[130] 117.18
[131] Thickly vegetated land		[132] 1.8	[133] 13.6
[134] Total		**[135] 100**	**[136] 756**
[137] (e) Rain induced manifestation and Slope material -potential for recharge			
[138] Parameter	**[139] Class**	**[140]**	**[141]**
[142] Rain induced manifestation	[143] Gully or stream bank erosion	[144] 59	[145] 446.04
	[146] Slope toe erosion	[147] 1	[148] 7.56
	[149] No effect	[150] 40	[151] 302.4
	[152] Total	[153] 100	[154] 756
[155] Slope material - potential for recharge	[157] Soil mass	[158] 14	[159] 105.84
	[160] Disintegrated rock mass	[161] 50	[162] 378
	[163] Blocky disturbed rock mass	[164] 36	[165] 272.16
[156]	**[166] Total**	**[167] 100**	**[168] 756**

This is known that the instability in slope increases as the height of the slope increases (Hoek and Bray [32]).

4.1.3 Slope material

The prominent rock types exposed in the study area are; very strong rocks that covers 36% (272.16 km^2) of the study area, belonging to Mesozoic Upper sandstone Formation, medium strong rocks that covers about 35% (264.6 km^2) of the study area, belonging to Ashangi Basalt Formation, strong rocks that covers 15% (113.4 km^2) of the study are, belonging to Molale Ignimbrite Formation and the remaining 14% (105.84 km^2) of the area is covered by alluvial and poorly graded colluvial soils (Fig. 6, Table 3).

Very strong rocks are exposed mainly in the upper reaches of gorges of Jema and Wenchit rivers and in the higher elevated northern area of the study area. Strong rocks are exposed in the lower and middle reaches of Jema gorge and the higher elevations in northern part of the study area. Further, medium strong rocks are evenly distributed throughout the study area mainly in the gorges of Jema and Wenchit Rivers. The colluvial soils are generally, present on gentle slopes of terraces whereas, alluvial soils are found mainly in the Wenchit and Jema River gorges. Further, data on past landslides reveal that majority of landslides in the area occurred within colluvial and alluvial soils and within medium strong rocks. Thus, colluvial and alluvial soils and medium strong rocks are more prone for landslide activities in the area. In general, colluvial soils are loose soils and have relatively low shear strength (Raghuvanshi et al. [2]).

4.1.4Structural discontinuity

The characteristics of discontinuities mainly define the shear strength along the discontinuities and may provide favorable conditions for rock mass failure along one or more discontinuity planes (Raghuvanshi et al. [8]; Anbalagan [10]; Johnson and Degraff [34]; Hoek and Bray [32]). Thus, during the present study facet wise data on these structural characteristics was collected from the field and kinematic relation with respect to general slope orientation was determined using stereographic analysis.

4.1.5Land use and Land cover

A perusal of Table 3 indicates that 33.4 % (252.5 km^2) of the study area is covered by moderately vegetated land, 27.4 % (207.14 km^2) is cultivated land, 21.9 % (165.58 km^2) is sparsely vegetated, 15.5 % (117.18 km^2) is bare-land and the remaining 1.8% (13.6 km^2) of land is thickly vegetated (Fig. 6). The results shows that about 36.7% of the study area is either bare-land (15.5%) or sparsely vegetated land (21.2 %), such landforms are prone for soil erosion and slope failures (Wang and Niu [30]). About 27.4% of the study area is covered by cultivated land. Cultivated land may also contribute for slope instabilities due to associated practices such as; alterations in slope geometry and irrigation practices (Raghuvanshi et al. [8]).

4.1.6Groundwater

For the present study facet wise surface manifestations of groundwater were observed and recorded during the field work. As per SSEP technique, observations were made to record conditions on slope facet such as; flowing in the form of springs, dripping of water through structural discontinuities and moist condition on rock surfaces. Besides, manifestations such as; water marks on rock surfaces and moss and algal growth in shadow areas were also recorded as these may also suggest about degree of saturation of slope for prolonged period of time (Raghuvanshi et al. [8]). Accordingly ratings were assigned as per SSEP technique, based on their location and density within an individual facet (Fig. 6). The results on groundwater indicates that on 54 slope facets, conditions such as; wet, dripping or flowing prevailed whereas, 219 slope facets were found to be damp or dry. This indicates that about 19.78% of the slopes may have significant effect of groundwater on potential instability.

4.2 Influence of External triggering factors

4.2.1Rainfall

The long term average annual precipitation data analysis revealed that the present study area fall in moderate class (701 - 1100 mm) as per the SSEP technique (Raghuvanshi et al. [8]). As reported, majority of landslides in the present study area occurred only during rainy season. This fact is true as most of the landslides in Ethiopian highlands occur during rainy season only (Girma et al. [1]; Raghuvanshi et al. [2]; Mulatu et al. [5]). The effect of rainfall over slope instability may be direct or indirect. Soil slopes may fail by the direct effects of surface flows leading to gully erosion, stream bank slope erosion or slope toe erosion (Raghuvanshi et al. [8]). Whereas, infiltration of rain water into slope material may recharge the groundwater that indirectly affects the slope instability (Arora [35]). Thus, during the field study facet wise observation were made for stream bank erosion, toe erosion and gully formation.

The results indicates that about 59% (446.04 km^2) of the slopes are affected either by gully or stream bank erosion and only 1% (7.56 km^2) of the slopes are affected by slope toe erosion (Fig.7). Further, results also showed that 14% (105.84 km^2) of slopes have soil mass mainly; colluvial and alluvial soils which are prone for stream bank erosion, toe erosion or gully erosions (Table 3). Also, among the exposed rock mass 50% (378 km^2) rock mass is disintegrated whereas 36% (272.16 km^2) rock mass is blocky disturbed (Table 3). Thus, disintegrated and block disturbed rock mass may result into considerable infiltration of rain water which may contribute to related instability (Raghuvanshi et al. [8]).

4.2.2Seismicity

As such no historical records revealed that landsides have occurred due to seismicity in the present study area. Even in general Ethiopian context, earthquake triggered landslides are little reported (Woldearegay [4]). However, in the present study effect of seismicity was considered for landslide hazard evaluation by considering horizontal earthquake acceleration. Accordingly, as per seismic map of Ethiopia (Asfaw [24]) the present study area lies in a Modified Mercalli intensity scale of 8 and the estimated horizontal earthquake acceleration will be 0.15g, thus the same value was considered for landslide hazard evaluation.

4.2.3Manmade activities

Manmade activates such as; road construction and cultivation practices over slopes may trigger wide spread landslides (Raghuvanshi et al. [8]; Wang and Niu [30]). In the present study area wide spread slope instability was observed along the route from Alemketema town to Ambat village. Also, number of landslides and related slope instability problems were observed in and around cultivated lands.

Facet wise observations were made to know the manmade activities and associated effects which may possibly contribute for landslides in the area. For cultivation activity observations were made to know the type of cultivated land and irrigation practice being followed. The results obtained revealed that about 27% (204.12 km^2) of the area is covered by densely cultivated land and about 14% (105.84 km^2) of area is covered by sparsely cultivated land. The facet wise observations made for manmade activities are presented in Fig.7.

4.3 Landslide Hazard evaluation and zonation

The landslide hazard evaluation and zonation in the present study, clearly indicates two hazard zones; 'high hazard zone' that covers 66.9% (506 km^2) of the study area and 'moderate hazard zone' that covers 33.1% (250 km^2) of the study area (Fig.8). In total, 182 slope facets fall within 'high hazard zone' whereas 91 slope facets fall within 'moderate hazard zone'. High hazard zones are mostly distributed in the central portion occupying Jema and Wenchit rivers gorges and mainly in the northern and north eastern parts of the study area. The 'moderate hazard zone' is evenly distributed in the study area with relatively more concentration in the northern and north-western parts of the study area.

In order to validate the landslide hazard zonation (LHZ) map the past landslide data was overlaid on this map (Fig.8). The overlay analysis reveals that out of total 137 past landslides in the study area, 110 falls within 'high hazard zone' whereas remaining 27 falls within 'moderate hazard zone'. It implies that about 80% of past landslides validates with the present LHZ map. Even the remaining 20% fall within 'moderate hazard zone' which also have relative potential for landslides. It is reasonable to say that the LHZ map prepared has satisfactorily validated with the past landslide data in the area. Thus, it reasonably confirms the rationality of adopted methodology, considered intrinsic and triggering parameters and their evaluation in producing LHZ map for the present study area. Thus, the high hazard zone depicted in this map may be considered vulnerable for any future development in the area and may require further detailed slope stability studies for the implementation of any construction activities. The 20% past landslides that do not fall within 'high hazard zone' may be because of a reason that the present methodology followed was carried out at a medium scale (1:50,000). Moreover, landslide is a complex process and it depends on the relative significance of intrinsic and triggering parameters (Raghuvanshi et al. [2]) and the methods by which parameter data has been generated for analysis (Carrara et al. [18]).

5 Conclusions

The present study was conducted in an area around Alemketema town in Oromiya regional state in north Showa zone, central Ethiopia, which is about 120 km north of Addis Ababa. The main objective of the present study was to prepare landslide hazard zonation map of the area by adopting GIS based 'slope susceptibility evaluation parameter' (SSEP) rating scheme. As per the methodology, the intrinsic parameters that were considered for landslide hazard evaluation are; slope geometry, slope material, structural discontinuities, land use and land cover and groundwater. The external triggering parameters that were considered are; rainfall, seismicity and manmade activities.

As a pre-field activity, thematic layers on slope facets and intrinsic parameters were prepared in GIS environment from secondary data, topographical map and satellite images. A total of 273 slope facets were delineated in the present study area. Later, during field work, primary data on various intrinsic and triggering parameters was collected facet wise and suitable modifications were made to the maps prepared from the secondary data. Also, landslide inventory mapping was carried out in the area. Further, geo-processing was done in GIS environment between each of the inherent and external triggering parameters and the facet map. Based on the field observations and the information gathered during the desk study appropriate ratings were assigned facet wise to each of the parameters as per SSEP technique. Finally, the sum total of all ratings for intrinsic and external triggering parameters were utilized to prepare the LHZ map using Arc-GIS software.

In total 137 past landslides were recorded in the present study area. The major causes for landslides in the present study area are; geological, geo-morphological and hydro-geological factors and the main external triggering factors are rainfall and road construction in the area. Landslide hazard evaluation and zonation indicated that 66.9% (506 km^2) of the area falls into 'high hazard zone' and 33.1% (250 km^2) falls into 'moderate hazard zone'. Validation of landslide hazard zonation (LHZ) map revealed that about 80% of past landslides fall within 'high hazard zone'. This reasonably confirms the rationality of adopted methodology, considered intrinsic and triggering parameters and their evaluation in producing LHZ map for the present study area. Further, the high hazard zone depicted in this map may be considered vulnerable for any future development in the area and may require further detailed studies for the implementation of any construction activities.

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