Landslide Hazard Evaluation and Zonation In and Around Hagereselam Town, Tigray, North Ethiopia

Searom Gebremicheal
A Thesis Submitted to
School of Earth sciences

Presented in Partial Fulfillment of the requirements for the Degree of Master of Science (Engineering Geology)

ADDIS ABEBA UNIVERSTY
Addis Ababa, Ethiopia
May, 2017

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DECLARATION

I hereby declare that this thesis is my original work that has been carried out under the supervision of Dr. Tarun Kumar Raghuvanshi, school of earth science, Addis Ababa University during the year 2017 as part of Master of Science Program in Engineering Geology in accordance with the rule and regulation of the institute. I farther declare that this work has not been submitted to any other University or institution for the award of any degree or diploma and all sources of material used for the thesis have duly acknowledge.

Searom Gebremicheal

Signature:

Place and Date of submission: School of Graduate Studies, Addis Ababa University
May 2017

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Addis Ababa University
School of Graduate Studies

This is to certify that the thesis prepared by **Searom Gebremicheal**, entitled: *Landslide Hazard Evaluation and Zonation in and around Hagereselam Town, Tigray, North Ethiopia* and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Engineering Geology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Landslide Hazard Evaluation and Zonation in and around Hagereselam Town, Tigray, North Ethiopia

Searom Gebremicheal

Addis Ababa University, 2017

The present study was carried out in Hagereselam, Wereda Degia Tenben, Tigray Regional State in Northern Ethiopia which is about 828 km far from Addis Ababa. The area is being affected by repeated landslide problems for the past several years therefore seeing the severity of landslide and related instability problems in the area the present research study was conducted. The main objective of the present research study was to evaluate landslide hazard (LHZ) in the study area. For this purpose two approaches were followed to produce the LHZ map. These methods are Slope susceptibility evaluation parameter (SSEP) rating scheme and integrated SSEP and statistical method. The parameters that were considered are slope geometry, slope material, structural discontinuities, landuse and landcover, groundwater, seismicity, rainfall and manmade activities. Beside, inventory on past landslides in the study area was also prepared. Thematic layers on, past landslides, slope facets and causative factors were prepared in GIS environment from secondary data, field observations, topographical maps and satellite images. In SSEP approach facet wise observations were made and ratings for each parameter class was assigned based on conditions prevailed on individual facet. For integrated approach hazard index value was first computed for each of the parameter class. For this density relation between past landslides in the area and each of the parameter class was established through GIS analysis. This hazard index value is a ratio between landslide did occurred to landslide did not occurred within each parameter class. Later, this hazard index value was utilized to modify the original SSEP ratings. Thus, by using these modified ratings LHZ map was produced. The results showed that LHZ map produced by SSEP approach and the integrated approach both has distributed the study area into high hazard and moderate hazard zones. On comparison; LHZ map produced by SSEP shows about 80 % validation, whereas map by integrated approach show about 91% validation with the past landslide activities. Thus, it may be concluded that both methods produced almost similar type of LHZ maps. However, LHZ map produced by integrated approach showed better validation with the past landslide activities.

Key words: Landslide evaluation, Landslide hazard zonation, Slope instability, Hazard index

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CHAPTER ONE INTRODUCTION

1.1 Background

Varnes (1984) defined landslides hazard as ‘‘the probability of occurrence of a potentially damaging phenomenon within a given area and in a given period of time’’. Although the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. Typically, pre-conditional factors build up specific subsurface condition that makes the area/slope to failure, whereas the actual landslide often requires a trigger before being released. There are many factors that cause the instability of slopes, but the main controlling factors are rainfalls, seismic activities and human activities. Landslides can involve flowing, sliding, toppling or falling movements, and many landslides exhibit a combination of two or more types of movements (Varnes, 1978; Crozier, 1986).

The range of landslide phenomena is extremely large, making mass movements one of the most diversified and complex natural hazard. The velocity of landslide hazard extends from creeping failures at millimeters per year (or less) up to rock avalanches moving at over hundreds of kilometers per hour. The Number of landslide hazard phenomena depends up on the cause of the sliding; multiple landslides occur almost simultaneously when slopes are shaken by an earthquake or over a period of hours or days of intense rainfall. Landslides can occur singularly or in groups up to hundreds or up to several hectares or square kilometers (Guzzetti et al., 2005).

The extraordinary extensiveness of the spectrum of landslide phenomena makes it difficult to define a single methodology to identify and map the landslides, to determine landslide hazards, and to evaluate the associated risk. The experience gained in experiments and surveys carried out by geomorphologists and engineering geologists in many areas of the world has shown that different strategies and a combination of different methods and techniques have to be applied. “Depending on the type and number of the landslides, the extent and complexity of the study area, and the available resources, this makes landslide mapping, landslide susceptibility and hazard assessment, and landslide risk evaluation a unique challenge for scientists, planners and decision makers" (Guzzetti et al., 2005).

1.2 Location and accessibility

The study area is located in Northern Ethiopia, Tigray Regional State, Miakelay Zone, in Degia Tenben Woreda, Hagereselam city and it is about 828 km far from Addis Ababa and 45 km far from Mekelle town towards west. The study area is located in the UTM Zone 37 and it is specifically bounded by geographic co-ordinates of 1,499,617 m N to 1,519,767 m N latitude and 510,008 m E to 534,348 m E longitude. The study area covers 58km^2, the location of the study area is shown in Fig. 1.1.

There is an asphalt road that passes by Hagereselam from Mekelle town which is the capital city of Tigray Regional State. There are small gravel roads which connect the different villages to the main asphalt road.

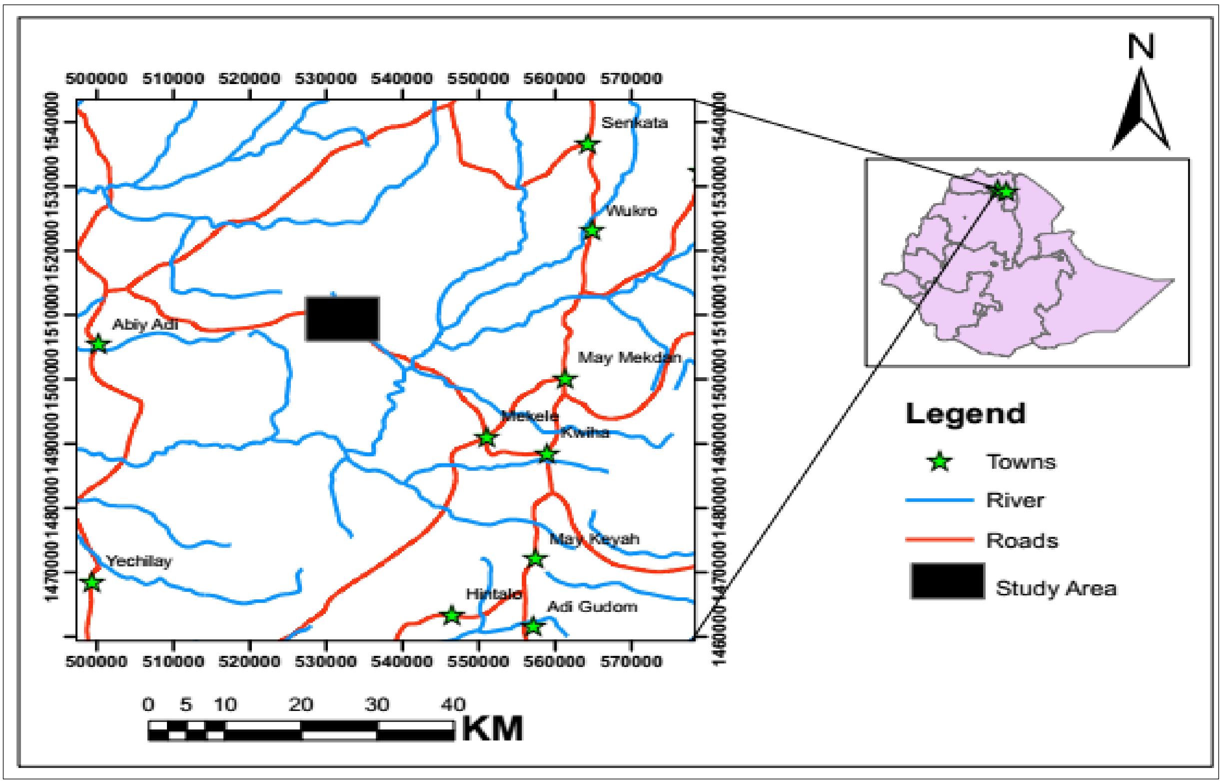

Fig. 1.1 Location map of the study area

1.3 Climate

According to the Degia Tenben Woreda Agriculture office, the climate of the study area falls in semi arid with altitude 2900m above sea level. The hottest month is May with a mean maximum temperature of 23.3^{o} C, and mean minimum temperature 9 ^{o} C. The coldest month is December which has a mean monthly temperature of 13.9 ^{o} C and the corresponding mean monthly maximum and minimum values being 21.2 ^{o} C and 6.6 ^{o} C.

The area has one main rainy season from June to September. According to the Ethiopian meteorological service agency (EMSA), about 90% of the total rainfall occurs during these months (Fig.1.2). The area receives an average annual rain fall of 670 mm.

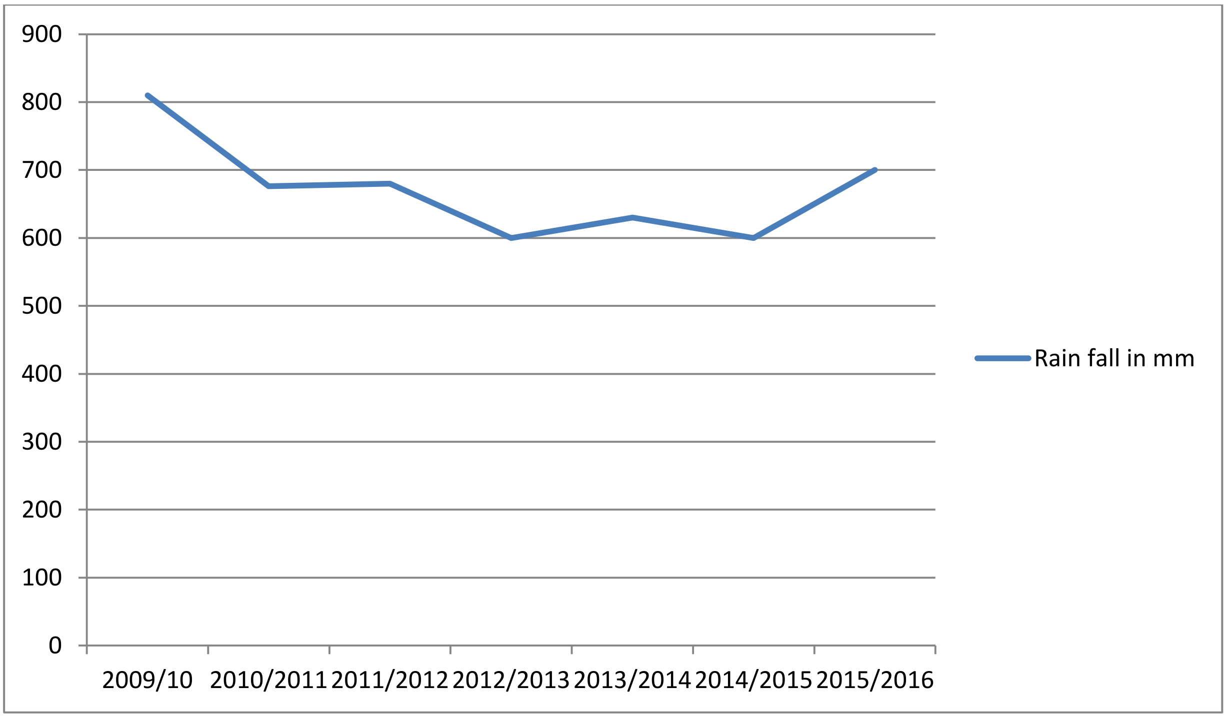

Fig. 1.2 Mean Annual rain fall of Hagereselam (from 2009 - 2016)

1.4 Geology

The study area is found within Geba Basin, Wereda Degia Tenben, Tigray, Northern Ethiopia. The geology of the Geba basin is highly diversified and complicated.

The study area comprises different geological units, adopted from program report (MUIUCP, 2010); lithological classification of the basin is made based on age and mode of formation as: (i) Quaternary deposits, (ii) Tertiary volcanic and Dolerite sills/dykes, (iii) Mesozoic sedimentary rocks, (iv) Paleozoic sedimentary rocks, and (v) Precambrian rocks.

1.4.1 Quaternary deposits

From quaternary deposits Only Alluvial sediments are mapped and described in the study area. They cover a small portion of the study area, adopted from program report (MUIUCP, 2010).

1.4.1.1 Alluvial sediments

The relief and topography of the study area is not as such convenient for the accumulation of extensive alluvial deposits; however, such sediments of limited areal extent are found mainly in some flood plains. A relatively smaller, 2 to 4 m thick exposure of alluvial sediment is also found at the northern part of the Hagereselam Town.

Smaller patches of veneer alluvial sediments can also be found along valleys of streams and some fault controlled depressions. The Alluvial sediments are composed of fluvial sediments ranging from well-sorted, well-rounded pebbles, and boulders to poorly sorted mixtures of clay, silt, sand, and pebbles (MUIUCP, 2010).

1.4.2 Tertiary Volcanic and Dolerite rocks

Intense magmatic and tectonic activity, which has continued to the present day, is the unique characteristics of the tertiary period in north Ethiopia. Flood basalt volcanism, tectonic uplift of African region and rifting are some of the major activities that were happened during this period. A significant portion of the study area is still covered by remnants of this flood basalt volcanism (Russo et al., 1997; Merla, 1973).

1.4.2.1 Volcanic rocks

Volcanic rock covers Almost up to 80% of the study area, horizontally lying over the Upper (Amba Aradam) Sandstone (in the south and central part) and the Lower (Adigrat) Sandstone (in the north). The volcanic rocks show two phases of eruption: a fine-grained aphanitic basalt at the base followed by a course-grained phaneritic basalt at the top. A discontinuous layer of thin Tertiary lacustrine deposit has been observed within most of the volcanic successions, separating the lower fine-grained from the upper course-grained basalt (Russo, 1997; Merla, 1973).

At the base of Hagereselam there is 47m thick black massive, fine grained basalt, so called Aphanitic basalt, on top of this there is 15m thick fine grained lacustrine sedimentary rock. At the middle of this deposit, there is black, which contains gastropods, relatively coarse grained sandstone, which is most probably belonging to the greywacke category. At top there is coarse, black, around 70m thick, Phaneritic basalt, which is found covering a large portion of the study area and forming a cliff (Russo, 1997; Merla, 1973; Levitte, 1970; Kuster, 2005; Kazmin, 2004; Beyth, 1972).

1.4.2.2 Dolerite sills and dykes

Sills and dykes are the second type of mafic rocks found in the study area. The sills are up to 40m thick and extended to large area. They found forming concordant relationship with upper part Jurassic lime stone-shale sedimentary rocks. Basically they are Basaltic to gabbroic dolerites in composition; in terms of grain size they are purely aphanitic to phaneritic. They are found exposed at east and north east parts of the study area (Russo, 1997; Merla, 1973; Levitte, 1970; Kuster, 2005; Kazmin, 1972; Beyth, 1972).

1.4.3 Mesozoic sedimentary rocks

1.4.3.1 Amba-Aradam Formation

Amba Aradam Formation (The Upper Sandstone Formation) is the youngest of the Mesozoic sedimentary succession exposed in the Geba catchment. This 50 m thick formation is found underlain and overlain by the Agulae shale and trap basalt respectively. It is exposed at two localities; in Ale-Asa and Agbe towns which are found East and south west of Hagereslam town (Merla and Minucci, 1938; Dainelli, 1943; Beyth, 1972; Bossellini, 1997).

1.4.3.2 Antalo Super sequence

Agulae Shale is the second youngest rock of the Mesozoic sedimentary succession exposed in the Geba catchment (Bosellini et al., 1997) conformably overlies the Limestone (Antalo). This group is comprised of mainly shale with minor intercalations of marly limestone, mudstone, and evaporite layers. The maximum thickness of the unit reaches about 400 m at Ale-Asa village, on the Mekelle Hagereselam road and covers significant parts of the Mesozoic sediments of the Mekelle Outlier. The lower part of the Agulae Shale is dominated by laminated shale characterized by a light to dark gray colored fissile layers, and black lime mudstone cupped by a relatively thick limestone, as compared to the other limestone layers in the group. Evaporate deposit are observed at the lower part along the road from Mekelle to Hagereselam (Dainelli, 1943; Beyth, 1972; Bossellini et al., 1997).

According to Worash., G. and Valera (2001) and seven members by Russo et al. (1997) The Antalo Formation is the major stratigraphic succession of the Antalo Super sequence; it covers large part of the Mekelle Outlier. The Antalo Formation is classified into three sequences.

- 250 to 350 m thick Limestone-Marl intercalation is the lower part of the formation.
- Marl and marly limestone rich in brachiopods ammonites is the next overlying unit.
- Shale-Marl-Limestone is the top most unit of the Super sequence and it is characterized by thin beds of Fossiliferous limestone, thick succession of marl, shale and a distinct cliff of about 8 m thick limestone.

1.4.4 Transitional unit

Between the Antalo Formation and the underlying Lower Sandstone there is calcareous sandstone at the base and sandy limestone at the top with intercalations of shale layers of 20 to 30 m thick; this is the transition unit (Merla and Minucci, 1938; Dainelli, 1943; Beyth, 1972).

1.4.4.1 Lower Sandstone Formation (Adigrat Sandstone)

Adigrat Sandstone Formation is the oldest of the Mesozoic sedimentary succession exposed in the Geba catchment and it is unconformably rest on the Precambrian basement rocks, with the exception in a few localities where it overlies the Paleozoic sediments. The maximum thickness of the Lower Sandstone in the Geba basin reaches about 700 m (Bossellini et al., 1997).

1.4.5 Paleozoic sedimentary rocks

1.4.5.1 Edaga Arbi Tillites

The Edaga Arbi Tillite is one of the Paleozoic sedimentary rocks exposed in the catchment. It normally consists of poorly sorted, unstratified, and poorly consolidated sediments, forming small conical hills or irregular slopes below the cliffs of the Lower Sandstone Formation (Sacchi et al., 2007; Down, 1971; Beyth, 1972; Kuster 2005).

1.4.5.2 Enticho Sandstone

This formation is the lower most sedimentary unit exposed in the Geba catchment. It is characterized by dome-shaped hills and flat-topped plateaus unconformably overlying the basement rocks (Sacchi et al., 2007; Down, 1971; Beyth, 1972; Kuster 2005).

1.4.6 Precambrian rocks

The Mozambique belt and the Arabian-Nubian Shield are the two folded belts of basement rock of Ethiopia. The basement rocks of Geba basin are Arabian-Nubian Shield Precambrian rocks. Thick and heterogeneous unit of volcanic rocks situated in a geosynclinal basin overlain by meta-conglomerates, greywacke, and meta-sediments are the basic characteristics of the Arabian-Nubian Shield Precambrian rocks (Russo et al., 1997; Asrat et al., 2001).

1.5 Vegetation

In the study area, the distribution of vegetation is more or less bushes, Eucalyptus and shrubs. Most of the steep mountains and ridges are covered by these types of vegetation. In the settlement areas, towards the southern hells of the study area, and at the mountains parts of the Northern of the city Eucalyptus trees are present. Almost Most of the plain area is used for cultivation of crops by the local people.

1.6 Landscape

Cliff, steep slope, plateau, valley and gorges are some of the landforms of the study area. More or less there is high relative relief almost all in the study area; the elevation ranges from 1670 m above sea level to 2900 m above mean sea level. The terrain feature of the study area is represented by three dimensions in Fig. 1.2.

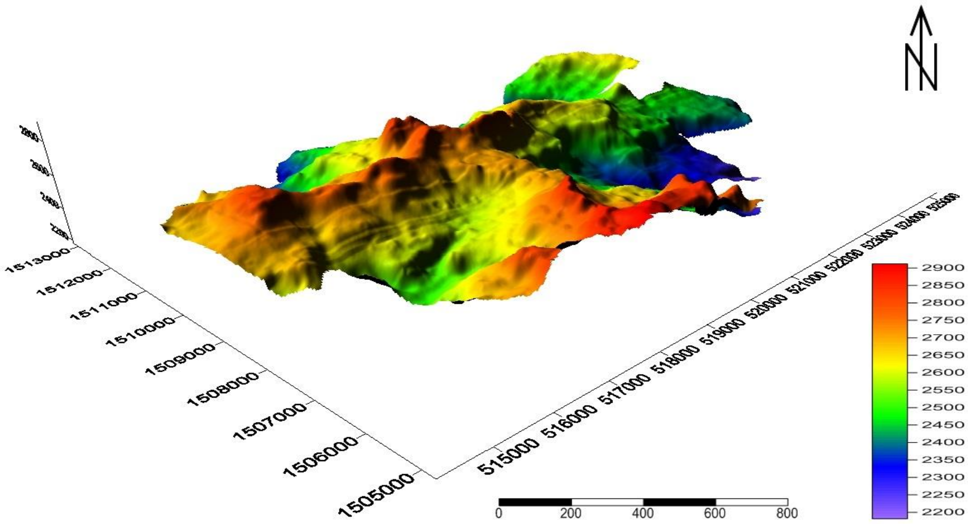

Fig. 1.2 Three Dimensional Terrain view of the study Area (source: DEM ASTER Satellite Image)

1.7 Drainage pattern of the study area

Drainage pattern is the network of stream channels and tributaries their shape or pattern develops in response to the local topography and subsurface geology. Drainage patterns or nets are classified on the basis of their form and texture. Their form and texture determined by the local geology and topography; if the runoff water excides infiltration depending on the local geology and topography different drainage patterns will create. In steep topography and uniform local geology the possibility of runoff increases and this leads to creating of dendritic drainage pattern. A dendritic drainage pattern is the most common form and looks like the branching pattern of tree roots. It develops in regions underlain by homogeneous material. That is, the subsurface geology has a similar resistance to weathering so there is no apparent controls over the direction of the tributaries take (Varnes, 1978). The study area has dendritic drainage pattern.

The study area is located within Gibe river basin. Gereb Zelakwa, Tsalet, and May Zegzeg Rivers are the major River which flows towards South West, West, and South, South East (SSE) direction, respectively and finally joins Giba River. Many small tributaries from different direction are flowing into these rivers. Though, there are some important tributaries from different directions the general direction of flow is towards Tsalet, Gereb Zelakwa, and May Zegzeg Rivers and their respective directions. Except May Zegzeg River Gereb Zelakwa and Tsalet Rivers are perennial rivers whereas, May Zegzeg River flows seasonally during the rainy season and after this season for about one or two months (Varnes, 1978).

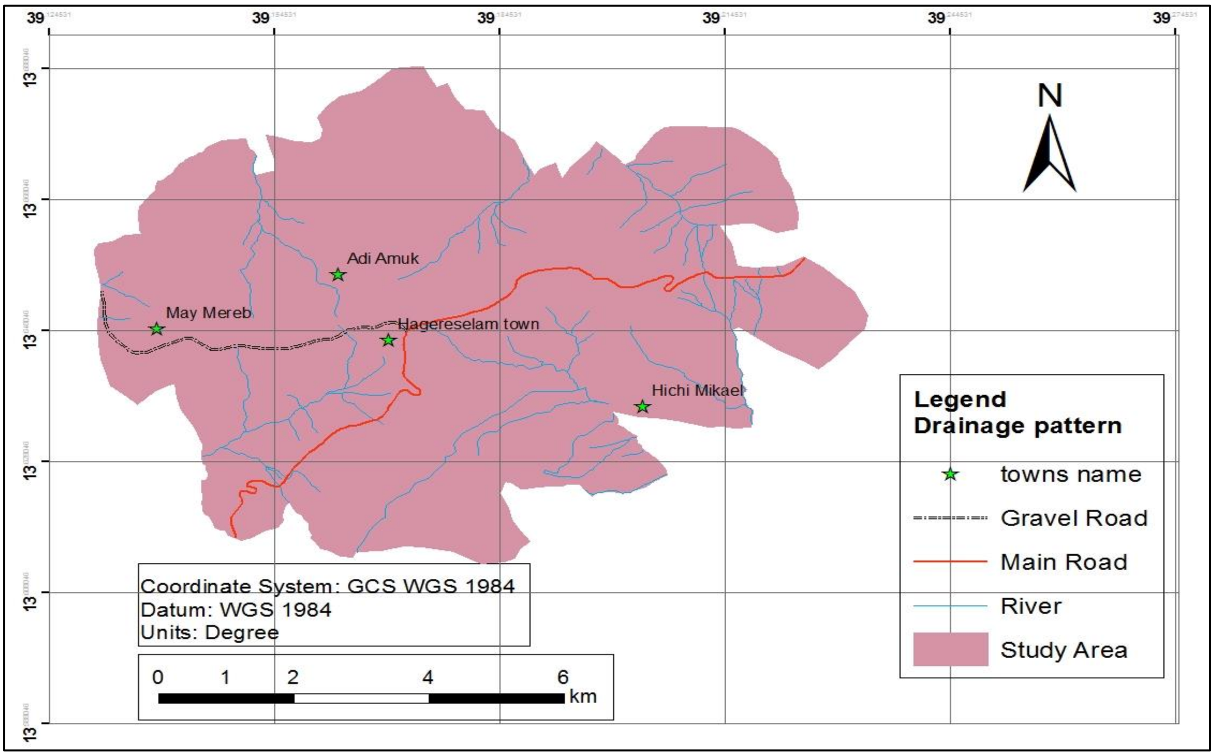

Fig. 1.3 Drainage Pattern of the Study Area

1.8 Objective

The general objective of this study is to prepare landslide hazard zonation of the study area by following an integrated statistical and expert evaluation technique.

Specifically, the objectives of this research work are the following:

- To conduct landslide inventory mapping of the study area.
- To evaluate various inherent and external triggering factors
- To evaluate statistical relations between various landslides related factors with past landslides.
- To correct ratings for various intrinsic and external triggering factors of Slope stability evaluation parameter rating scheme (SSEP) based on statistical relations
- To prepare landslide hazard zonation map by following modified SSEP
- To evolve general remedial measures for high hazard zones.

1.9 General methodology

The general methodology followed in the present study was based on thorough literature review, field investigations, and data collection of past landslide distributions in the study area. Further, density value of past landslides with respect to various factor classes was computed. Later, these density values were used to modify the original SSEP ratings. Finally, using the modified ratings for various factor classes' landslide hazard assessment of the study area was done. Generally, the methods followed during this study are presented as a flow diagram (Fig. 1.4).

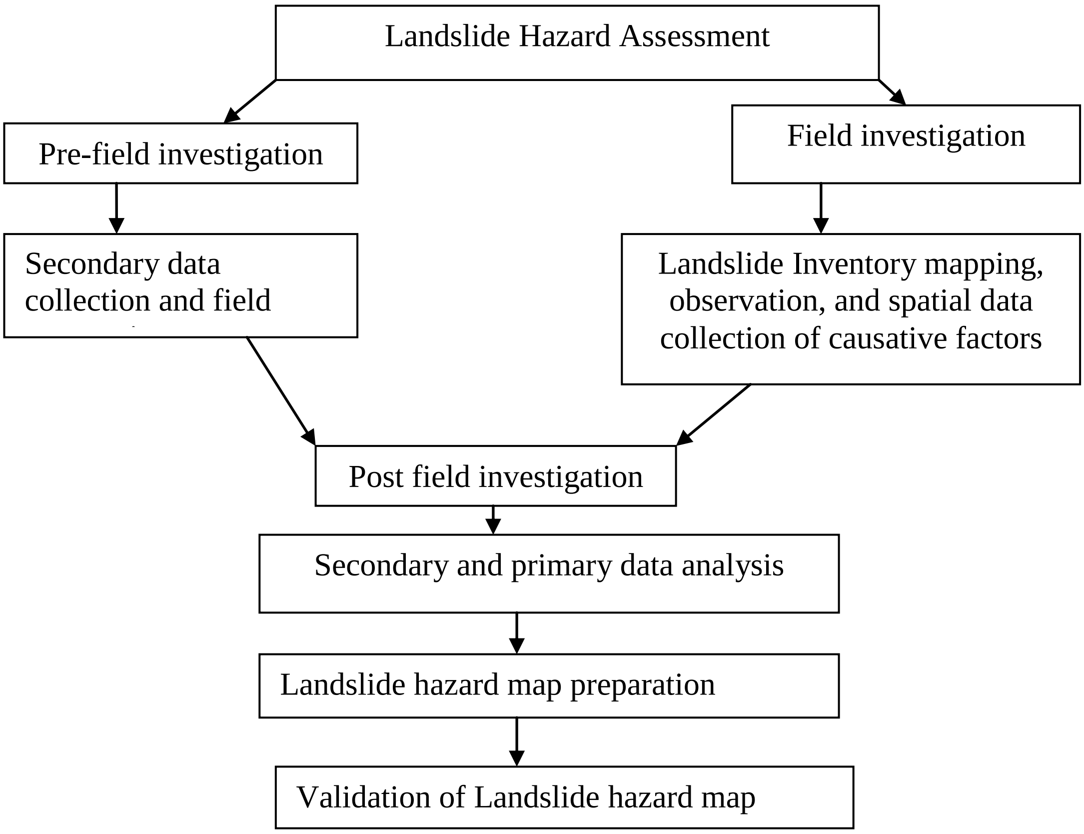

Fig. 1.4 Flow diagram showing general methodology followed during present study

1.10 Significance of the study

The landslide hazard map of the study area can be used to recognize the spatial likelihoods of landslide for safer strategic planning of future developmental activities. This may help to select appropriate sites for agriculture, construction and other development activities in the study area. Further, it will also help to minimize the upcoming impact in landslide prone areas by providing important information for concerned bodies and local government in managing present and future land utilization.

1.11 Limitation and scope of study

The scope of this study was to modify the SSEP approach by integrating with statistical approach and come up with a method in which subjectivity of SSEP in assigning rating to various landslide causing factors can be removed. However, factors related to landslide events like; seismicity, rain fall, parallelism between discontinuities dip direction and slope, relationship between dip of discontinuity and inclination of slope, soil cover depth, dip of discontinuity or plunge of line of intersection of wedge forming planes, and characteristics of structural discontinuity cannot be modified by statistical approach, due to scale difference in taking observation on these parameters. Due to this limitation the current study was forced to modify SSEP factors for the statically suitable factors only that can be processed at same scale and statistical relations between the factors and past landslides can be established.

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CHAPTER TWO LITERATURE REVIEW

1.1 Background

The term "landslide" is used to describe a wide variety of processes that result in the detectable downward and outward movement of a slope material (soil, rock, and vegetation) under gravitational influence. The materials may move by: falling, toppling, sliding, spreading, or flowing (Kanungo et al., 2009). Landslides can be triggered by both natural and man-induced changes in the environment. Geological history and human activities of an area directly determines the possibility of slope failure within that area. The very common causes of landslide are classified in to two classes; inherent causes of slope failure such as; weakness in the geological composition or geological structures within the rock or soil and external triggering mechanisms such as; rain fall, earthquake or volcanic activity, snowmelt and change in ground water level, and human activity (Varnes, 1984).

2.2 Landslide Hazard

Any natural geological phenomenon is part of a natural earth process, but if this natural phenomena causes damage to life, property as well as in infrastructure it is called hazard (USGS, 2004). Landslides event are natural phenomenon that may trigger by human induced or natural induced causing factors. Any human activity that modifies the natural environment may end up to disturbing the natural form of the area. This disturbed natural environment reacts to the new modification depending on the amount and type of modification made to it. This reaction of the natural environment is what is called human induced natural phenomenon. On the other side, natural event like; seismic activity, Volcanism, heavy rain fall, tsunami and etc…may disturb the natural form of an area due to this external natural force exerted on the natural environment a modification may come (Varnes, 1984).

Like the other natural events a landslide event is also natural phenomenon that may triggered by natural causes or human induced developmental activities. Either of them changes the natural form of the environment (Raghuvanshi et al., 2014).

Landslide is defined as the movement of a mass of rock, debris or earth down the slope, when the shear stress exceeds the shear strength of the material (USGS, 2004). The occurrence of landslides is the consequence of a complex field of forces (stress is a force per unit area) which is active on a mass of rock or soil on the slope (USGS, 2004). Basically, the two main determinative parameters are:

- An increase of shear stress on the material
- A decrease of material strength

Landslide events become hazard when this event causes damage to property, life, and infrastructure. Worldwide landslide events cause great loss in economy the following (Chart 2.1) chart tries to show average economic loss by country:

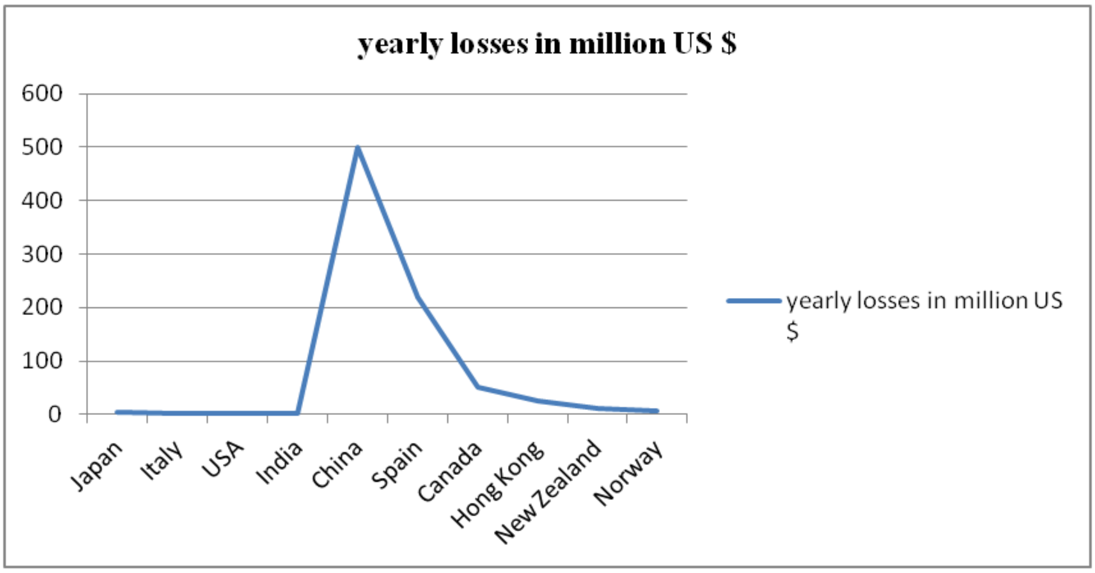

Fig. 2.1 Average economic loss by country (source USGS, 2004)

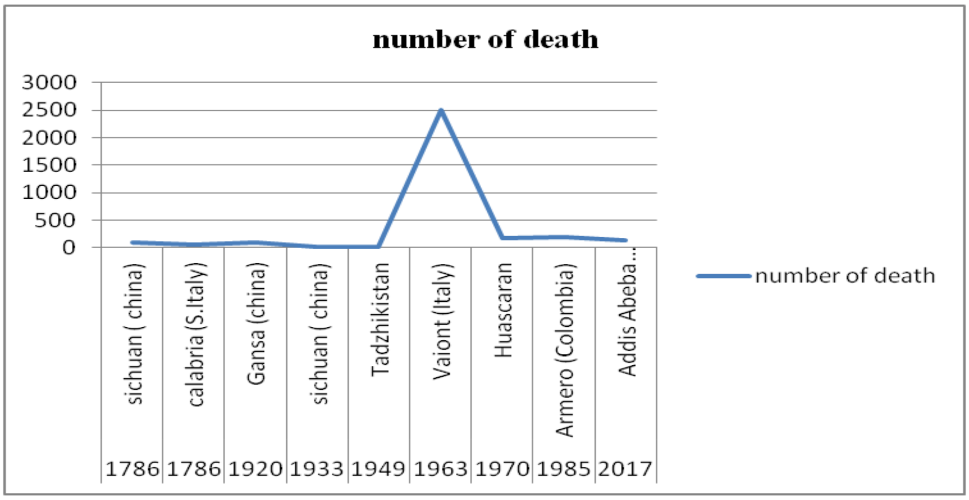

Fig. 2.2 Human life loss by Country (source USGS, 2004)

2.3 Factors influencing slope stability

According to Anbalagan (1992) and Raghuvanshi et al. (2014), factors that affect slope stability are classified in to two classes; intrinsic and external factors. Intrinsic factors are inherent parameters that affect the slope stability like slope geometry, slope material, structural discontinuities, land use land cover, and Groundwater condition of the slope. External parameters are parameters that are from the external environment like seismicity, rainfall, and manmade activities.

2.3.1 Intrinsic Factors

2.3.1.1 Slope geometry

Slope geometry is intrinsic parameters that describe ones slope relative relief and slope morphometry. Relative relief of a slope describes the relative difference in elevation of one slope facet that means the difference between the highest and lowest points of a slope. With increasing slope relative relief the possibility of landslide occurrence will also increase (Bekele Abebe et al., 2010; Raghuvanshi et al., 2014). Slope morphometry describes slope angle or steepness of a slope though landslide occurs in all slopes however, the possibility of occurring increase with increasing slope steepness (Varnes, 1984; Bray, 1981).

2.3.1.2 Slope Material

Rock or soil or rock and soil are the main materials of a slope. The composition, fabric, texture, cementing material and other properties of slope material influence shear strength, permeability and susceptibility to chemical and physical weathering of slope material (Varnes, 1984). According to Varnes (1984) unconsolidated slope materials are more susceptible to instability than consolidated, because they have less shear strength due to their looseness, have higher infiltration rates as a result they will form pore water pressure which leads to instability than consolidated slope materials. According to Varnes (1984), material which is susceptible for landslides are those with loose or open structures such as loess, volcanic ash on steep slopes, and saturated sands of low density, fine grained “sensitive” deposits of clay or rock flour, and cliffs of fractured rock. The advanced weathering which will lead to degradation of the geotechnical properties of the volcanic tuffs and to the disintegration of the basalts to soils are the main causes of instabilities (Fall et al., 2006).

Slope material and slope geometry determine the type of landslide within the slope. In areas where the slope geometry is steep and the slope material is covered by hard bed rock like basalt, welded ignimbrite, limestone and sandstone landslide like rock falls, toppling and rockslides/avalanches are common (Varnes, 1978; Berhanu Temesgen et al, 1996). As Sensitive or quick clays, which are those that lose much of their strength up on remolding at constant water content, have been involved in many serious flow-type landslides Varnes (1984). In deeply weathered residual and colluvial soils and alluvial deposits translational and rotation slide usually occur (Kumar, 2009).

2.3.1.3 Structural discontinuity

The inter relationship of structural discontinuities within a slope like parallelism between discontinuities dip direction and slope, relationship between dip of discontinuity and inclination of slope, dip of discontinuity, soil cover depth, structural discontinuity and rock mass condition, and characteristics of structural discontinuity controls the slope stability condition to a great extent (Raghuvanshi et al., 2014).

Down slope dipping planes separating rocks of different competence or alteration, as well as joints and fractures oriented in the same direction, may allow vertical infiltration and root penetration, as well as acting as potential failure planes. Therefore, presence of discontinuity and the inter relationship of those discontinuities in a slope is an important factor in the stability of natural hill slopes (Marden et al., 1992).

When the direction of the intersection of the discontinuities surfaces and the slope becomes parallel, the condition is conducive to failure and these increases with its inclination until the angle of inclination of the intersection of the discontinuity surface reaches beyond the angle of slope (Kumar, 2009).

2.3.1.4 Land Use/Land Cover

‘’Land cover is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. whereas Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods.

In different areas peoples of that locality or any investors or governmental body can use the slope for different activities. When they use the slope depending on their purpose they will modify the area from its natural form. During these activities the earth or the slope starts to react for the activities that have been done on it. For example; the slope may became very suitable for sliding if the vegetation cover of the slope is disturbed or removed. If the slope becomes bare land the soil material of the slope loses its shear strength due to the removal of the slope vegetation. If the slope toe is eroded the slope will become suitable for sliding due to loss of slope support. Similarly, if there is irrigation activity at the slope face there will be water infiltration in to the slope as a result development of pore water pressure will occur. This may possibly trigger sliding. Also, if there is lose material dumped along the slope face the sliding of this material may occur, etc. Therefore, land use land cover of an area can determine the possibility of landslide occurrence in the area (Raghuvanshi et al., 2014).

2.3.1.5 Groundwater

Shear strength is the inherent strength of sediments and rocks in a normal condition created by the materials friction and cohesion to each other. Materials shear strength becomes higher when the open spaces between soil grains and fractures are filled by air and if there is no any lubricant within the structure **(**Raghuvanshi et al. 2014**).**

Steep to moderately steep terrains are mostly rocky and with same sediments; when these materials are dry pore space among grains or open fractures in rock are filled with air. In this case their shear strength is high however**,** below the water table, the pores and fractures are filled with water which exerts pressure (i.e. pour water pressure**)** that tends to counteract some of the friction and cohesion forces. In other words, the presence of groundwater reduces the shear strength of the earth materials (Raghuvanshi et al. 2014). Under normal conditions these slope materials remain stable however, if fluid pressures rise significantly they can completely negate the forces of friction; in such cases the shear strength of sediment and rock is reduced to **zero** and it is at this point that slope materials will fail (Dai and Lee 2000). .

2.3.2 External Factors

External factors are dynamic factors caused by heavy rainfall, natural earthquake, human induced seismic activity, different developmental activities, slope modification, etc…which will result in to slope instability (Raghuvanshi et al. 2014).

2.3.2.1 Rainfall

Rainfall results in increase moisture content of slope material, which can increase pore water pressure above the stable condition and results in slope failure (Dai and Lee 2000). Based on this theory many different attempts have been done to formulize and measure the relationship between landslide occurrence and rainfall variables (i.e. intensity and duration) (Dai and Lee 2000).

2.3.2.2 Manmade activity

Deforestation for the sake of settlement or for timber harvesting especially in hill sites results the soil to lose it shear strength and it will be suitable to erosion and sliding, Mining in search of natural minerals or fossil fuels, excavation for construction of infrastructures (roads, bridges, canals, and etc.), traffic in use of roads, leakages of water in large irrigational activities, excavation in search for construction material (quarrying), blasting of heavy explosives, overstepping of slopes by undercutting the bottom slope, and loading the top of slope. Directly or indirectly these human activities makes the slope to lose its stability (Kifle Woldearegay, 2013).

2.3.2.3 Seismic activity

In stable landforms the driving and resisting forces are at equilibrium or the resisting force exceeds the driving force (Dai and Lee 2000). A force from Seismic activity gives additional driving force for landslide to occur. The higher the magnitude of an earthquake (seismic activity) the more energy it exerts on slope material. If seismic and other driving forces exceeds the resisting forces landslide will occur. The higher the magnitude of an earthquake, the more mass wasting will occur (Shimelies, 2009).

2.3.2.4 Gravity

Gravitational force is the reason behind ever falling thing on the surface of the earth mass wasting or Landslide is also triggered by the force of gravity. On a slope, the force of gravity can be resolved into two components: a component acting perpendicular to the slope and component acting tangential to the slope or in the direction of down slope. During instable condition, the shear stress or tangential component of gravity increases and the perpendicular component of gravity decreases. Therefore, the down-slope movement of a material is favored by steep slope angles which increase the shear stress, and anything that reduces the shear strength, such as lowering the cohesion among the particles or lowering the frictional resistance (Shimelies, 2009).

2.4 Classification of Landslide

According to International Institute for Aerospace Survey and Earth Sciences (ITC), the following criteria's can be used or have been used to classify landslides:

(i) Material: Rock, Soil Lithologies, structure, Geotechnical properties
(ii) Geomorphic attributes: Weathering, Slope form
(iii) Landslide geometry: Depth, Length, Height etc.
(iv) Type of movement: Fall, Slide, Flow etc
(v) Climate: Tropical, Periglacial etc.
(vi) Water: Dry, wet, saturated
(vii) Speed of movement: Very slow, slow etc.
(viii) Triggering mechanism: Earthquake, rainfall etc.

2.5 Types of landslide

According to Varnes (1978) landslides are classified based on their principal behavior they show during sliding: type of movement, Type of material accordingly landslide types are divided into six main groups: falls, topples, slides, flows, lateral spreads, and complex movements includes combinations of two or more of the other types of movement.

Table 2.1; Landslide classification by Varnes (1978)

Type of movement			Type of material		
			Bed rock	Engineering soils	
				Predom. coarse	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
			Rock block slide	Debris bloc slide	Earth block slide

	translational	Many units	Rock slide	Debris slide	Earth slide
Lateral spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow	Earth flow (soil creep)
Complex	Combination of two or more principal types of movement				

2.5.1 Fall

A fall starts with the detachment of soil or rock from a steep slope along a surface on which little or no shear displacement takes place. In this type of landslide, the mass moves as individual particles with no coherent structure developing between particles. The material then descends mainly through the air by falling, bouncing, or rolling (Fig.2.3). The triggering mechanism of fall are undercutting of slopes by streams and rivers or differential weathering, excavation during road building, loosened by rain, plant-root wedging, expanding ice and earthquake shaking. It is common in steep slopes (Varnes, 1975).

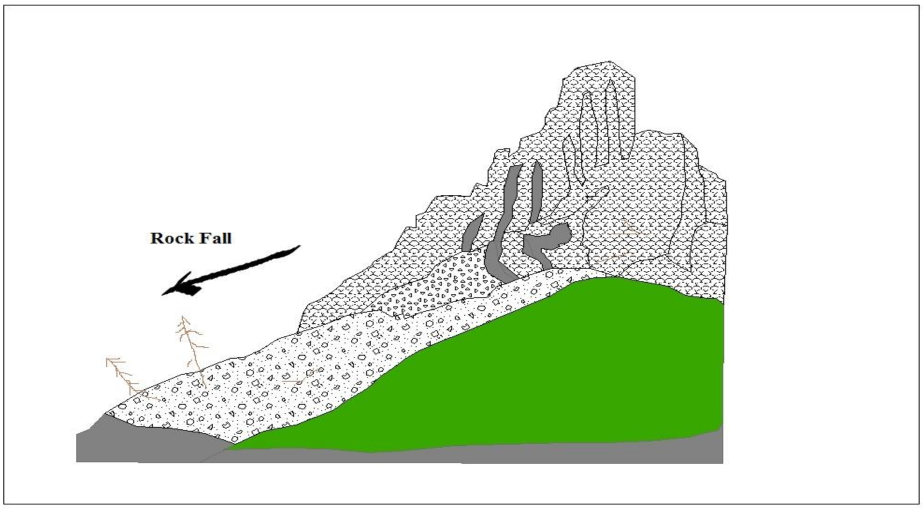

Fig. 2.3 Rock fall

2.5.2 Topples

Topples is the forward rotation out of the slope of mass of soil or rock (Fig. 2.4) about a point or axis below the centre of gravity of the displaced mass. Toppling failures occur as a result of overturning of the blocks rather than sliding (Varnes, 1975). The triggering mechanism of topples are gravity, water or ice occurring in cracks within the mass, vibration, undercutting, differential weathering, excavation or stream erosion. It occurs in columnar jointed volcanic terrain, as well as along streams and river courses where the banks are steep. It can consist of rock, coarse and fine materials. The rate of movement ranges from extremely slow to extremely rapid. It can be extremely destructive especially when failure is sudden or velocity is rapid (Highland and Peter, 2008).

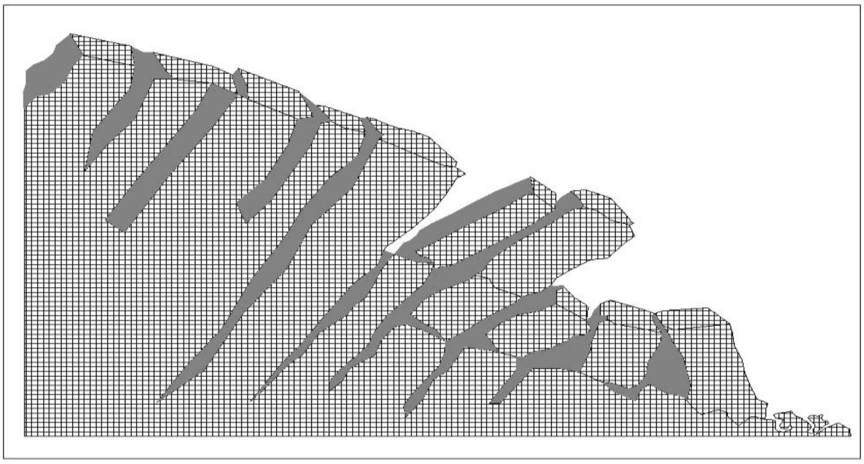

Fig.2.3 Rock mass toppling (source USGS, 2004)

2.5.3 Slides

A slide is a down slope movement of soil or rock mass occurring predominantly on the surface of rupture or on relatively thin zones of intense shear strain in slides the materials move as coherent blocks or masses along the failure plane According to USGS (2004), the two major types of slides are rotational and translational slides. Rotational slides are in which the surface rupture is curved concavely upward and the slide movement is roughly rotational about the axis that is parallel to the ground surface and transverse across the slide. Translational slide is the landslide mass which moves along a roughly planar surface with little rotation or backwards tilting (Fig. 2.4) (Highland and Peter, 2008).

2.5.3 Flows

Mass flow is down slope movement of soil, bedrock, or debris. Often, there is a gradation of change from slides to flows, depending on the water content, mobility, and evolution of the movement. Flows can be classified into debris flow or earth flows. Debris flows is a form of rapid mass movement that consists of loose silt, sand sized material, rock and sometimes organic matter combine with water to form slurry that flows down slope (Highland and Peter, 2008). It occurs around in steep gullies and canyons and, nearly saturated, and consists of a large proportion of silt and sand-sized material. They are commonly caused by intense surface water flow, due to heavy precipitation or rapid snowmelt, which erodes and mobilizes loose soil or rock on steep slopes (Fig.2.5).

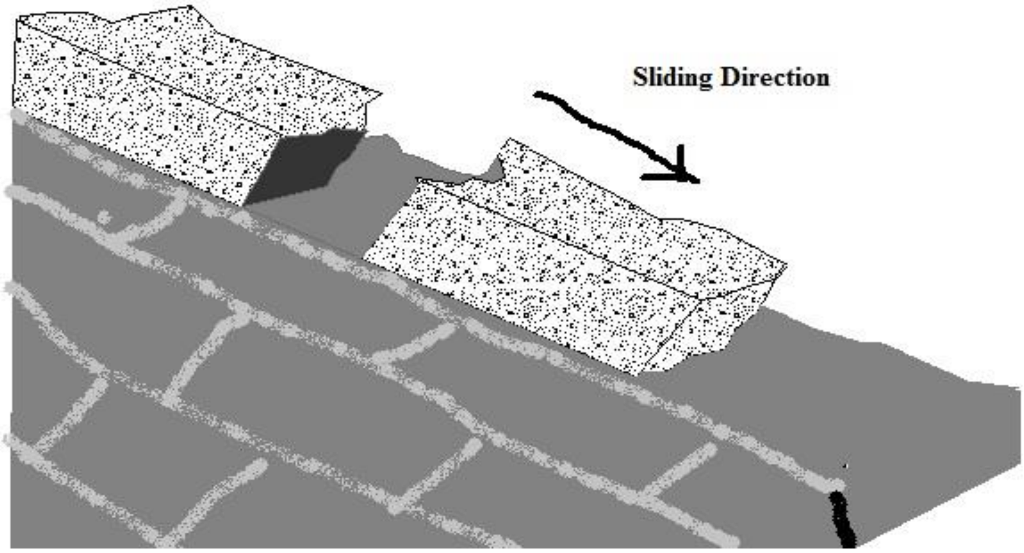

Fig. 2.4 Sliding (source USGS, 2004)

2.5.4 Spread

According to Highland and Peter (2008) spread is an extension of cohesive soil or rock mass. In spread the dominant movement is lateral accommodated by shear or tensile fractures. Spread commonly occurs in gentle slopes and cohesive soil or rock mass.

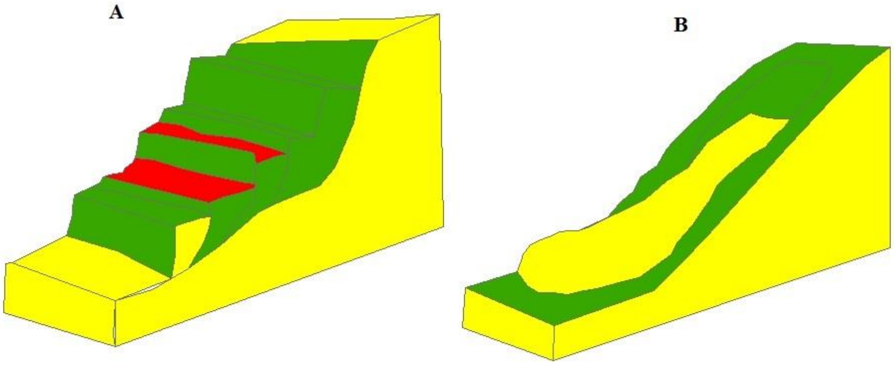

Fig. 2.5 Slump (A), Flow (B) (source USGS, 2004)

2.6 Landslide Hazard Zonation

Due to national and worldwide high rate of growth in the human population and related developmental activities the need of land for settlement and investment is growing. The scarcity of plane area leaves no choice Worldwide establish human settlements, they do not have other option than to establish their houses in hill regions. For construction of all facilities in hilly regions they are not considering factors like deforestation, erosion hill face disturbance, drainage pattern, water resources disturbance, rainfall, weather and seismic activities that are crucial for design of houses, road and other life line facilities. Landslide hazard zonation of an area helps to give information of the area in terms of landslide suitability of an area. Due to this reason the classification of an area in terms of the suitability of the area to land sliding is vital (Raghuvanshi et al., 2014).

In the current study area due to past records of very hazardous landslide events the classification of the area in terms of potential for sliding is very important. By classifying the landslide prone hilly terrain into different zones according to the relative degree of susceptibility to land-slides provides very crucial information for the people; this requires the identification of those areas that are, or could be affected by landslides (Raghuvanshi et al., 2014).

The LHZ maps do not incorporate directly the magnitude and time of landslide occurrences. LHZ mapping serves as one of the many components in landslide risk assessment. The methodology to develop landslide hazard map depends upon several factors like nature of terrain, parameters to be considered, available data on geology, soil, slope, rainfall, seismicity etc. (Varnes, 1975). However, for the simplicity, we can discuss available methods for landslide hazard zonation into five groups.

2.7 Techniques for Landslide Zonation Mapping and Landslide Assessment

In the last few decades different types of methods have been invented by researchers for landslide hazard assessment for example; Physical methods, Inventory Based Approach, Bi-Variate and Multivariate Statistical Approaches, Probabilistic Approach, and in now days Remote Sensing and Geo Information Systems in Landslide Hazard Zonation Mapping is widely becoming applicable (Tesfahunegn Abera., 2008).

2.7.1 Inventory Based Approach

Inventory based approach it is also known as distribution approach is one of the qualitative methods, which allows to map all landslides in the area through field survey, historic data, satellite imagery and aerial photo interpretation,. Landslide distribution and the land slide severity maps are created which provide basis for landslide susceptibility methods. It is one of the basic qualitative methods of land slide hazard zonation mapping. In this technique, the spatial and temporal patterns of landslide distributions are represented in the landslide inventory maps, which portray type of debris movement, rate of debris movement, type of displaced material etc. (Tesfahunegn Abera., 2008).

2.7.1.1 Statistical Approach

Statistical approach is a quantitative way of evaluating area with landslide suitability. This method has been developed mainly to correct high level of subjectivity in connection with expert judgments evaluation. This development involves the determination of various combination of variables that may be main reason of earlier instability. It is after this development investigation of stable slope and region where similar conditions exist as the landslide occurred areas begin (Dai and Lee, 2001). The statically methods are based on relationships that have been observed between every factors that have contributed to present and past landslide distribution. All possible causative terrain parameters are weighted and integrated using GIS for landslide susceptibility analysis. Generally, this statistical approach provides much more benefits such as;

- Less subjectivity
- The same results can be reproduce by another researcher

Although, statistical approaches have much more benefits it also have some disadvantages such as;

- The reliability and capacity of functional method is depends on quantity and reliability of collected data.

2.7.1.2 Bi-Variate Statistical Approaches

In this statistical approach every individual causative factor weight to landslide is evaluated. The weight or contribution of a causative factor to the landslide hazard is determined on the basis of landslide density. In this approach GIS plays a great role starting from division of each parameter maps into number of relevant class; determination of landslide density and weighting the value of each parameter map; geo-processing of thematic maps; and weighting of values to the various parameter maps. In the bi-variate method causative factors for landslide to occur are compared to the existing landslides. Based on landslide severity and distribution the weights are assigned to the landslide causing factors. Bayesian Model, Frequency Analysis approach, Information Value Model (IVM) are a few bi-variate methods applicable for hazard zonation mapping. The main drawback of bivariate statistical method is independency between different parameter maps with respect to probability to landslide occurrence, (Van Westen et al., 1997; Tesfahunegn Abera., 2008).

2.7.1.3 Multi-Variate Statistical Analysis

Multivariate statistical model were developed for landslide hazard zonation by Carrara et al. (1991). In this landslide zonation approach geometric or morphometric units of the study are reclassified into landslide hazard classes. This method is based on purpose of absence or presence of landslides. The resulting matrix is analyzed by multiple regression methods. A statically model of slope instability in hazard is assessed through correlation of past landslides with several influential factors. Although multivariate techniques can be applied to different scales landslide zonation, their use becomes quite restricted at the regional scale, where exact input map of landslide occurrences may not be available and most of the causative factors cannot be collected with satisfactory accuracy. At macro scales, different factors will have to be used (such as ground water depth, soil sequences and thickness, ground water Logistic regression models, discriminant analysis, Artificial Neural Networks (ANN) are some of the multi-variate statistical analysis. In this method each pixel of the landslide area are calculated and the presence or absence of landslide is predicted (Tesfahunegn Abera., 2008).

2.7.1.3 Logistic Regression Analysis

By determining the relation between occurrence and nonoccurrence of landslide logistic regression analysis is used in predicting the occurrence or nonoccurrence of landslide. Lee and Pradhan (2006) have applied this approach for landslide hazard mapping.

2.7.1.3 Discriminate Analysis Method

According to Lee et al., (2008) this discernment method determines the maximum difference for each independent variable between landslide causing and non-causing factors. Gorsevski et al. (2000) used this method to map land slide hazards using GIS.

2.7.1.4 Probabilistic Approach

According to Kanungo et al., (2006) in this method distribution of landslide in an area is compared with probabilistic framework that explains various factors: Bayesian probability, certainty factor, favorability function etc. are some of the explanatory factors. Based on probability distribution function the strong relationship between thematic data layer and landslide distribution is converted into a value which tells the probability of the occurrence or nonoccurrence of landslides (Varnes, 1984).

2.7.1.5 Physical Approaches

This method is applicable in areas with insufficient data or for areas which do not have long term data. In this method land slide hazard assessment is made by understanding the physical and mechanical processes responsible for the susceptibility of landslides. This approach mainly considers the ground water data, slope values and the rainfall data (Varnes, 1984).

2.7.1.6 Remote Sensing and GIS in Landslide Hazard Zonation Mapping

In recent years development of GIS technology for data integration, combined with the availability of high resolution digital elevation models to analyze geographic and geologic data, has greatly increased the applicability of many techniques for landslide hazard assessment (Brabb, 1984; Varnes, 1984; Van Westen, 1994; Carrara et al., 1995). Geo information systems (GIS) and remote sensing technology can be employed for landslide hazard assessment and analysis. The data of landslide causing factors like slope Geometry, lithology and land use/ land cover data before and after occurrence of landslides can be obtained from satellite images taken before and after the occurrence of landslides and the data can be used to predict future occurrences.

Most of the conventional GIS techniques for landslide mapping are based on ‘map overlaying’, which only allows for the comparison of different maps on the same location and scale by placing them one on top of the other and using the criteria for landslide assessment.

Such techniques for modeling slope instability have been employed by different investigators; Shimele, (2009) uses GIS and numerical modeling techniques in Hagereselam area. Reviews demarcated the methods are given by, Hansen (1984), Carrara et al. (1995), Hutchinson (1995), Soeters and Van Westen (1996), Van Westen et al. (1997), Long (2008).

The methods for ranking slope instability factors and assigning different susceptibility levels can be divided into:

<u>Qualitative or quantitative</u>: Qualitative methods are subjective. They establish susceptibility heuristically, and portray susceptibility levels using descriptive (qualitative) expressions. Such techniques depend highly on experience, knowledge and previous works on the study area. It is based on how well and how much the investigator understands the geomorphologic processes acting upon the terrain. On the

contrary, Quantitative methods produce numerical estimates, i.e. probabilities of the occurrence of landslide incident in any susceptibility zone (Guzzetti et al., 2005).

Direct mapping methods are those that recognize the spatial distribution of landslides directly from existing failure zones or using specific knowledge of areas of potential instability. A direct method consists of geomorphological mapping of landslide susceptibility in the field, using aerial photographs or from satellite images (Verstappen, 1983; Nossin, 1989). It still relies on the ability of the investigator to estimate actual and potential slope failures. Indirect mapping techniques are those that employ causative relationship based on possible triggering factors to estimate potential instability. Indirect methods for landslide susceptibility assessment are essentially stepwise.

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CHAPTER THREE

METHEDOLOGY

3.1 General

Landslide hazard zonation is one mechanism that can help to predict or forecast areas of potentially hazardous landslide events. The geologic, topographic and climatic conditions that led to past slope failures often provide clues to the locations and conditions of future slope failures. It expresses the spatial correlation between affected terrain factors and the distribution of past landslide (Van westen et al., 2006; Dai and Lee, 2001; Brabb, 1984). Many researchers and institutions used different methodologies to determine and zone landslide events. The methods that help to determine and zone potentially unstable areas are divided in to three general categories: expert evaluation, statistical methods, and mechanical approach (Leroi, 1997; Engedawork Mulatu et al., 2009; Bekele Abebe et al, 2010; Kifle Woldearegay, 2013; Raghuvanshi et al., 2014; 2015).

3.1.1 General Methodology for SSEP

Slope stability suitability evaluation parameter (SSEP) approach is classified under expert evaluation method and it is used for landslide hazard evaluation (Raghuvanshi et al., 2014). According to Dai et al. (2002), Tenalem Ayenew and Barbieri (2005) expert evaluation method is classified in to two; landslide inventory mapping and heuristic methods. Landslide inventory mapping is the simple method in which the landslide events are recorded for their location and dimension. They are considered as an elementary form of susceptibility map because they highlight the position and dimension of recorded landslides. In the heuristic methods, the opinion is used to estimate and or classify the landslide hazards based on intrinsic and external triggering parameters (Dai and Lee, 2001; Dai et al., 2002; Anbalagan, 1992; Raghuvanshi et al., 2014). SSEP approach falls within heuristic, expert evaluation approach. SSEP approach uses internal and external causative factors to evaluate the landslide hazard zonation of an area.

3.1.1.2 Factors required to evaluate landslide hazard zonation by SSEP approach

The following intrinsic factors are required to perform landslide hazard zonation of an area by using SSEP approach; relative relief, slope morphometry, structural discontinuity land-use/land-cover and groundwater surface manifestations. Among external factors rain fall, seismicity, and developmental activity are considered. Detailed explanation on how those factors were used in this study is presented in the following section;

First of all the study area to be cover in this study was classified in to slope facets. Slope facet means to demarcate area having more or less uniform slope inclination and direction in to one unit using topographic map (1:50,000) or by using DEM (digital elevation model) obtained from satellite data. In this study topographic map and DEM were used to demarcate the slope facets in the present study area.

After preparation of the facets Relative relief (elevation difference with in a facet) map was prepared with the help of DEM of the study area. DEM of the study area was clipped to each facet using ERDAS Software. For each individual slope facet maximum and minimum elevations were noted and the difference of the two elevations classified the slope facet into various relative relief classes. Accordingly, the relative relief map was prepared using ARC GIS 10.3 software and the statistical ratings were assigned to each individual slope facet using the original rating from the SSEP approach. The same step is followed for slope morphometry.

In this study in order to prepare slope material map pervious study map in the area and field investigation were utilized. Base geological map was prepared from the secondary geological map using topographic map during pre field investigation, where the lithology and soil coverage was transferred over the slope facet map. Later, modification on the map was made during field investigation.

For structural discontinuities (spacing, continuity, surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces, parallelism between discontinuities, relationship between dip of discontinuity and inclination of slope) facet wise observations or simple measurements were made during the field work and accordingly, ratings were assigned from the standard SSEP tables.

Land use land cover map was prepared using previous studies in the area, field investigation, and using satellite imagery. Classification of land-use/land-cover map was done using ARC GIS 10.3 software. Finally, rating for land-use/land-cover was assigned based on the rating given by Raghuvanshi et al. (2014). Also, groundwater surface manifestations map was prepared based on facet wise observations during field investigation, accordingly, ratings were assigned from the standard SSEP tables.
For mean annual rainfall the data was obtained from the Ethiopian metrological agency, however rain induced manifestations were observed facet wise during the field investigations. The seismicity intensity of the present study area was obtained from the Ethiopian seismic map prepared by Laike Mariam, (1986) and accordingly ratings were assigned from the standard SSEP tables. For developmental activities in the present study area observations were made facet wise during the field investigations.

3.1.1.3 Evaluation of SSEP approach

The total estimated landslide hazard is evaluated facet wise, where all the ratings for intrinsic and external factors are summed up to get the evaluated landslide hazard value (ELH). Based on these ELH values each of the facet can be classified into various landslide hazard classes as proposed by Raghuvanshi et al (2014).

Table 3.1: information on Landslide Evaluation classes (adopted from Raghuvanshi et al., 2014)

Landslide Hazard Class	Code	Evaluated Value
Very Low Hazard	VLH	< 2
Low Hazard	LH	2 - 4.9
Moderate Hazard	MH	5 - 7.9
High Hazard	HH	8 - 12
Very High Hazard	VHH	> 12

3.1.1.4 Shortcoming of SSEP approach

Slope stability Susceptibility Evaluation Parameter (SSEP) is an expert approach which was developed by Raghuvanshi et al. (2014) by considering both intrinsic and external landslide causative parameters. Slope geometry (relative relief and slope morphometry), slope material, structural discontinuity, land-use/land-cover, and groundwater are intrinsic causative parameters whereas rainfall, seismicity and manmade activity are the external causative parameters that considered in this method. In SSEP technique the rating are assigned for each causative parameter on the basis of logical judgments acquired from experience of studies of intrinsic and external triggering factors and their relative impact on instability of slopes.

The major shortcoming of SSEP approach is in its subjectivity in assigning ratings to causative factors on the basis of logical judgments acquired from experience of studies of intrinsic and external triggering factors and their relative impact in inducing instability to slope. However, such subjectivity is always inherent with all expert evaluation techniques, example; LHEF technique of Anbalagan (1992), LHZ technique by Turrini and Visintainer, (1998); Romana’s (1985) Slope mass rating technique; Bieniawiski’s (1989) Rock mass rating etc. Besides, the causative factors are not interrelated to each other; there is no dependence of one causative factor on the other.

In order to overcome the subjectivity of SSEP technique, in the present study attempt was made to integrate SSEP with statistical technique and derive the ratings based on actual relationship of various causative factor classes with the past landslides in the study area. A detailed discussion on method and procedures thus followed is discussed in later part of this chapter.

3.1.2 Statistical Approach

Statistical approach is quantitative way of landslide evaluation approach which has been developed to resolve high level of subjectivity in connection with better expert judgments evaluation. This approach simplifies the process of assigning weights which was followed by expert evaluations (Dai and Lee, 2001). In the statistical methods there are two variants the bi-variate method and multi-variate method. In the bi-variate method comparison of landslide causing factors with past landslide events are required to come up with landslide hazard zonation of an area (Carrare et al., 1991).

3.1.2.1 Criteria’s required to evaluate landslide hazard zonation bi-variate statistical approach

The following criteria’s are required to perform landslide hazard zonation of an area using bi-variant statistical approach; all the causative maps of the study area such as; facet map, slope morphometry map, land-use/land-cover map, groundwater surface manifestations map, developmental activity map, past landslide in the study area, and structural discontinuity map of an area are required. Every variant map in the study area is utilized to get the past landslide density value in the study area and to evaluate the density value in terms of the distribution of the causative factors in the study area (Carrare et al., 1991).

3.1.2.1 Evaluation of Bi-variant Statistical Approach

The evaluation of the bi-variant statistical approach is done following the following steps;

- Every causative factor map is converted in to raster form.
- Past landslide inventory map of the area is converted in to raster form.

- Overlay analysis all the causative factors with the past landslide is done with the help of ARC GIS 10.3 software.
- After intersection of raster causative factors distribution of past landslide in terms of causative factor is found.
- Density analysis is made for each parameter class – landslide occurred to landslide did not occurred.
- At last the future probability of landslide occurrence of an area based on the past landslide and causative factor distribution is done.

3.1.2.2 Drawback of Bi-variant statistical approach

Independence between different parameters of the bi-variant statistical causative factors is the main drawback of this method (Van Westen et al., 1997).

3.1.3 Integrated (SSEP and Statistical) Approach

In present study integrated Slope stability Susceptibility Evaluation Parameter (SSEP) and statistical Value approach was used. Slope stability Susceptibility Evaluation Parameter (SSEP) is an expert approach which was developed by Raghuvanshi et al. (2014) by considering both intrinsic and external landslide causative parameters. Slope geometry (relative relief and slope morphometry), slope material, structural discontinuity, land use/land cover, and groundwater are intrinsic causative parameters whereas rainfall, seismicity and manmade activity are the external causative parameters that are considered in this method. They have assigned the rating values for each causative parameter on the basis of logical judgments acquired from experience of studies of intrinsic and external triggering factors and their relative impact on instability of slopes.

The Landslide Hazard Zonation of study area can be carry out in the following order: First, the area is classified into facets (a land unit with more or less uniform slope geometry in terms of slope inclination and slope direction). Secondly, the data on intrinsic and external causative parameters was collected and rating for each causative parameter was assigned for each facet. Thirdly, the ratings values of all causative parameters for individual facet have summed up to obtain Evaluated landslide hazard (ELH) which indicates the net probability of instability. Raghuvanshi et al., (2014) proved the rationality of considered governing parameters, the adopted Slope stability Susceptibility Evaluation Parameter (SSEP) technique, tools and procedures in developing the landslide hazard zonation mapping. The advantage of using this to landslide hazard evaluation and zonation is that it uses detailed facet wise field based data as input, it is simple, it is applicable, and it is time and cost-effective for larger study area. But its drawback is in subjectivity in landslide hazard evaluation and zonation, which is true for all expert evaluation techniques (Leroi, 1997). Therefore, in the present study attempt is made to reduce the subjectivity of the SSEP approach by integrating it with the bi-variate statistical approach.

The main objective of bi-variate statistical approach is to drive the density of landslide occurrences within each causative factor map. In this approach the landslide zonation of the study area was carried out in the following order: first, thematic maps (A thematic map is a vector map that emphasizes a particular theme or special topic such as the average distribution of rainfall in an area, soil and rock mass distribution, slope map.etc.) of each causative factors were created.

Secondly, conversion of thematic maps in to raster based data has been carried out in order to get the pixel counts of past landslide occurred areas and sliding does not occur areas; this step is essential because it helps to know better in what condition sliding can occur and the possibility of non occurrence. Thirdly, based on the class distribution and the landslide density, respective weights can be derived. Fourthly, based on the results the hazard index can be calculated and normalize by dividing to the highest hazard index value. The advantage of this method is that it is less subjective and simplifies the process of assigning weights and gives better results which can be reproduced.

Generally, the stage followed in the present study was classified into pre-field investigation, field investigations, and post-field investigation.

3.1.3.1 Pre-field Investigation

In this stage of investigation secondary data and required field materials were gathered and prepared. The following materials were gathered from their respective organizations: Topographic map at scale of 1:50,000 from Ethiopian maps agency, climate data (rainfall and temperature) from Ethiopian metrological agency, and field equipment include GPS, compass, and geological hammer from Mekelle university. Thematic maps of the following three causative factors are derived from DEM data of the study area, i.e. slope map, elevation map, and aspect map is extracted from DEM data. Landslide inventory map, soil and rock mass map, and land use/land cover maps are modified from previous works on the area with the help of Google earth and satellite images. Before field data was collection Facet wise classification of the study area was carried out with the help of ARGIS10.3 software.

3.1.3.2 Field Investigation

The overlapped map that contains topographic map together with facet map is help full to easily demarcate facets in the field area. Facet wise observation and measurement of field data of slope material, land-use and land-cover, groundwater surface manifestations, structural discontinuity, rain induced manifestations, manmade activities and landslide inventory were collected. Topographic map, Measuring Meter, Clinometers, Geological hammer, GPS, and Compass were very helpful to identify facets, to take measurements of structural discontinuities, to know dipping direction of slope, to measure strength of rock units, to demarcate the exact location of an area during inventory landslide mapping, and for direction respectively.

Landslide inventory maps show locations and characteristics of landslides that have moved in the past but generally do not indicate the mechanism that triggered them. The geologic, topographic and climatic conditions that led to past slope failures often provide clues to the locations and conditions of future slope failures. Therefore, inventory map provide useful information about the potential for future land sliding. It is the most straightforward initial approach to any landslide hazard study and such inventories are the basis for most susceptibility mapping techniques (Dai et al., 2002, Nyssen et al., 2002, and Moeyersons et al., 2006). Thus, a systematic landslide inventory was made in the present study and all past landslides were identified and mapped with the help of GPS locations on the periphery of such past landslides in the area. Also pre-field data and maps were verified and modified during field work.

3.1.2.3 Post Field Investigation

For the present study ten prominent causative factors were considered from SSEP approach for the evaluation of LHZ and to integrate with statistical approach in order to modify the SSEP method; six from internal causative factors and three from external causative factors. The internal causative factors are; (1) Slope material (Soil and Rock), (2) Relative Relief, (3) Slope, (4) Structural Discontinuity, (5) Land use/land cover, and (6) Groundwater surface traces. From the external causative factors; (7) manmade developmental activities, (8) Rain Induced Manifestations, (9) seismicity, and (10) Rain fall (Anbalagan, 1992; Ayalew et al., 2004; Raghuvanshi et al., 2014; Lensa et al.,2015; Jemal et al.,2011). The basic assumption here is that the combination of these factors might have resulted into triggering of past landslides in the present study area. The causative factors have their own relative contribution for the instability of the slope.

During the post field investigation all the causative factors thematic maps were produced, and converted in to raster format. Using the raster format of every causative factor and by integrating with past landslide in the study area the density count for every thematic map was carried out. By using the pixel count of the causative factors and by integrating with past landslide in the study area calculation of hazard index for every causative factor has been carried out.

Hazard index of every causative factor indicates the relative importance of one causative factor in relation to the past landslide in the area. The hazard index is the ratio between the pixel counts for the area where landslide occurred to pixel count for the area where landslide did not occurred within a respective parameter class. Thus, such computations were made for each parameter and for each parameter class to obtain the hazard index for every parameter class. The hazard index value greater than ‘1’ indicates that a particular parameter class has more probability for landslide occurrence and if it is less than ‘1’ it indicates less probability.

In order to correct the SSEP ratings for various parameter class the computed hazard index for each parameter was normalized to 1 with the help of maximum hazard value within each parameter by using eq. 3.1.

$$Hin = \frac{Hi}{H_{maxj}} * 1 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq (3.1)}$$

Where; Hin is the normalized hazard index, Hi_{maxj} is maximum hazard index value within parameter (j).

The SSEP rating was revised by using eq. 3.1

$$SSEP_R = Hin * SSEP_O \qquad \ldots\ldots\text{eq.(3.2)}$$

Where; $SSEP_R$ is the revised rating based on normalized hazard index (Hin), Hin is the normalized hazard index, $SSEP_O$ is the original SSEP rating as proposed by Raghuvanshi et al. (2014).

Further, $SSEP_R$ was normalized based on maximum $SSEP_O$ rating for a parameter j.

$$SSEP_{Rn} = \left(\frac{SSEP_R}{Max.SSEP_R in\ Parameter\ j}\right) * \max SSEPo\ in\ Parameeter\ j$$

……eq.(3.3)

Finally, by using the modified ratings that are calculated by eq. 3.1, 3.2, 3.3 and by combining the SSEP approach landslide hazard zonation map was prepared. For this each of the intrinsic and causative maps was geo processed with the facet map in GIS environment, so that within each facet it can be deduced that what parameter classes are present. Later, depending on existing of various parameter classes within the respective faced corresponding modified ratings $SSEP_{Rn}$ were assigned. Further, within each facet all $SSEP_{Rn}$ ratings for various parameter classes were summed up to get evaluated landslide hazard value (ELH). Based on these ELH values each of the facets was classified into various landslide hazard classes as proposed by Raghuvanshi et al (2014).

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CHAPTER FOUR DATA ANALYSIS AND COMPUTATIONS

4.1 Landslide Inventory mapping

According to Dai and Lee (2002) landslide inventory mapping is the most straightforward initial approach to any landslide hazard study and such inventories are the basis for most of the susceptibility mapping techniques. Landslide inventory map show locations and characteristics of landslides that have moved in the past but generally do not indicate the mechanism (s) that triggered them. The causative factors that led to 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 land sliding (Dai et al., 2002). Most of the time inventory maps are prepared primarily by using geomorphic analysis of Google earth images, aerial photographs, field reconnaissance, and interpretation of topographic map contours and review of previous mappings (Moeyersons et al., 2006; Dai and Lee et al., 2002). During this study the same trend was followed. Thus, detailed investigation of images from secondary data sources and detailed field surveying were used to demarcate and locate the landslides and related mass movements in the present study area.

Earlier study by Moeyersons et al., (2008) distinguished 34 different types of landslides; 11 landslide depletion areas, 10 debris flow plateau layers, 1 slump, 3 debris and rock slides, 3 landslide belt, and 6 rock fall were identified.

For the present study, detailed investigation on major geomorphic features was done using Google earth images, previous works on the area, and by field investigation at a scale of 1:50,000 (EMA, 1996). From previous studies of landslide in the study area, Nyssen et al. (2002; 2006), Moeyersons et al. (2006, 2008), and Shimeles T (2009) were carefully reviewed. In the present study a total of 39 landslide events were identified 3 debris and rock slide, 2 debris fall, 10 debris flow plateau layers, 1 earth slide and debris fall, 2 earth slide, 4 earth slide belt, 9 landslide depletion area, 2 creep, 3 landslide belt, and 3 slumps were identified.

The first type is debris and rock slides; A debris and rock slide is a type of slide characterized by the messy movement of rocks, soil, and debris mixed with water

(Varnes, 1978). These are usually triggered by the saturation of slopes which results in an incoherent mixture of debris and soil mass. This is usually a result of lower cohesion or higher water content and these types of landslide events are commonly appear in steeper slopes of Hagereselam at 2740 m above sea level, Adi amuk ridge with a height of more than 100m (Fig. 4.1). The rock fragments slide and roll down the valley. On the opposite side of the 2740 m above sea level mountain debris flows are also recognized. North East of Adewro Mikael, South West of Dinelat Maryam, and towards north of Dinelat Maryam there are rock fall types of land sliding with different rock size and degree of falling.

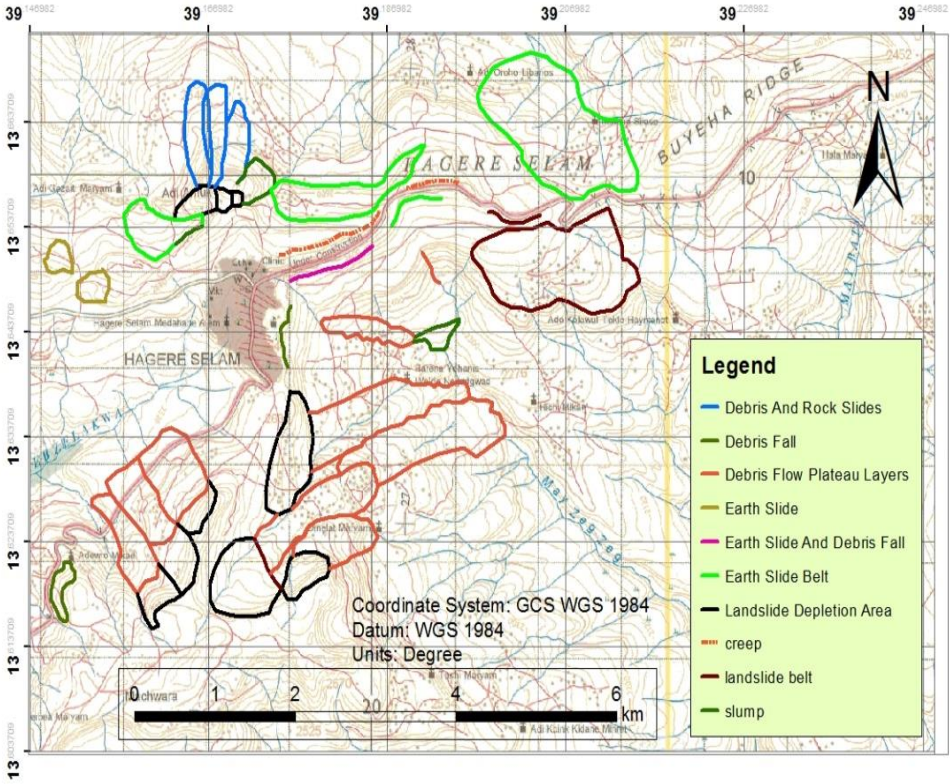

Fig. 4.1 **Landslide inventory map of the study area**

The second one is debris flow plateau layers produced by over saturation of slope material by rain water and down ward pool by gravitational force (Varnes, 1978). This type of land sliding is located East of Hagereselam city about 2 km towards east, below the cliff forming mountain, North East of Adewro Mikael below the plateau, at a radius of 200 m around Dinelat maryam, and North of the Dinelat maryam.

Third type of failure in the study area is earth slide belt which is produced by loss of shear strength of the soil and rock mass in response to external loading, over saturation of slope by ground water, gravitational force, slope toe erosion, earth pressure and etc. (Varnes,1978), which is found West and East of Adi Amuk village at about 1.5 km and 3km respectively, and surrounding the Adi Oroho Libanos at a radius of 1km.

Fourth type of failure in the study area is landslide belt produced due to loss of soil mass shear strength (Varnes, 1978; Nyssen et al., (2002, 2006); and Moeyersons et al., (2006, 2008) which is found North-West of Ado kolawul Tekele Haymanot church.

Fourth type of failure in the study area is earth slides following the main road starting 1 km from Suyeha Ridge towards Hagereselam city and starting from the exit of Hagereselam towards Abi Adi at least at an interval of 200 m there is earth slide along the main road that is probably produced by relatively over steeping of the slope and over load due to trafficking.

Finally slumps and earth slides are identified around Harena Yohanis Welde Negodgad church, Adwaro Mikael church and May Mereb localities.

4.2 Mechanism of failures

4.2.1 Debris flow

According to Moeyersons et al. (2008) the Upper basaltic layer, the whitish sandy clay lacustrine deposit, the lower basaltic series and the weathering product of the basalts i.e. swelling clays start flowing as a massive surge from a nearly horizontal Amba Aradom structural surface and descend down the valleys. Amba Aradom sandstone is an aquicludes/ aquitard which could sufficiently block the passage of water (Tesfaye and Gebretsadik, 1982). The increase in water content of the upper layers can mobilize the landslides in two ways: (i) by destroying the natural waterfront between particles and decreasing the shear strength of the materials (Moeyersons et al., 2008), (ii) by developing pore water pressure and increasing the shear stress acting on the plateau layers

4.2.2 Landslides affecting the Antalo super sequence

Most of the landslide failures in Ethiopia are rainfall triggered (Kifle Woldegeorgis, 2013). The landslides affecting Antalo Limestone is also related with pore water pressure built up above massive layers acting as an aquicludes or aquitard. The first massive formation recognized as an aquitard or aquiclude is the Adiwerat layer (Van de Wauw et al., 2008). It is a massive shale layer on the top of which landslides of Agula shale is mobilized. Following these movements the cliffs resting over the Agula shale will start sliding. Thus, these flows are characterized with sandstone and basalt inclusions (Van de Wauw et al., 2008).

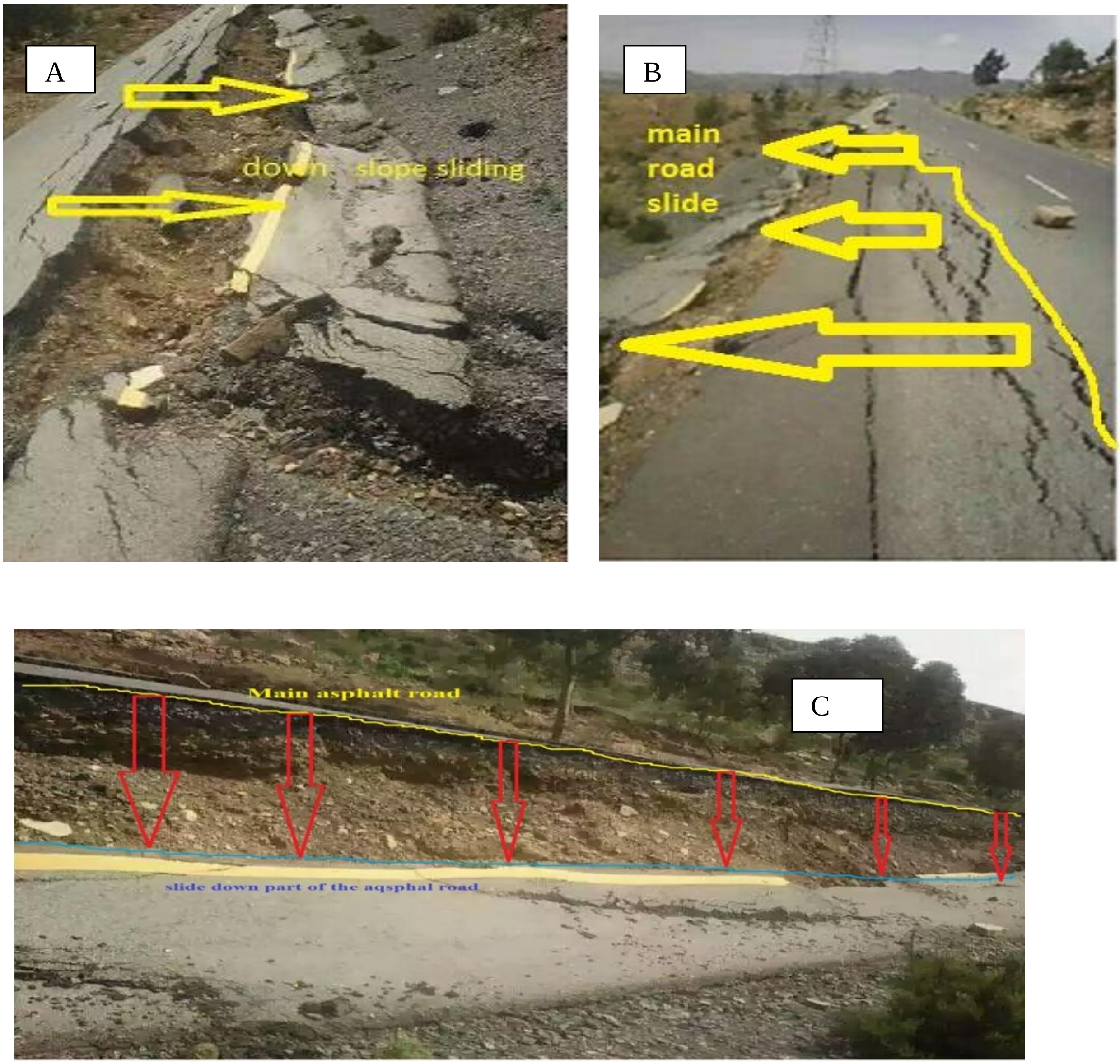

Plate 4.1 (A), south western part of Hagereselam to ward abi adi (B), and at the entrance of the Hagereselam city from Mekelle (C) Landslide of the main road at Hagereselam, North Eastern part of Hagereselam about 1.5 km away from the city.

The second aquitard is the upper shale or marl layer (Moeyersons et al., 2008). It has a low small hydraulic conductivity and water can hardly move to lower layers.

However, the carbonate layer resting over the shale has a considerable vertically permeability resulting from cracks. Thus water is allowed to stand in the cracks. When the water table is increased to a higher level pour water pressure will be built up in the upper formation and will mobilize the landslides. The third aquitard is the lower shale/ marl layer under carbonate cliffs layer. The mechanism of failure is similar to what is explained for the upper series.

4.2.3 The landslide depletion areas

Most part of the ridges in the study area is composed of dolerites. Unlike other places, the landslides around these ridges are not characterized by structural topography but are composed of fresh dolerite boulders resting over core stone weathering profiles. These slides are huge enough that the lobes are clearly identified by aerial photographs. However, field observations reveal that the area is not characterized by rugged topography (Moeyersons et al., 2008). The landslide depletion areas are not completely identifiable with aerial photograph interpretation. Some erosion belts visibly start from the steepest parts of the ridges, while other lack morphological justification to delineate the zones. However, Moeyersons et al. (2008) state a field recognition result with a significant difference in size and freshness of dolerite boulders with the weathering profiles. Thus the erosion belts are considered to start from the steepest parts of the ridges.

4.2.4 Rock falls

A landslide analysis in Hagereselam area will not be complete without including the effect of rock falls. The failure mechanism is believed to be detachment and toppling of boulders from rocky cliffs after every rainy season (Moeyersons et al., 2008; Nyssen et al., 2006). In addition, a secondary movement of the rocks has to be considered. Creep effects are not easily realized in short period of time, but are very devastating as the attachment between the rocks particles will get removed with time. From 1998 to 2001, slopes below the ridges have been investigated twice a year, at the end of the rainy season and mid of the dry season (Nyssen et al., 2006). The investigation includes identification of down slope scars of damaged vegetation, freshly fallen boulders and information of local shepherds.

For the present study, detailed investigation on the cliffs using field surveying, topographic map investigation and the DEM analysis was carried out.

4.3 Landslide Hazard Triggering Parameters and their distribution in the study area

4.3.1 Intrinsic Causative Parameters and their Distribution

Intrinsic parameters are the inherent or static causative parameters which define the favorable or unfavorable stability conditions within the slope (Anbalagan, 1992; Raghuvanshi et al., 2014). Relative relief, slope morphometry, slope material, structural discontinuities, land use and land cover and groundwater surface manifestations are intrinsic causative parameters which were considered in landslide hazard zonation of the present study. In case of landslide hazard evaluation using integrated Slope Stability Susceptibility Evaluation Parameter (SSEP) and statistical approach except some sub class parameters of the structural discontinuity all the other parameters were considered. Due to the complexity of the parameter data, scale difference and non availability of supportive previous work in terms of required structural discontinuity parameters (parallelism between discontinuity dip direction and slope, relationship between dip of discontinuity and inclination of slope, soil cover depth, dip of discontinuity or plunge of line of intersection of wedge forming planes), original SSEP ratings were considered. However, all other parameter classes were statistically treated and required modifications in SSEP ratings was made in the present study.

In the following paragraphs an attempt is made to clarify the relative distribution of causative factors and the past landslide.

4.3.1.1 Slope material

The main soil and rock material exposed in the study area are a fragmentation of the flood basalt residual soil, residual expansive soil, and very weak rock with intact blocks, weak rock, and a very small part of alluvial deposit**.** In the present study area Tertiary volcanic and dolerite rocks are exposed in the upper most parts of the area and shows typical discontinuity sets (columnar jointing). Much of the study area is covered by these formations. Based on the prominent rock and soil types present in the present study area slope material was classified into various classes as presented in Fig. 4.2. A slope material map was prepared using field and Google earth map. A slope material map indicates that 48% of the total area is covered by residual expansive soil, 7% by alluvial deposits, 20% by residual soil, 11% by disintegrated very weak rock and 14% by weak rock (Table 4.1).

4.3.1.2 Structural Discontinuities

In order to get data relating to structural discontinuities facet wise data collection was needed. Every facet in the study area was classified according to the SSEP classes of structural discontinuity, by integrating these facets the structural discontinuity map of the study area produced. In this class only structural discontinuity and rock mass condition was considered, the rest of the sub-classes were evaluated only by SSEP approach. In the SSEP approach facet wise structural discontinuity of the slope material and its relation to slope inclination structural discontinuity data was determined. Besides, data of characteristics of structural discontinuities with respect to spacing, continuity, and surface characteristics, separation of discontinuity surface and thickness and nature of filling material within the discontinuity surfaces has also been collected. Those data are not used in the statistical analysis method; only structural discontinuity with respect to slope and structural discontinuity and rock mass condition are used in statistical analysis the rest were evaluated based on SSEP rating parameters. As it is clearly indicated in the table (Table 4.1) 32% of the study area is covered by disintegrated rock mass, 53% block disturbed, 15% very blocky rock mass.

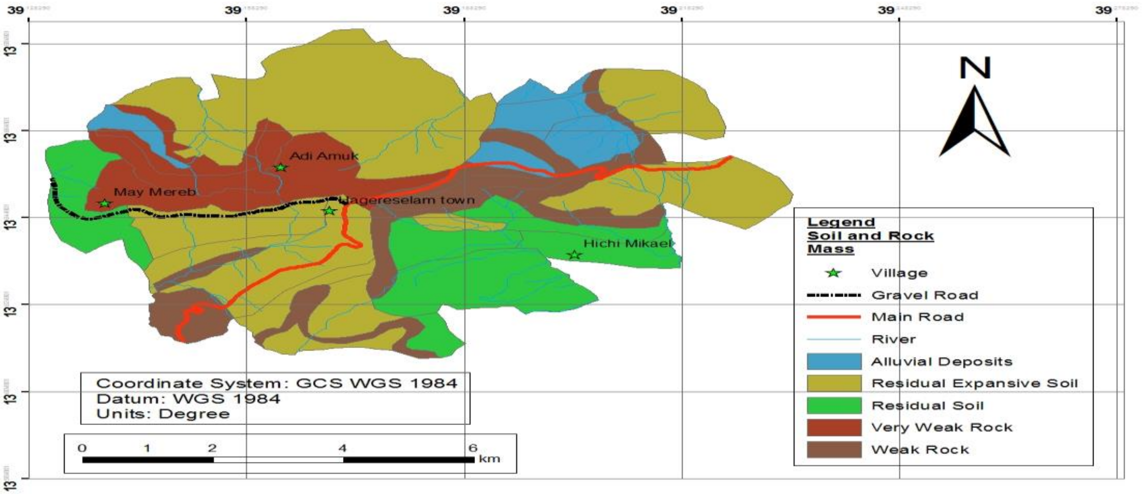

Fig. 4.2 Slope material distribution of the study area

4.3.1.3 Land-use and Land-cover

The land-use/land-cover map of the study area was prepared by the help of previous works on the area, by field investigation, and largely with the help of Google earth. Using those sources of information the land-use/land-cover map of the study area is modified and created. The land-use/land-cover of the study area is characterized as sparsely vegetated land, barren land, cultivated land, developmental activity, moderately vegetated, and thickly vegetated there relative distribution in the study area is 16%, 13%, 65%, 3%, 2%, 2%, respectively (Table 4.1).

4.2.1.4 Groundwater surface manifestations

In order to know the potential of ground water occurrence in the study area the SSEP approach provide easy parameter to determine the rating of each facet. Surface indications such as damp, wet, dripping, flowing, and dry are the parameters that are provided by the SSEP approach, using those parameters and their respective ratings detailed field investigation was made to create surface groundwater manifestations map of the study area. (Fig. 4.4). Later this map was used to get the density distribution for the integrated approach. As indicated in Table 4.1; most part of the study area is dry (63%) the rest 28%, 6%, 3% and 1% is damp, flowing, wet, and dripping, respectively.

Table 4.1 Causative factor distribution by percent

Man Made Developmental Activity	**Percent**	**Land Use/ Land Cover**	**Percent**
Moderately cultivated land	15%	Sparsely vegetated	16%
No activity	10%	Barren land	13%
Sparsely cultivated land	26%	Thickly Vegetated	2%
Steep rock mass cut	6%	Cultivated Land	65%
Densely cultivated land	33%	Developmental Activists	3%
Quarry site	1%	Moderately Vegetated	2%
Dumped excavated material	1%	**Relative Relief**	**Percent**
Gentle soil mass cut	5%	Medium	35%
Steep soil mass cut	4%	Moderate	23%
Rain Induced Manifestations	Percent	High	25%
Gully Erosion	75%	Very high	2%
No Rain Induced Manifestations	12%	Low	14%
Stream Bank Erosion	11%	**Slope Material**	**Percent**
Slope Toe Erosion	3%	Weak Rock	14%
Slope	Percent	Very Weak Rock	11%
<15˚	79%	Residual Soil	20%

16°-25°	17%	Alluvial Soil	7%
26°-35°	4%	Residual Expansive Soil	48%
36°-45°	0%		
>45°	0%		
Structural discontinuities and Rock mass condition	**Percent**	**Surface Groundwater Manifestations**	**Percent**
Disintegrated	32%	Flowing	6%
Blocky/ Disturbed	53%	Wet	3%
Very Blocky	15%	Damp	28%
Discontinuity orientation with respect to slope	**Percent**	Dripping	1%
		Dry	63%
Soil Mass	31%	***The percentage of same classes of a sub-class is not zero this value is evaluated by rounding. The value of >45º slope is not zero it is 0.096%. 36º - 45º slope is 0.165% ***	
More than one discontinuity dipping into the hill	50%		
At least one discontinuity dipping into the hill	15%		
None of the discontinuities **Dips into the hill**	4%		

4.2.1.5 Slope

On steeper slopes, the tangential component of the weight of a mass and the shear stress increases while the perpendicular component of the weight decreases. The resistance to the down slope movement is favored by the frictional resistance and cohesion among the particles that make up the object. When the shear stress is greater than the combination of forces holding the object on a slope, the object will tend to move down-slope. Thus the slope of a terrain is a principal factor involving in the analysis of landslides (Hoek and Bray, 1997). The slope map of the study area is extracted using ARC map 10.3 GIS from the digital elevation model prepared using ASTER data set with pixel size of 30m.

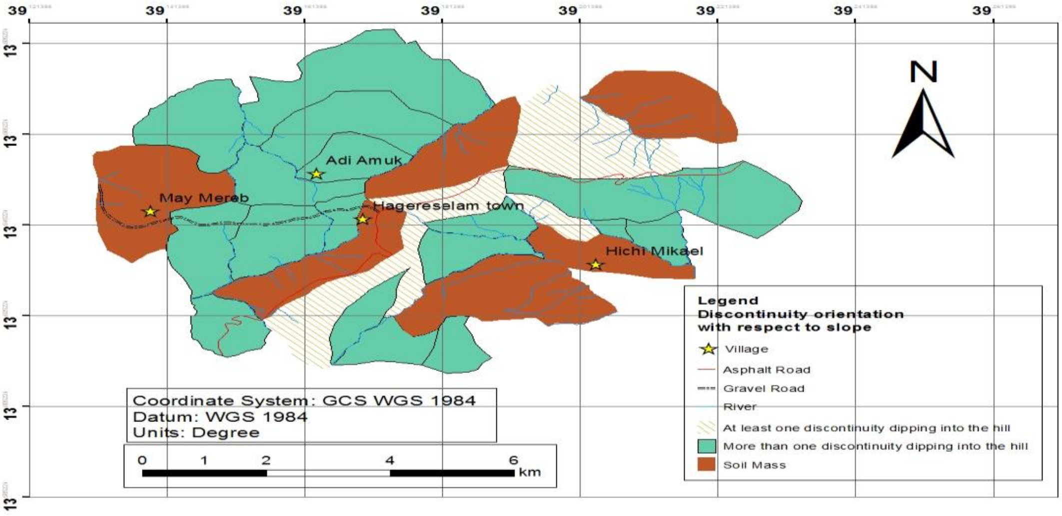

Fig. 4.3: Discontinuity orientation with respect to slope as rain fall parameter

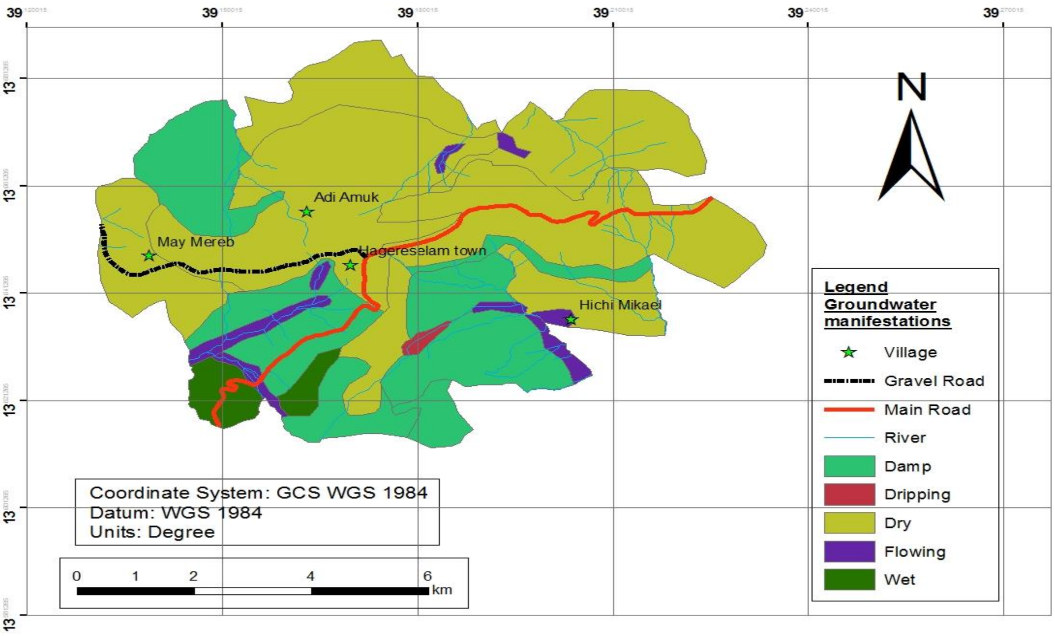

Fig. 4.4: Groundwater manifestations map of the study area

The minimum slope angle along flat sections is <15° while the maximum slope observed on nearly vertical cliffs is 51°. A slope category map is prepared for five categories: very gentle (0-15°), gentle (16º- 25º), moderately steep (26º-35º), steep (36º-45º), and Escarpment/Cliff (>45). The classification indicates that 79% of the study area is dominated by very gentle terrain, While 17% gentle, 4% moderately steep, 0.165% and 0.096% of the area is characterized by steep and escarpment or cliff terrains respectively (Table 4.1).

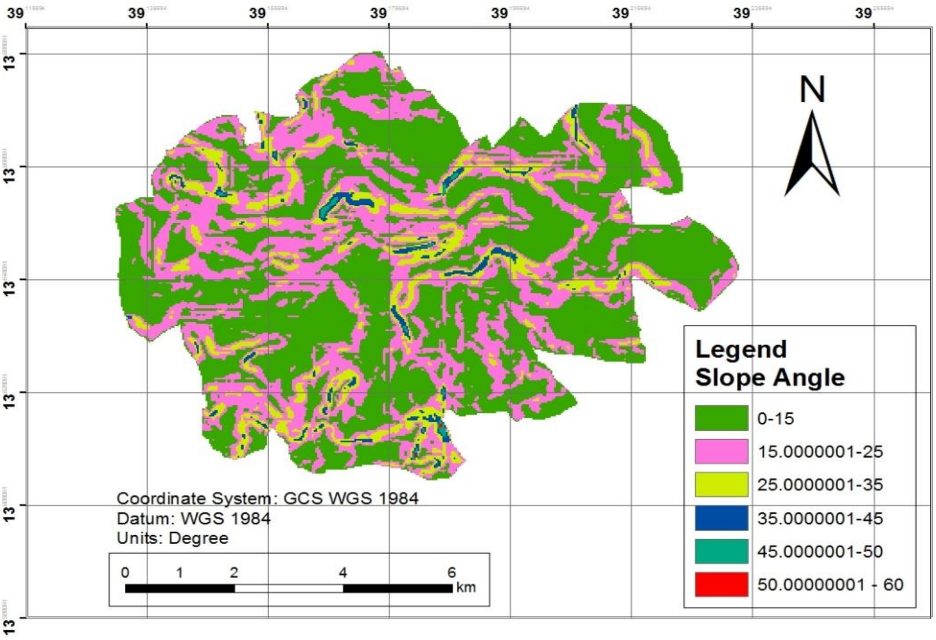

Fig. 4.5: slope map of the study area

4.2.1.6 Relative relief

Slope will be more prone for instability if the relative relief is higher; the critical height of slope depends on shear strength, density and bearing capacity of the slope foundation. Slope stability generally decreases with increase in height of slope. As the slope height increases, the shear stress within toe of slope increases due to added weight. Shear stress is also related to the mass of the material and the slope angle. With increasing slope angle, the tangential stress increases which result in increase in shear stress thus reducing its stability (Hoek and Bray, 1997).

Relative relief data of the study area is collected by considering the facets of the study area, therefore based on this assumption the highest and the lowest elevation within the facet is taken. By subtract the lowest elevation from the highest a relative relief map of each facet was created. By using this map density value of each facet was calculated.

4.2.2 External Causative Parameters

According to Varnes (1984), Dai and Lee (2001), and Raghuvanshi et al., (2014) external causative parameters are parameters which may trigger instability in slopes by exerting force from external environment such as rainfall, seismicity and manmade activities. The external causative factors are relatively dynamic, temporary and imposed by new events which include rainfall, volcanic activity, seismic vibration, manmade activities, transportation trafficking, and etc...

In this study, those external causative factors are treated exceptionally rainfall, seismicity and manmade developmental activities as external causative parameters in landslide hazard zonation of study area by using SSEP approach. Further, in Landslide hazard evaluation of the study area by using integrated approach (SSEP and statistical approach) manmade developmental activity and rain induced manifestations were considered to modify the ratings. For mean annual rainfall and seismicity the original SSEP ratings were used.

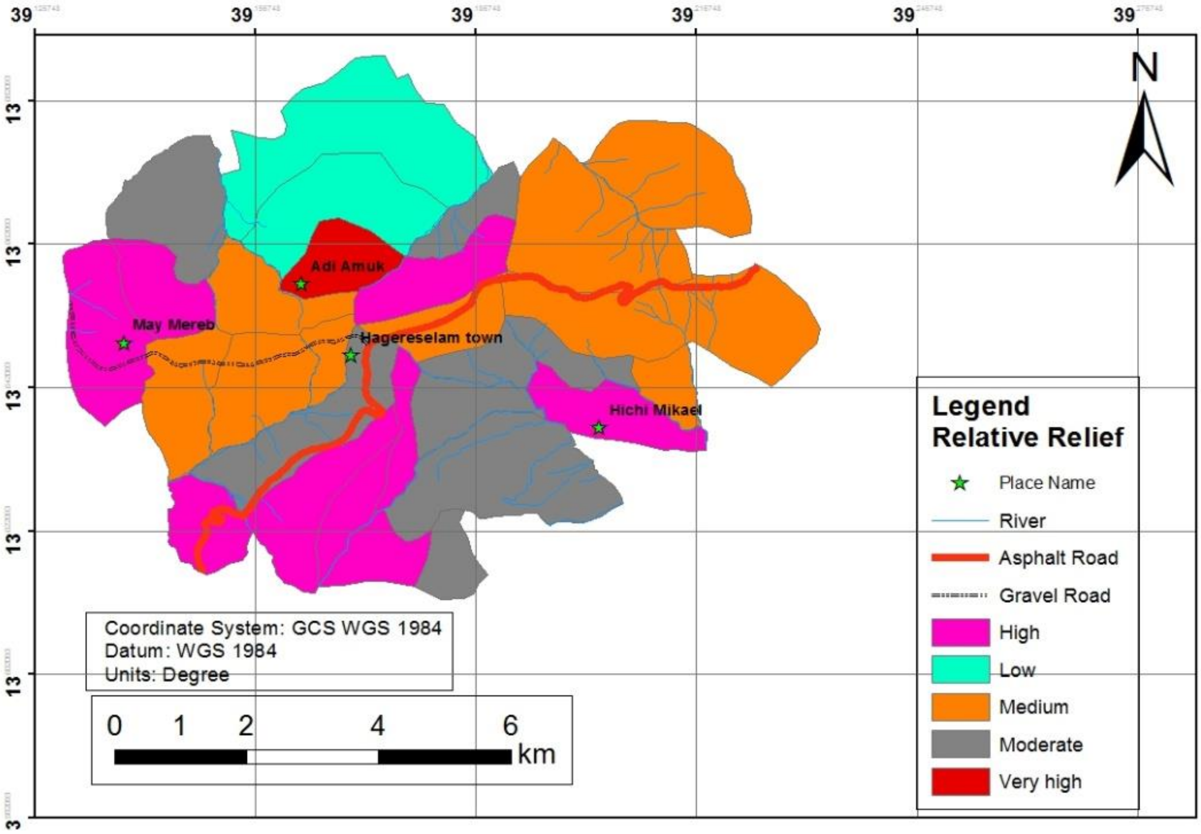

Fig. 4.6: Relative Relief map of the study area

4.2.2.1 Rain induced manifestations on slope

A data from Ethiopian metrological agency indicates that Hagereselam (the study area) receives 670 mm annual rainfall which is classified as low according to the SSEP rating parameters. According to Bekele et al. (2010) and Kifle Woldeargegay (2014) rainfall has a significant influence over the slope stability. Most of the rain fall in the study area is concentrated starting from May up to September (Chart 4.1). In this study rain induced manifestation on slope such as; slope face gully erosion, slope toe erosion, and stream bank erosion were considered. As it is clearly indicated in the table (Table 4.1) of rain induced manifestations; gully erosion of the slope face has the highest value with 75%, and slope toe erosion is the least with 3%. Rain induced manifestations on slope was produced by integrating information from detailed field investigation, secondary data, and Google earth.

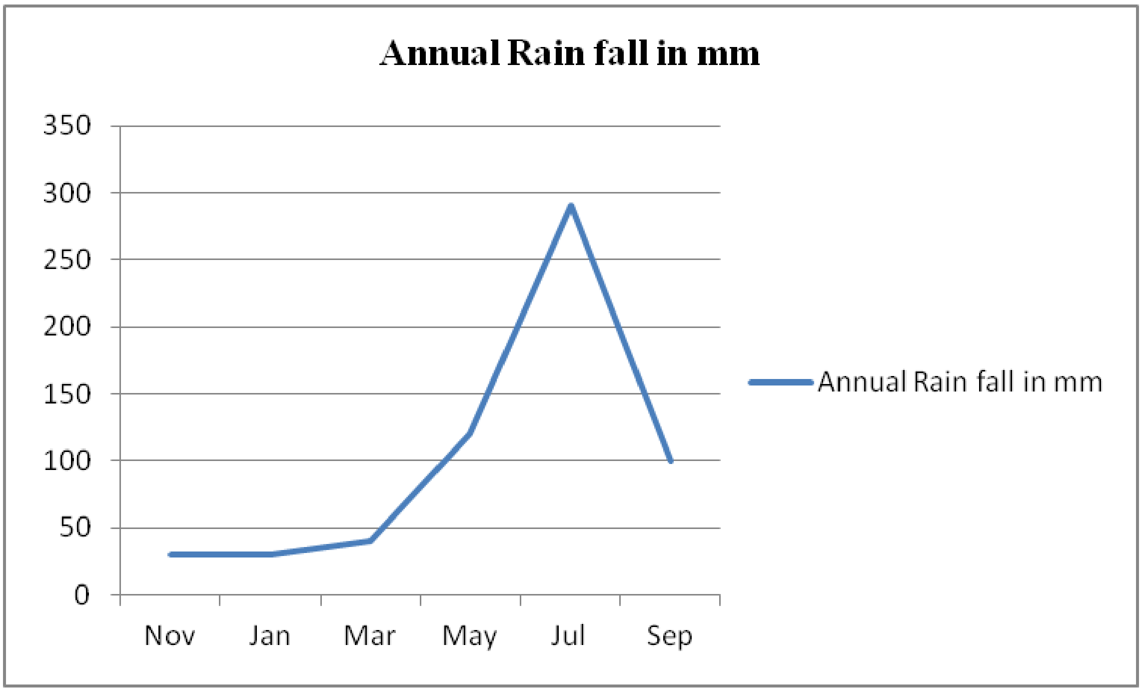

Chart 4.1: Annual Rain fall of Hagereselam 2016 (source https:// worldweatheronline.com)

4.2.2.2 Manmade Developmental Activities

As it was attempted to explain earlier in this chapter; except seismicity and rain fall parameters all other external causative factors are included in the modified technique. The other two are evaluated only by SSEP approach. In the manmade developmental activity class there are about 9 sub-classes (Table 4.1); moderately cultivated land, land without any man made activity, sparsely cultivated land, steep rock mass cut, densely cultivated land, quarry site, dumped excavated material, gentle soil mass cut, and steep slope mass cut are the sub-classes that were identified during the field work and through different secondary data sources.

As it is indicated in the table (Table 4.1) densely cultivated land, sparsely cultivated land, moderately cultivated land, no activity land, steep rock mass cut, gentle soil mass cut, steep soil mass cut, quarry site, and dumped excavated material have highest to lowest areal coverage with 33%, 26%, 15%, 10%, 6%, 5%, 4%, 1%, and 1%, respectively.

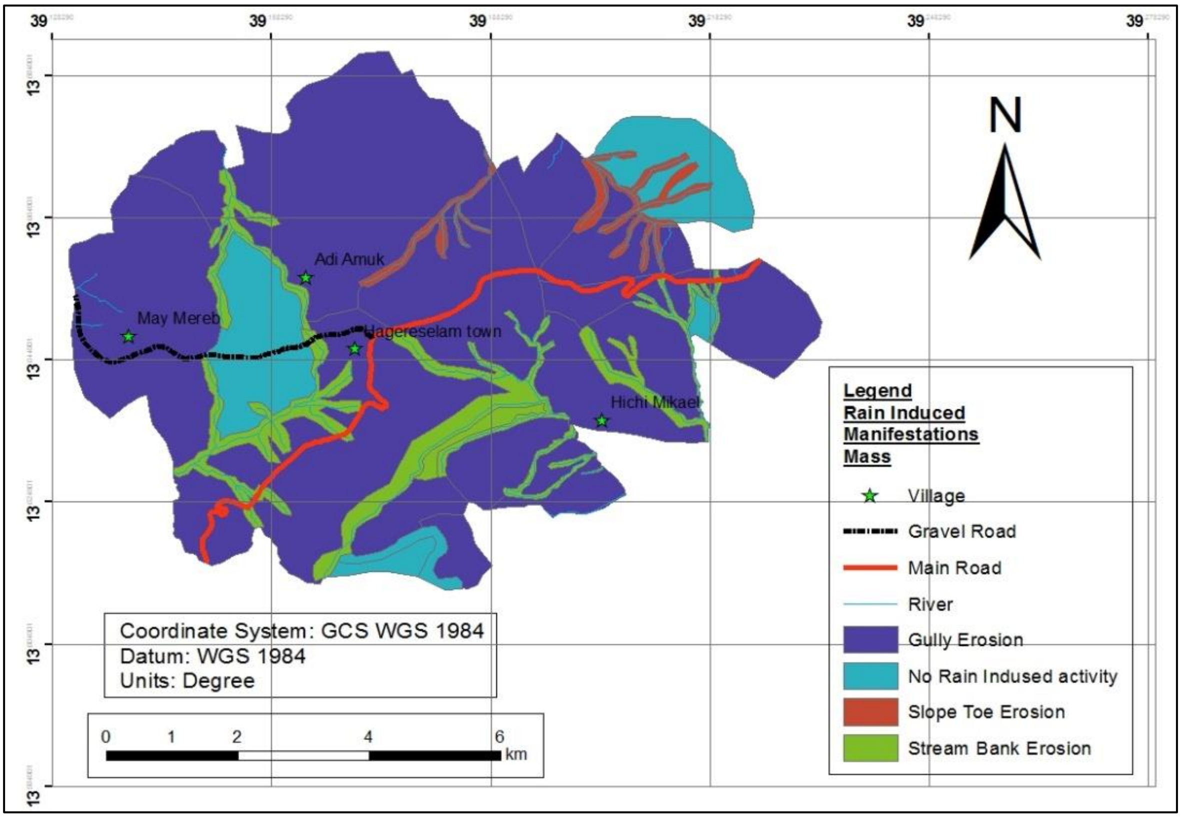

Fig. 4.7: Rain induced manifestations on slope

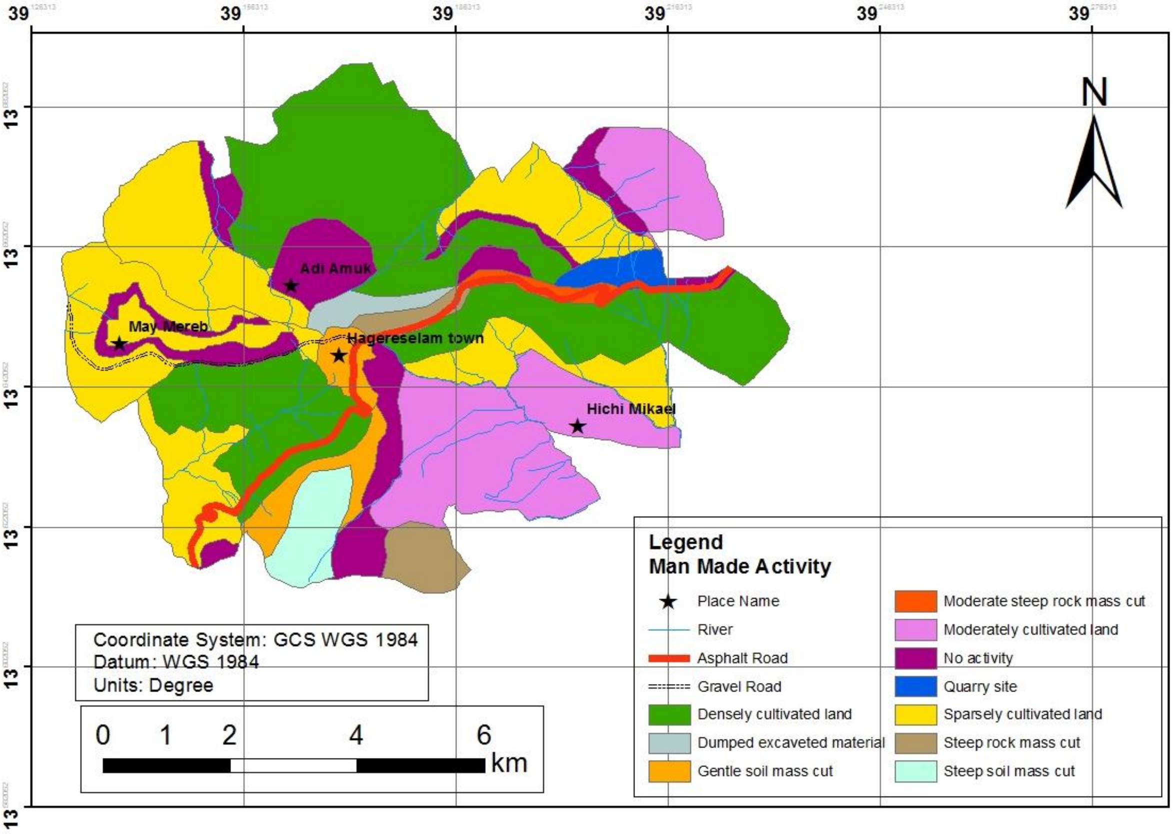

Fig. 4.8 Manmade developmental activity map of the study area

4.2.2.3 Seismicity

According to the Ethiopian Seismic Risk Map produced by Laike Mariam (1986) the likely peak ground acceleration with a hundred year return period and 0.99 probabilities the study area falls within 6 M.M scale. Based on the Modified Mercalli intensity scale the estimated horizontal earthquake acceleration comes out to be 0.06 g, as determined from the MM intensity graph (Johnson and De Graff, 1991).The seismic intensity over the study area is the same therefore the corresponding ground acceleration will be 0.06 g throughout the study area. Accordingly, the seismicity rating value of the study area is 0.8 based on the SSEP rating.

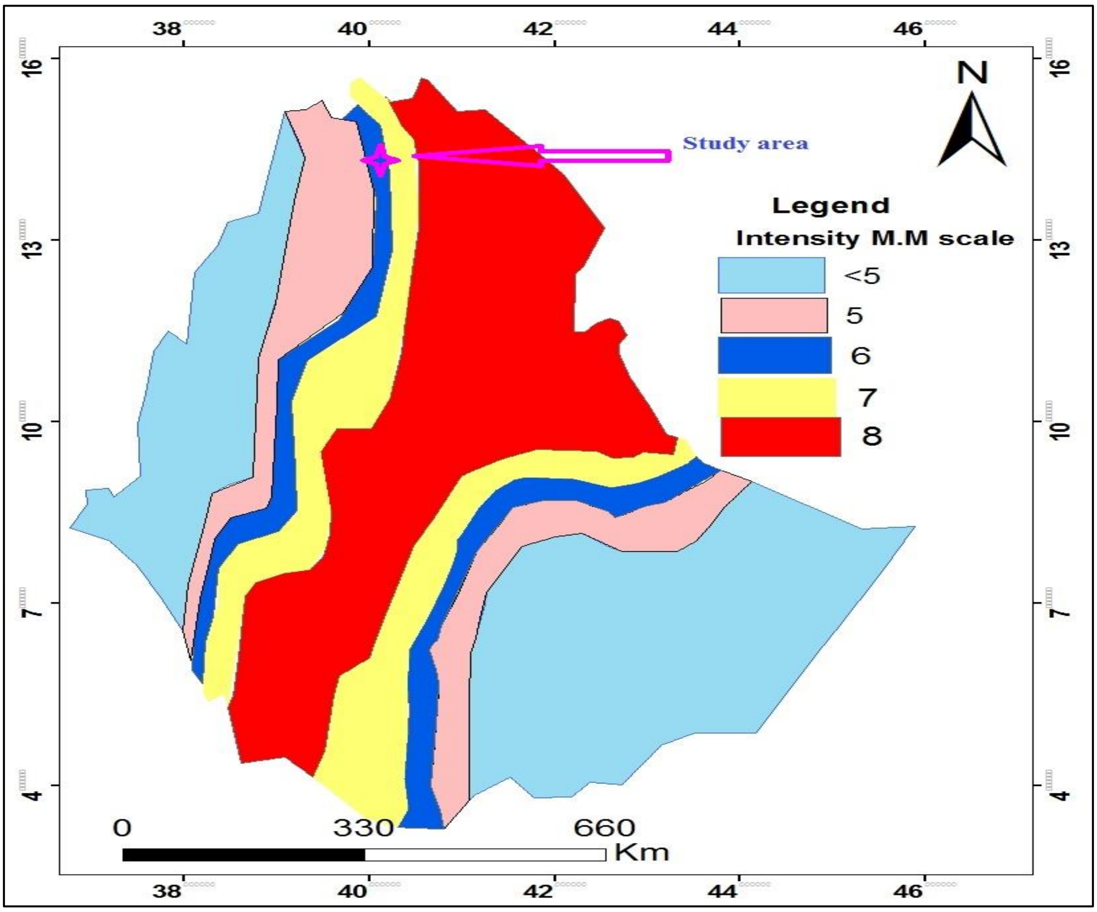

Fig. 4.9 Seismic map of Ethiopia (source: Liake Mariam 1986)

4.3 Causative Factors and Past Landslide Distribution

Table 4.2 presents the area percent coverage of each parameter class within the landslide occurrence. For example in the manmade developmental activity class the highest past landslide is occurred in the moderately cultivated land sub class with percent occurrence of 34%. Likewise for every sub-class past landslide distribution is calculated.

4.4 Geo-processing of causative factors

Geo-processing of causative factor maps was done using ARCGIS10.3 software by following systematic steps. Firstly by using field and secondary data of every causative factor a shape file in the form of polygon was created in the ARCGIS 10.3 soft ware. These shape files (data in a vector form) has attribute tables that explains the characteristics of the selected causative factor features. Secondly, by using the intersect command in the geo-processing tool in ARCGIS 10.3 software combination of all causative factor shape files were done. The combined shape file has information of all he causative factors distribution in the study area. This is done in order to have one full map that has every information of the study except for factors that are not considered in the integrated approach such as; seismicity, rain fall, and some structural discontinuity parameters. Thirdly the causative factor ratings that are not included in the integrated approach were added to the total value of the evaluation. Fourthly all the combined parameters and their respective values are summed up and the average value per a facet was computed.

Table 4.2: Past landslide and causative factor distribution

Type	Landslide occurred	percent %	Landslide not occurred	percent %
	Count		Count	
Manmade Developmental Activity				
Moderately cultivated land	2666	34%	5192	66%
No activity	1304	23%	4339	77%
Sparsely cultivated land	1331	10%	12596	90%
Steep rock mass cut	882	29%	2138	71%
Densely cultivated land	2416	14%	15282	86%
Quarry site	206	28%	523	72%
Dumped excavated material	112	22%	407	78%
Gentle soil mass cut	675	27%	1856	73%
Steep soil mass cut	557	28%	1408	72%
Land Use/ Land Cover				
Sparsely vegetated	1549	18%	7031	82%
Barren land	1035	15%	6035	85%
Thickly Vegetated	245	28%	637	72%
Cultivated Land	6591	19%	28209	81%
Developmental Activity	270	19%	1179	81%
Moderately Vegetated	459	41%	650	59%
Relative Relief				
Medium	2952	16%	16067	84%
Moderate	3214	25%	9441	75%
High	3023	22%	10554	78%
Very high	875	66%	453	34%
Low	85	1%	7226	99%

Rain Induced Manifestations				
Gully Erosion	7303	18%	32974	82%
No Rain Induced Manifestations	748	12%	5721	88%
Stream Bank Erosion	1836	32%	3896	68%
Table 4.2 Cont…. Type	**Landslide occurred**	**percent %**	**Landslide not occurred**	**percent %**
Slope Toe Erosion	262	19%	1150	81%
Slope Material				
Weak Rock	1729	23%	5687	77%
Very Weak Rock	1387	23%	4624	77%
Residual Soil	2304	21%	8502	79%
Alluvial Soil	801	21%	3101	79%
Residual Expansive Soil	3928	15%	21827	85%
Slope				
<15˚	7319	17%	35365	83%
16˚-25˚	2205	24%	6807	76%
26˚-35˚	591	29%	1462	71%
36˚-45˚	21	24%	68	76%
>45˚	13	25%	39	75%
Surface Groundwater Manifestations				
Flowing	991	32%	2150	68%
Wet	737	45%	919	55%
Damp	3776	25%	11059	75%
Dripping	373	68%	175	32%
Dry	4272	13%	29438	87%
Structural discontinuities and Rock mass condition				
Disintegrated	3043	18%	14095	82%
Blocky/ Disturbed	4343	15%	24383	85%
Very Blocky	2763	34%	5263	66%
Discontinuity orientation with respect to slope				
Soil Mass	2943	17%	14000	83%
More than one discontinuity dipping into the hill	2521	9%	24181	91%
At least one discontinuity dipping into the hill	2760	33%	5560	67%
None of the discontinuities Dips into the hill.	193	10%	1732	90%

Finally, Geo-processed full map of all the causative factors and the distribution of past slide data is found. This helps the landslide study by clearly showing the past landslide distribution in the study area and the areal coverage with respect to the causative factors.

4.5 SSEP corrected normalized rating computation

Slope stability Susceptibility evaluation parameter (SSEP) corrected normalized rating computation is made based on the assumption that if the original values of the

SSEP approach are integrated with pixel count from statistically geo-processed data from statistical approach less subjective and more applicable rating for the SSEP can be produced. Therefore, in order to evaluate the relative contribution of a sub-class of each causative factor on past landslide, and to modify the Ratings given in SSEP corrected normalized rating computation was done.

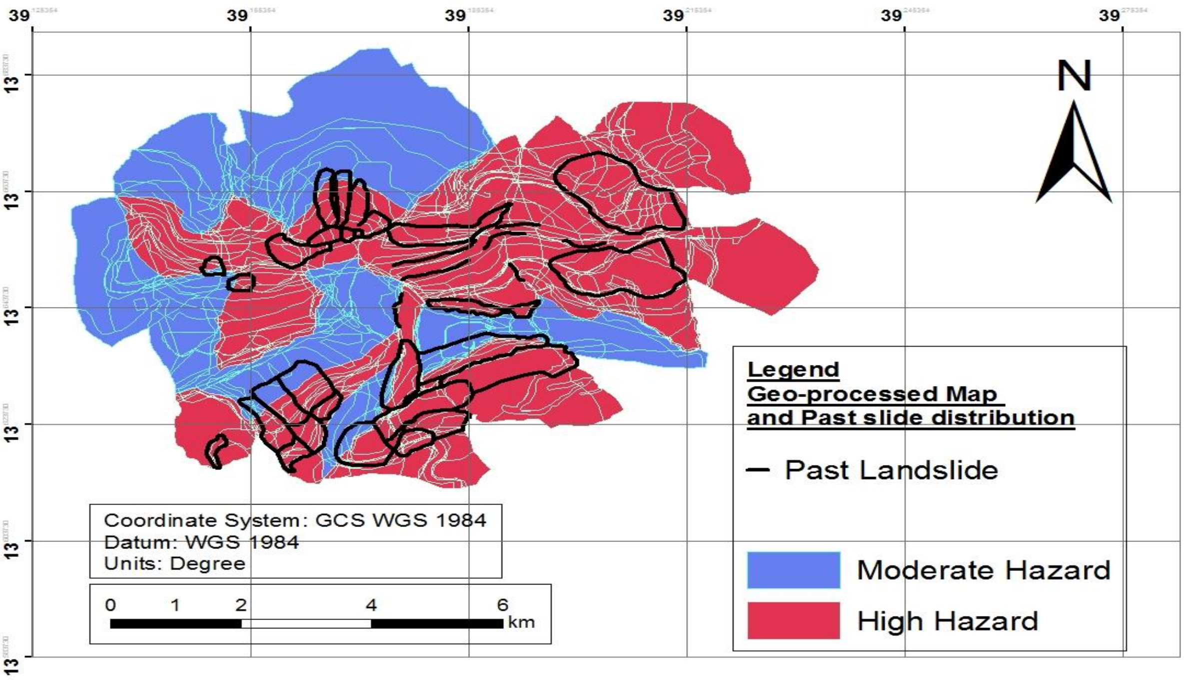

Fig. 4.10 Geo-processed thematic map and past landslide distribution

As it is clearly shown in the below table (Table 4.3) the thematic map that shows the distribution of past landslide in the study area is converted in to raster data to get the pixel count. The same is done for every class and sub-classes of causative factors that are included in this approach. This pixel count is used to determine the landslide distribution in terms of the causative factor distribution in the study area.

Hazard index of every causative factor indicates the relative importance of one causative factor in relation to the past landslide in the area. The hazard index is the ratio between the pixel counts for the area where landslide occurred to pixel count for the area where landslide did not occurred within a respective parameter class.

Thus, such computations were made for each parameter and for each parameter class to obtain the hazard index for every parameter class. The hazard index value greater than ‘1’ indicates that a particular parameter class has more probability for landslide occurrence and if it is less than ‘1’ it indicates less probability.

In order to correct the SSEP ratings for various parameter class the computed hazard index for each parameter was normalized to 1 with the help of maximum hazard value within each parameter by using eq. 4.1.

$$Hin = \frac{Hi}{H_{maxj}} * 1 \text{ ……………………………………………………………..eq (4.1)}$$

Where; Hin is the normalized hazard index, Hi_{maxj} is maximum hazard index value within parameter (j).

The SSEP rating was revised by using eq. 4.1

$$SSEP_R = Hin * SSEP_O \qquad \text{……eq.(4.2)}$$

Where; $SSEP_R$ is the revised rating based on normalized hazard index (Hin), Hin is the normalized hazard index, $SSEP_O$ is the original SSEP rating as proposed by Raghuvanshi et al. (2014).

Further, $SSEP_R$ was normalized based on maximum $SSEP_O$ rating for a parameter j.

$$SSEP_{Rn} = \left(\frac{SSEP_R}{Max.SSEP_R in\ Parameter\ j}\right) * \max SSEPo\ in\ Parameeter\ j$$
……eq.(4.3)

This corrected normalized value is used for the evaluation of the landslide hazard zonation of the study area. For detail information see Table 4.3.

Table 4.3 Hazard index value on all causative factors and corrected normalized value

A	Landslide occurred
B	Landslide not occurred
CO	Count
R	Ratio (a)%
H	Hazard index (a/b)
N	Hazard Normalized to 1 (N)
O	SSEP Original rating
C R’	Corrected Value Revised value

A – represents Past landslide occurred in the study area

B – represents landslide did not occurred area.

CO – represents the pixel count of every causative factor class in the study area

Ratio is the ratio of causative factor class from the total pixel count of the causative factor, Hazard index is the probability of landslide occurrence for every causative factor class which is calculated by dividing the Landslide occurred the ration of landslide occurred to not occurred values, hazard normalized to one

H - is a normalized value of hazard index value in to one or unity by dividing every hazard index value of causative factor class to the highest value of the causative factor,

O - is the original rating value of the SSEP approach which was proposed by Raghuvanshi et al.,(2014),

R is the revised value of the SSEP rating, and finally

C - is the corrected normalized new ratings.

Table 4.3 Cont….

TYPE	**A**		**B**		**H**	**N**	**O**	**R'**	**C**
	CO	**R**	**CO**	**R**					
Man Made Developmental Activity									
Moderately cultivated land	2666	26.27	5192	11.87	2.213	1	0.15	0.15	0.2
No activity	1304	12.85	4339	9.92	1.295	0.585	0	0	0
Sparsely cultivated land	1331	13.11	12596	28.8	0.455	0.206	0.1	0.021	0.03
Steep rock mass cut	882	8.691	2138	4.888	1.778	0.803	1	0.803	1
Densely cultivated land	2416	23.81	15282	34.94	0.681	0.308	0.25	0.077	0.01
Quarry site	206	2.03	523	1.196	1.698	0.767	0	0	0
Dumped excavated material	112	1.104	407	0.93	1.186	0.536	0	0	0
Gentle soil mass cut	675	6.651	1856	4.243	1.567	0.708	0.75	0.531	0.7
Steep soil mass cut	557	5.488	1408	3.219	1.705	0.77	1.25	0.963	1.25
Total	**10149**	**100**	**43741**	**100**	1				
Land Use/ Land Cover									
Sparsely vegetated	1549	15.26	7031	16.07	0.95	0.312	1.2	0.374	0.75
Barren land	1035	10.2	6035	13.8	0.739	0.243	1.5	0.364	0.7
Thickly Vegetated	245	2.414	637	1.456	1.658	0.545	0.4	0.218	0.4
Cultivated Land	6591	64.94	28209	64.49	1.007	0.331	0.4	0.132	0.3
Developmental Activity	270	2.66	1179	2.695	0.987	0.324	0	0	0
Moderately Vegetated	459	4.523	650	1.486	3.043	1	0.75	0.75	1.5
Total	**10149**	**100**	**43741**	100	1				
Relative Relief									
Medium	2952	29.09	16067	36.73	0.792	0.095	0.6	0.057	0.06
Moderate	3214	31.67	9441	21.58	1.467	0.176	0.2	0.035	0.04
High	3023	29.79	10554	24.13	1.234	0.148	0.8	0.119	0.12
Very high	875	8.622	453	1.036	8.325	1	1	1	1
Low	85	0.838	7226	16.52	0.051	0.006	0.1	0	0
Total	**10149**	**100**	**43741**	100	1				
Rain Induced Manifestation									
Gully Erosion	7303	71.96	32974	75.38	0.955	0.47	0.1	0.047	0.1
No Rain Induced Manifestations	748	7.37	5721	13.08	0.564	0.277	0	0	0
Stream Bank Erosion	1836	18.09	3896	8.907	2.031	1	0.15	0.15	0.3
Slope Toe Erosion	262	2.582	1150	2.629	0.982	0.483	0.25	0.121	0.25
Total	**10149**	**100**	**43741**	100	1				
Slope Material									
Weak Rock	1729	17.04	5687	13	1.31	1	0.8	0.8	0.8
Very Weak Rock	1387	13.67	4624	10.6	1.293	0.987	1	0.987	1
Residual Soil	2304	22.7	8502	19.4	1.168	0.891	0.2	0.178	0.2
Alluvial Soil	801	7.892	3101	7.09	1.113	0.85	0.8	0.68	0.7
Residual Expansive Soil	3928	38.7	21827	49.9	0.776	0.592	0.6	0.355	0.4
Total	**10149**	**100**	**43741**	100	1				
Slope									

<15˚	7319	72.12	35365	80.85	0.892	0.621	0.3	0.186	0.2
16˚-25˚	2205	21.73	6807	15.56	1.396	0.972	0.6	0.583	0.6
26˚-35˚	591	5.823	1462	3.342	1.742	1.213	1	1.213	1.2
36˚-45˚	21	0.207	68	0.155	1.331	0.926	1.7	1.575	1.6
>45˚	13	0.128	39	0.089	1.437	1	2	2	2
Total	**10149**	**100**	**43741**	**100**	1				
Surface Groundwater Manifestations									
Flowing	991	9.765	2150	4.915	1.987	0.216	2	0.433	0.6
Wet	737	7.262	919	2.101	3.456	0.376	1	0.376	0.5
Damp	3776	37.21	11059	25.28	1.472	0.16	0.6	0.096	0.13
Dripping	373	3.675	175	0.4	9.186	1	1.5	1.5	2
Dry	4272	42.09	29438	67.3	0.625	0.068	0	0	0
Total	**10149**	**100**	**43741**	100	1				
Structural discontinuities and Rock mass condition									
Disintegrated	3043	29.98	14095	32.22	0.93	0.411	0.25	0.25	0.103
Blocky/ Disturbed	4343	42.79	24383	55.74	0.768	0.339	0.2	0.068	0.2
Very Blocky	2763	27.22	5263	12.03	2.263	1	0.1	0.1	0.2
Total	**10149**	**100**	**43741**	**100**	**1**				
Discontinuity orientation with respect to slope									
Soil Mass	2943	29	14000	32	0.91	0.42	0.25	0.106	0.22
More than one discontinuity dipping into the hill	2521	24.8	24181	55.3	0.45	0.21	0.25	0.053	0.1
At least one discontinuity dipping into the hill	2760	27.2	5560	12.7	2.14	1	0.12	0.12	0.25
None of the discontinuities Dips into the hill.	1925	19	0	0	0	0	0	0	0
Total	10149		43741						

As can be noted from Table 4.3 parameter classes having hazard index >1 has high probability for landslide. According to the results of this study the following causative parameters from their respective class has highest hazard index .i.e. highest probability of landslide occurrence in the study area; at least one discontinuity dipping in to the hill with hazard index of 2.14 from structural discontinuity class, very blocky sub class from structural discontinuity and rock mass condition with 2.26 hazard index, dripping surface groundwater manifestations with hazard index value of 9.18, 26º-35º slope inclination with hazard index value of 1.74, weak rock slope material with hazard index value of 1.31, stream bank erosion rain induced manifestation with hazard index value of 2.03,very high relative relief 8.32 hazard index value, moderately vegetated land cover 3.04 hazard index value, and finally moderately cultivated land with hazard index value of 2.21 are the highest hazard prone causative factor classes from this study area.

4.6 Landslide hazard Zonation

Landslide hazard zonation map of the study area has been prepared from the distribution of the total ratings of each parameter class of intrinsic and external factors as specified in SSEP technique and modified ratings by integrated approach. In order to make a comparison LHZ map two LHZ maps were prepared one following the original SSEP approach and second by integrating statistical approach with SSEP. Later, both the LHZ maps were compared to see the effectiveness of the two approaches, on the same time both the maps were validated with the past landslides in the study area. A detailed discussion on LHZ maps is presented in Chapter 5.

*****

5.1 Landslide hazard Evaluation of the study area

On the bases of the evaluated landslide hazard (ELH) value of SSEP which include both the causative intrinsic and external factors, Landslide hazard can be classified into five different landslide hazard zones. Very high hazard (VHH) zone which is >12 ELH value, High hazard (HH) zone; with ELH value from 8 to 12, Moderate hazard (MH) with ELH value from 7.9 to 5, Low hazard (LH) zone with ELH value from 4.9 to 2, and finally Very low hazard (VLH) zone with ELH value less than 2 (Raghuvanshi et al., 2014).

Landslide hazard zonation map of the study area has been prepared from the distribution of the total modified ratings of each parameter class of intrinsic and external factors as specified in SSEP technique. However, in order to make a comparison LHZ map was also produced by considering original ratings of various parameter classes as proposed in SSEP technique. Thus, two LHZ maps were prepared one following the original SSEP approach and second by integrating statistical approach with SSEP. Later, both the LHZ maps were compared to see the effectiveness of the two approaches, on the same time both the maps were validated with the past landslides in the study area.

5.2 Landslide evaluation by SSEP approach

The LHZ map produced by SSEP original approach has delineated the entire study area into two landslide hazard zones; Moderate hazard and High hazard. About 36% of the area is covered by Moderate hazard zones whereas, 64% is covered by High hazard zone (Fig. 5.1). The total area coverage by moderate hazard zones is about 20.88 km^2, whereas 37.12 km^2 area is covered by high hazard respectively.

5.2.1 Moderate hazard (MH) zone

The MH zones are identified mostly in Northern, Northeastern, Southeastern and Southwestern parts of the study area. The MH zones in the study area are generally characterized by relatively moderately steep to gentile slopes. The MH zones that are present in Northern and South western parts of the study area generally have slopes that contain residual expansive soils, whereas the MH zones that fall in Southeastern parts have slopes covered by residual soils (Fig. 5.1). Similarly, MH zones that fall in North eastern parts have slopes covered by alluvial deposits. The slopes in general are dry (Facet 2, 9, 25, and 29), some facets showed damp (Facet 23, 24) and flowing (Facet 12) groundwater surface traces. ELH and percent area coverage for MH zones, facet wise is presented in Table 5.1.

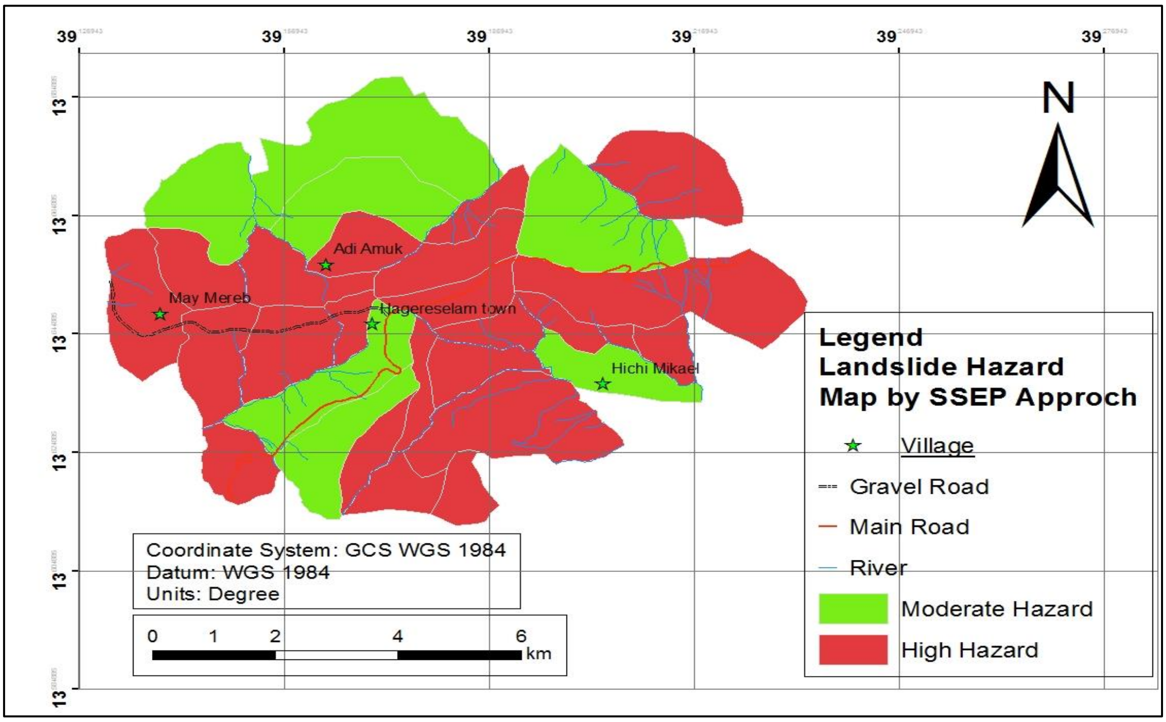

Fig.5.1 Landslide Hazard Map by SSEP original approach

Table 5.1 Evaluated landslide hazard (ELH) Value, hazard class and area coverage MH Zones

Facet No.	**Evaluated landslide hazard (ELH) Value**	**Hazard Class**	**Area in m^2**	**Percent Area Coverage (%)**
2	6.733	MH	3959308.679	7
9	7.68125	MH	1738456.271	3
12	7.4025	MH	2771034.726	5
23	7.277375	MH	2557118.599	4
24	7.656375	MH	2178553.361	4
25	6.7335	MH	2948416.634	5
29	6.7335	MH	4941403.944	9

5.2.2 High hazard (HH) zone

The HH zones in the present study area are mainly delineated in the central parts, Eastern, Western, North eastern and the Southern parts (Fig. 5.1). In total 23 Facet fall within HH zone (Table 5.2). The HH zones are characterized by high to very high relative relief, most of the area is characterized by damp surface groundwater traces, steep to moderately steep slope morphometry, very weak to medium strong rock and all most residual expansive soil slope material, steep rock and soil mass cut, and moderately to densely cultivated land. ELH and percent area coverage for HH zones, facet wise is presented in Table 5.2.

Table 5.2 Evaluated landslide hazard (ELH) Value, hazard class and area coverage for HH Zones

Facet No.	Evaluated landslide hazard (ELH) Value	Hazard Class	Area in m^2	Percent Area Coverage (%)
1	10.45875	HH	2966523.735	5
4	10.1537	HH	797835.6192	1
3	8.73375	HH	4904698.023	8
6	8.7675	HH	694338.2756	1
5	9.05375	HH	206714.0741	0.356
11	9.398125	HH	749351.4054	1
10	9.92875	HH	908994.0396	2
7	10.152	HH	1371417.74	2
13	8.9225	HH	647831.4084	1
8	11.2425	HH	1777050.116	3
14	8.6375	HH	1727952.016	3
16	9.128125	HH	2063166.692	4
17	10.67063	HH	1375252.596	2
18	9.702	HH	962940.5695	2
19	10.10875	HH	1089293.126	2
20	9.058125	HH	4032025.454	7
21	9.362125	HH	1507209.194	3
22	9.271375	HH	2588595.933	4
15	9.40875	HH	2033906.122	4
26	10.9225	HH	1395214.173	2
27	8.671056	HH	948685.08	2
28	8.06225	HH	1282959.389	2
30	8.23925	HH	888781.907	2

5.3 Landslide hazard evaluation by integrated approach

The LHZ map produced by integrated approach has also delineated the entire study area into two landslide hazard zones; Moderate hazard and High hazard. About 39% of the area is covered by Moderate hazard zones whereas, 61% is covered by High hazard zone (Fig. 5.2). The total area coverage by moderate hazard zones is about 22.46 km^2, whereas 35.54 km^2 area is covered by high hazard.

5.3.1 Moderate hazard (MH) zone

Out of total 30 evaluated facets using integrated approach ($58km^2$), 10 facets fall under moderate hazard zone with areal coverage of 22472663.6 m^2. The MH zones are mostly present in Northern, Northwestern, Wesstern, Cental, Eastern and some Southern parts of the study area (Fig.5.2).

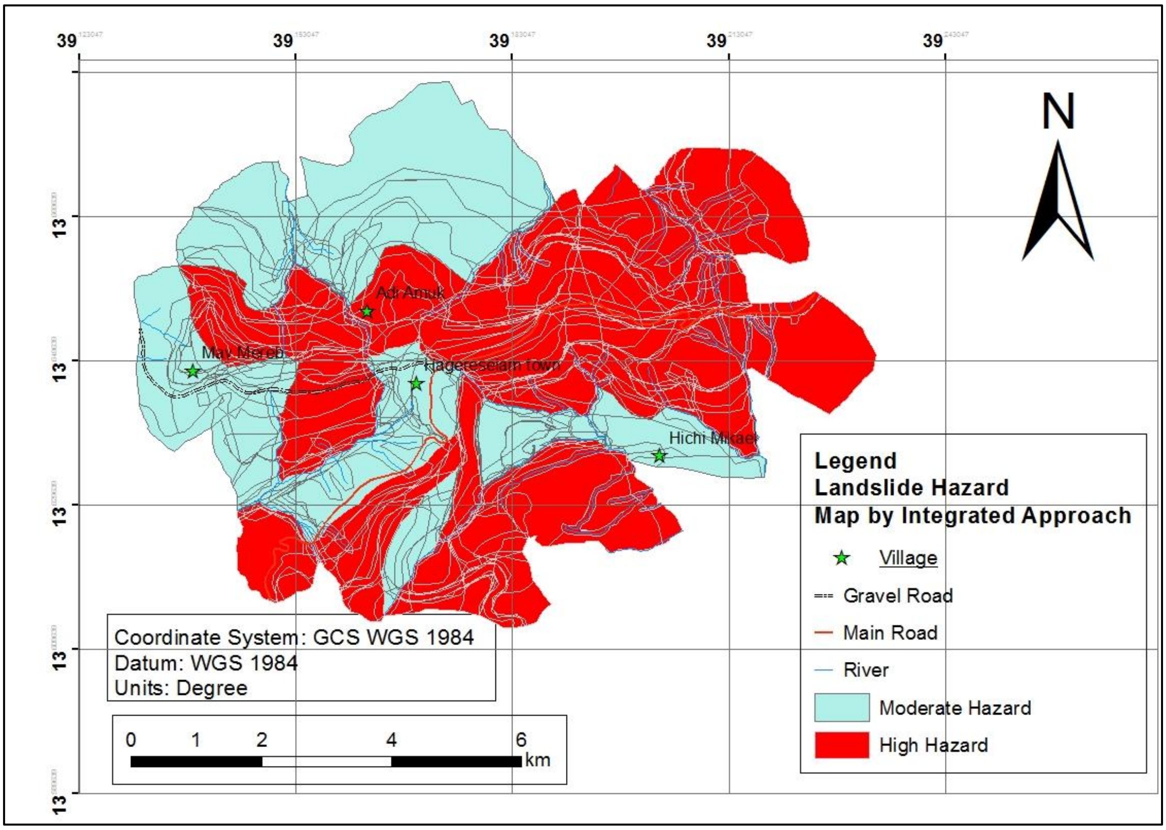

Fig. 5.2 Landslide hazard map by integrated approach

This zone is characterized by relatively moderately steep to gentile slopes. Most of the slopes that fall in MH zone are dry (Facet 9, 18, 25, 29), some are damp (Facet 23, 13) and in some damp and flowing (Facet 12) groundwater surface traces were observed. ELH and percent area coverage for MH zones, facet wise is presented in Table 5.3.

5.3.2 High hazard (HH) zone

Out of total 30 evaluated facets ($58\ km^2$) 20 facets fall in high hazard zone, with area coverage of 35542365.31 m^2 all most 61% of the study area falls under high hazard zone. The MH zones are mostly present in Central, Eastern, Northeastern, Southern and Southwestern parts of the study area. The high hazard zones are characterized by high to very high relative relief. Most of the slopes falling in HH zones are characterized by damp surface groundwater traces, step to moderately steep slope morphometry, very weak to medium strong rock. Residual expansive soil as slope material, steep rock and soil mass cut, and moderately to densely cultivated land. ELH and percent area coverage for HH zones, facet wise is presented in Table 5.4.

Table 5.3 Evaluated landslide hazard (ELH) Value, hazard class and area coverage MH Zones

Facet No.	Evaluated landslide hazard (ELH) Value	Hazard Class	Area in m^2	Percent Area Coverage (%)
9	6.234811	MH	1738456.271	3
13	6.798308	MH	647831.4084	1
12	6.348912	MH	2771034.726	5
18	7.713868	MH	962940.5695	2
22	6.476162	MH	2588595.933	4
15	7.644693	MH	2033906.122	4
23	7.749502	MH	2557118.599	4
25	6.712864	MH	2948416.634	5
28	5.89867	MH	1282959.389	2
29	5.423032	MH	4941403.944	9

Table 5.4 Evaluated landslide hazard (ELH) Value, hazard class and area coverage HH Zones

Facet No.	Evaluated landslide hazard (ELH) Value	Hazard Class	Area in m^2	Percent Area Coverage (%)
1	8.482276	HH	2966523.735	5
4	8.01	HH	797835.6192	1
3	8.140963	HH	4904698.023	8
6	8.295482	HH	694338.2756	1
5	8.217455	HH	206714.0741	0.356
2	7.991	HH	3959308.679	7
11	8.464118	HH	749351.4054	1
10	7.9823	HH	908994.0396	2
7	9.321157	HH	1371417.74	2
8	8.364023	HH	1777050.116	3
14	8.734025	HH	1727952.016	3
16	7.9776	HH	2063166.692	4
17	8.094709	HH	1375252.596	2
19	8.1	HH	1089293.126	2
20	8.614536	HH	4032025.454	7
21	8.265121	HH	1507209.194	3
24	8.808636	HH	2178553.361	4
26	10.81489	HH	1395214.173	2
27	8	HH	948685.08	2
30	8.711045	HH	888781.907	2

5.4 Comparison of LHZ maps prepared by SSEP and integrated approach

In the present study attempt was made to prepare LHZ map by using two different approaches; first one by using original SSEP approach and second by integrating SSEP with statistical approach. The two LHZ maps thus, produced were compared to know the effectiveness of the two different approaches.

When compared, both approaches have delineated the study area into two zones; moderately hazard (MH) and high hazard (HH). However, the area distributed by hazard zones in the two LHZ maps produced by these two approaches varies marginally. In case of SSEP about 36% (21 km^2) of the area is covered by Moderate hazard zones whereas, 64% (39.69 km^2) is covered by High hazard zone (Fig.5.3). In case of integrated approach, about 39% (22.46 km^2) of the area is covered by Moderate hazard zones whereas, 61% (35.54 km^2) is covered by High hazard zone.

In both methods the Northern part of the study area is classified as moderate hazard zone and there was no past landslide history investigated or recorded in Northern area. The Eastern part, except for Facet 2, was classified as high hazard zone by both the methods. The Facet 2 was classified as moderate hazard zone by SSEP approach whereas, integrated approach classified it as high hazard zone. Similarly, Facet 13, 15, 18, 22 and 28 falls under high hazard zone by SSEP approach however by integrated approach they are classified as moderate hazard. Facet 24 falls under high hazard by integrated approach but it is classified as moderate hazard by SSEP approach. Generally, except the above mentioned cases all the other facets are equally identified under the same hazard class by both the approaches.

The results clearly showed that the criteria in assigning SSEP ratings to various causative factor classes are quite reasonable. As already stated, in SSEP approach the ratings for various parameter classes are based on the experience and logical judgment based on relative influence of each parameter class in inducing instability to slopes. Although it is a subjective criteria in assigning ratings but still the results of the present study has showed that the ratings assigned in SSEP approach are quite reasonable as the LHZ map produced by this approach is quite comparable with the map produced by integrated approach. Further, the criteria followed in integrated approach is based on hazard index, which is developed based on the quantitative relationship between each parameter class and past landslides, is purely objective.

5.6 Validation of Landslide Hazard Zonation maps

The methodology followed for the present study is formulated by considering an assumption that ‘using the density of the past landslide distribution within each parameter class of the study area and by integrating with the original SSEP rating a modified and statically supported hazard index value can be created’. Therefore, the LHZ map prepared by following the above mentioned methodology must logically validate with the past landslide activities in the study area. This implies that the past landslide activities in the present study area must fall within very high or high hazard zones of the LHZ map prepared during the present study.

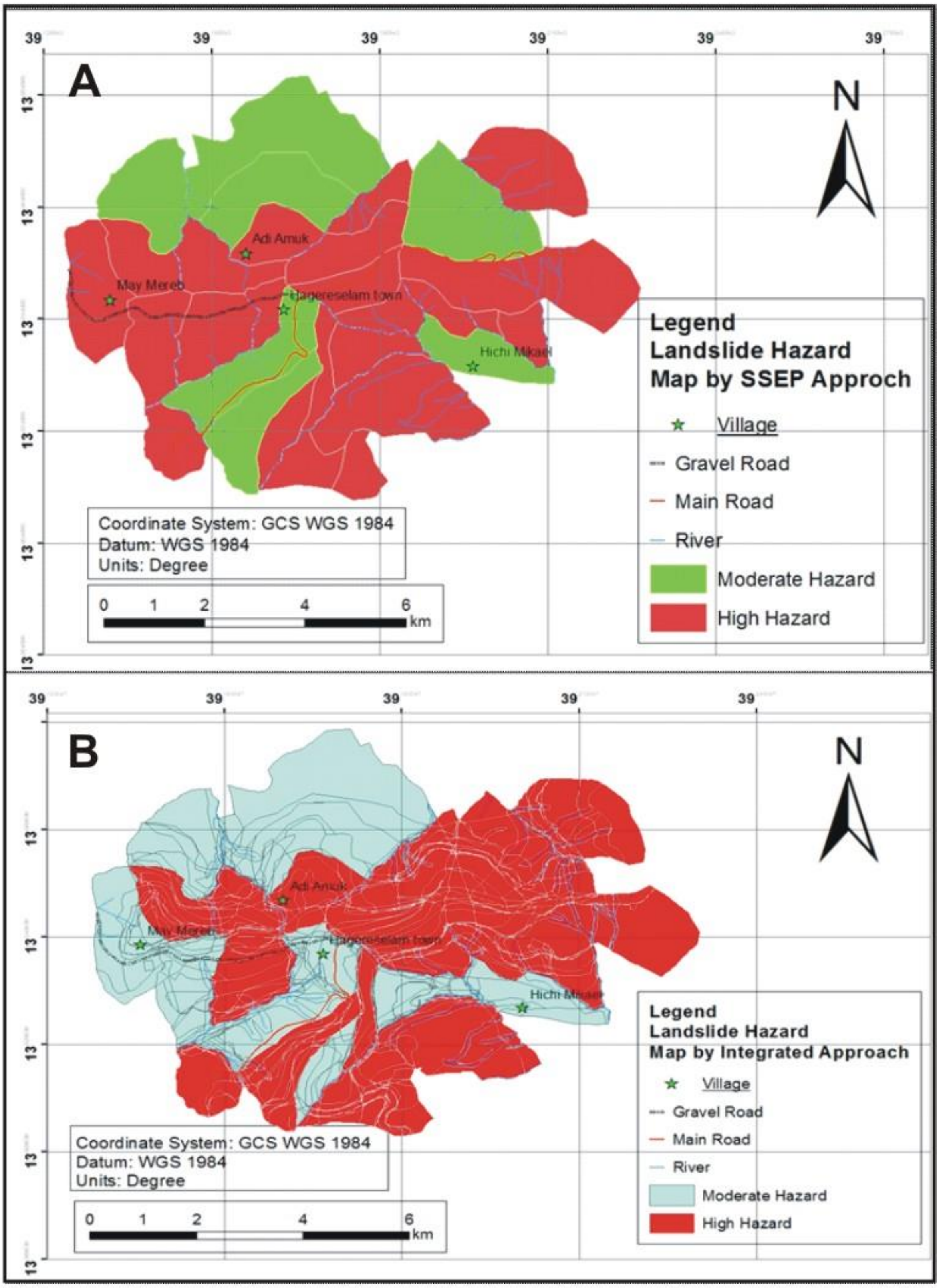

Fig. 5.3 Landslide hazard zonation maps A - SSEP approaches, B – Integrated approach

5.6.1 Validation of LHZ map prepared by SSEP approach

In order to check the validation of LHZ map prepared by SSEP approach an overlay analysis in GIS environment was performed. Past landslide activity map was overlaid on LHZ map prepared by SSEP approach. The analysis revealed that out of 39 past landslides 31 (80%) past landslides fall within high hazard zone and about 8 (20 %) falls within moderate hazard zone (Fig. 5.4).

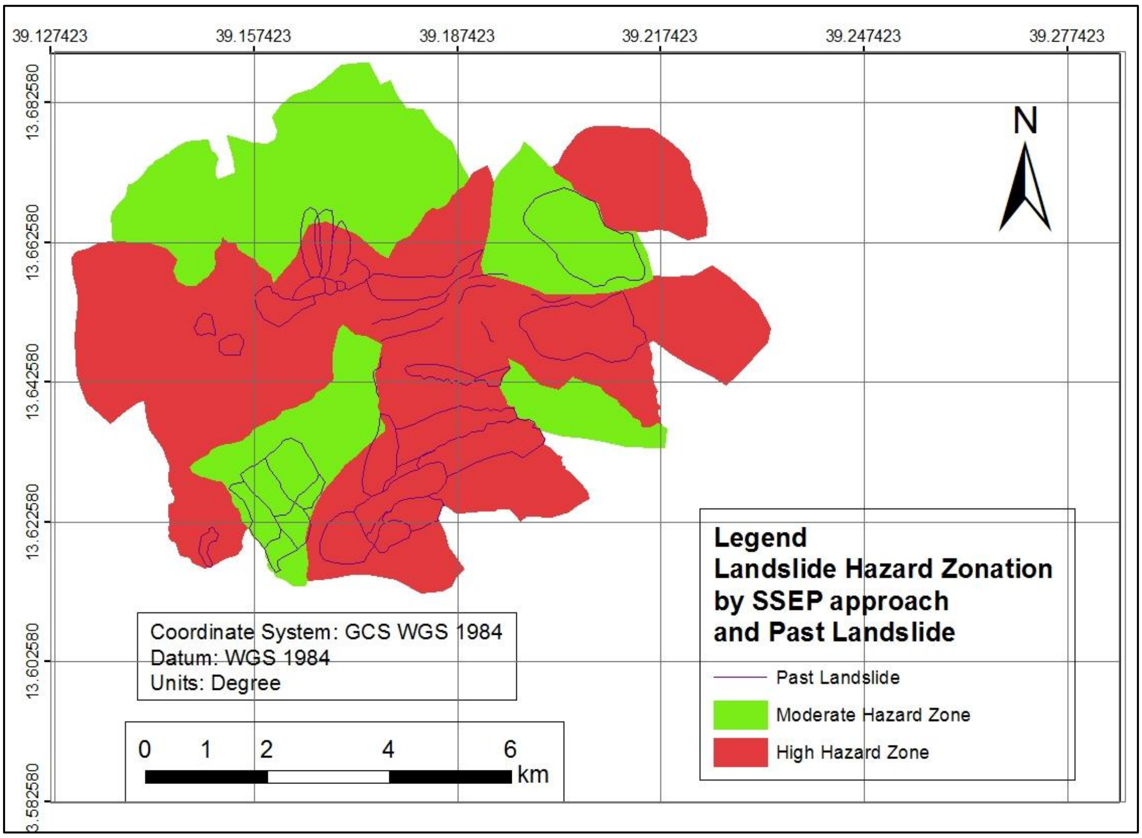

Fig. 5.4 Past Landslide distribution overlaid on LHZ map prepared by SSEP approach

The results gave satisfactory validation as 80% of the past landslides fall within high hazard zone, delineated by SSEP approach. The remaining 20% which fall within moderate zone has also some degree of landslide hazard.

5.6.2 Validation of LHZ map prepared by integrated approach

The overlay analysis between past landslides and the LHZ map prepared by integrated approach revealed that out of 39 past landslides 35.65 (91.4%) fall under high hazard zone and remaining 3.35 (8.6%) falls under moderate hazard zone (Fig. 5.5). The results gave satisfactory validation as 91.4 % of the past landslides fall within high hazard zone, delineated by integrated approach. The remaining 8.6 %, which fall within moderate zone has also some degree of landslide hazard.

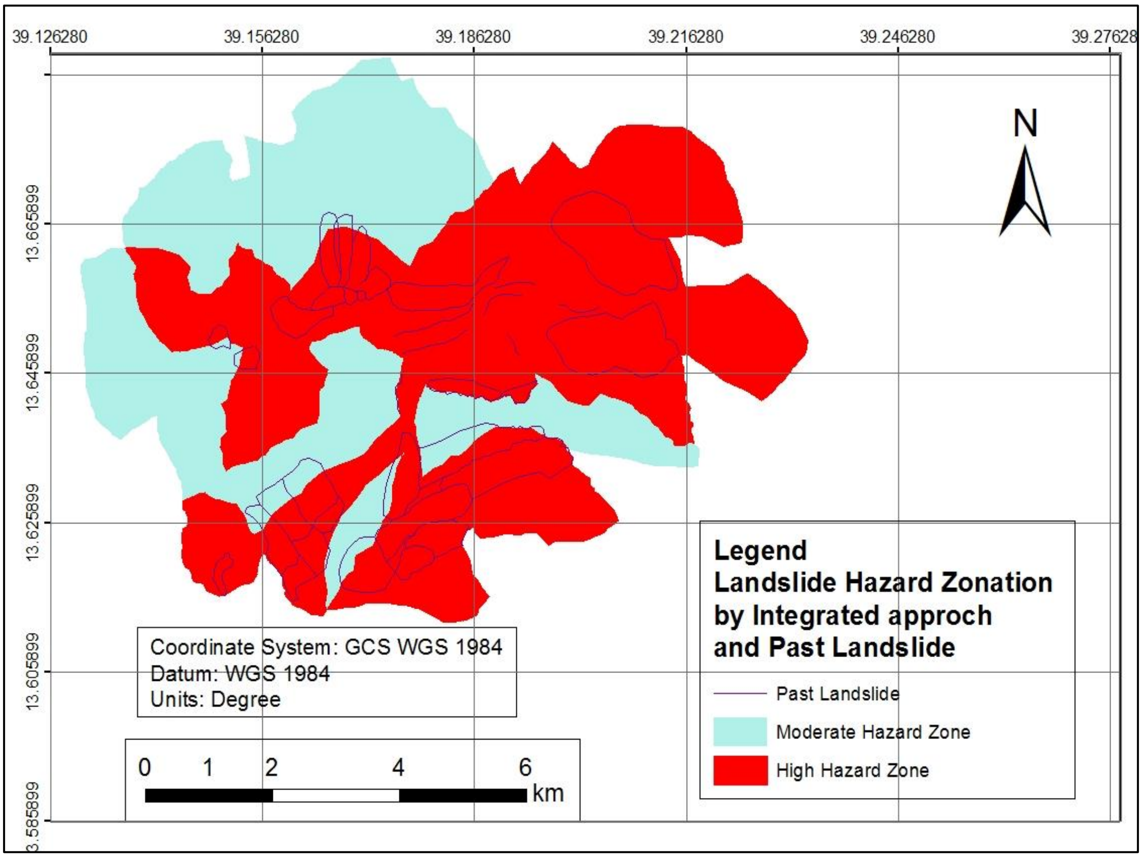

Fig. 5.5 Past Landslide distribution overlaid on LHZ map prepared by integrated approach

5.7 Effectiveness of 'SSEP' method versus 'Integrated Approach' in LHZ evaluation

The input parameters considered in SSEP and integrated approach were same; slope material, slope geometry, manmade developmental activity, land use/land cover, groundwater surface traces, seismicity, rain fall, and structural discontinuity were used. The rating criteria considered in both the approaches were different. However, the LHZ maps produced by two methods are fairly comparable. Both approach delineated study area into two zones; high hazard and moderate hazard. In case of SSEP about 36% (21 km^2) of the area is covered by Moderate hazard zones whereas, 64% (39.69 km^2) is covered by High hazard zone (Fig.5.3). In case of integrated approach, about 39% (22.46 km^2) of the area is covered by Moderate hazard zones whereas, 61% (35.54 km^2) is covered by High hazard zone (Table 5.5). The results by two methods distributed HH zone in almost comparable area coverage. When compared validation of two LHZ maps; LHZ map produced by integrated approach show about 91% validation, whereas LHZ map by SSEP shows about 80 % validation with the past landslide activities (table 5.5). Thus, it may be concluded that both methods produced almost similar type of LHZ maps. However, LHZ map produced by integrated approach showed better validation with the past landslide activities.

Table 5.5 Comparison of results by SSEP and integrated approaches

Landslide hazard zone	**SSEP approach**			**Integrated approach**		
	Area Coverage	**Number of Past landslides**	**Validation (%)**	**Area Coverage**	**Number of Past landslides**	**Validation (%)**
Very high hazard	0	0	0	0	0	0
High hazard	64% (37.12km^2)	31.25	80%	61% (35.54 km^2)	35.65	91%
Moderate hazard	36% (20.88 km^2)	7.75	20%	39% (22.46 km^2)	3.35	9%
Low hazard	0	0	0	0	0	0
Very low hazard	0	0	0	0	0	0

Thus, the two methods are quite comparable and may be applied individually for the landslide hazard zonation. However, the integrated approach may need further application in other areas to get similar results as that of SSEP. In terms of application SSEP approach is simple and straight forward as the standard ratings for various parameter classes can directly be applied. However, in integrated approach to evolve ratings the procedure is complicated and requires tedious GIS overlay analysis.

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6.1 Back ground

The landslide in the study area has caused significant social and economical loses to the government and the local society. Besides, most of these devastating landslides have occurred along the road. Such disaster along the road will not only create the enormous direct economic loss, but also the indirect economic loss which is difficult to estimate and the bad social impact because of the disaster interrupting traffic (Li et al., 2009). Therefore, besides preparing the landslide hazard zonation map of the study area, finding appropriate remedial and preventive measures for critical slopes will be very helpful to reduce the economic and social problems in the area. As it was clearly attempted to explain though the present study that combination of causative factors were responsible for inducing slope instability in the study area. Therefore, combination of different mitigation measures that can overcame or reduce the effect of the causative factors should be applied to avoid influence of some causative factors in reducing the instability to the slopes in the study area. Therefore, based on the present study and the general assumptions thus made, the following remedial measures for the study area are recommended;

6.1.1 Proper management for stream bank and drainage system

Most of the streams of the study area are affected by stream bank erosion and slope toe erosion. Therefore, it needs proper remedial measurement like; designing terracing like protective mesh reinforced with rock along the stream banks. This may possibly helps the stream bank not to erode easily. Such activities were done at Enderta Wereda and they were very effective in protecting stream bank erosion. The other measure is to properly manage the drainage system of the slopes. This requires construction of trench drain, interceptor drain and construction of collection chamber and diverting the water to the existing drainage systems.

6.1.2 Reforestation

Most parts of the hill sides of the study area and areas that are affected by the landslides are either sparsely vegetated or barren lands. This has resulted from deforestation by different reason (developmental activity, for energy supply, for settlement, and for agricultural activity). The effect of vegetation in reducing slope instability is enormous, especially for shallow depth landslides. Plant roots and vegetation cover may stabilize the underlying slope by reducing the pore water pressure through Evapo-transpiration, intercept direct impact of precipitation and the plant roots tightly strengthen the underlying soils. Therefore, by reforestation the sparsely vegetated and barren lands of the study area may possibly reduce the land sliding and associated slope instability problems by a great deal in the present study area.

6.1.3 Supporting critical slopes

In the present study area, as observed no retaining walls were constructed to support the critical slopes. During the present study it was observed that in the absence of retaining wall along a critical slope section a landslide event has disrupted the main road for about three days and the access to the regional capital city Mekelle was stopped. Therefore, there is a necessity to identify all such critical slope sections along the main road and where required properly designed permanent or temporary retaining structures should be placed.

6.1.4 Constructing catch walls

The debris flow and rock falls impact on the road, along the Adi Amuk ridge in the study area is very significant and hazardous. Therefore, it is required to properly design and place catch wall along the Adi Amuk ridge area. Besides, all other road sections which have a potential threat from such rock fall need to be identified and similar catch walls should be constructed.

6.1.5 Avoiding quarry sites along main road

Traditionally operated quarry sites were observed along the main road at three different locations in the present study area. As observed, slopes in these quarry sites are generally very steep to moderately steep. Slope Toe support removal due to quarry activity may result in to devastating landslide along the main road. Therefore, there is a constant threat and the people involved in the quarry activity and the nearby settlement areas are at a risk. Proper management of quarry operation and detailed slope stability studies in these areas is essential.

6.1.6 Managing steeply cut slopes

In the present study area along the Hagereselam main road whenever there is a steep soil mass cut a landslide is resulted. An effort was made to collect any previous investigation reports related to slope stability studies along the main road, however no such studies were carried out. Therefore, it is obvious that the slopes along the main road were cut in an unplanned manner without any systematic slope studies. Besides, it was also observed that the excavated materials from the construction of the road were simply dumped down the slope in an unplanned manner. The poorly graded slope material, soils, and highly weathered basalts, become unstable in the steep rock mass cut. This loose material which is dumped down the slope in unplanned manner may easily be eroded and degraded. This may intern will make the overlying road to be affected by landslide. Therefore, it is necessary that proper slope cut should be designed and unplanned dumping of excavated rock and soil material on the slope face should be avoided.

6.1.7 Creating awareness

Unless adequate measures are taken the growth of human population and related demand for settlement, infrastructure, agricultural land, expanding of the city into high hazard zones will increase the intensity of landslide hazard. The intensity of landslide hazard can be reduced by avoiding risky areas. Local governments can reduce landslide effects by imposing restrictions on the high hazard zones. Individual investors, family members can reduced the effect of landslide by having a good knowledge on their localities potential for natural hazard causing events. This helps to get ready for what to come and most of all they can protect their lives and their properties from a devastating natural hazards.

6.1.8 Resettlement

Based on the results of the present study, area that fall under high hazard zone should be avoided from settlement and any developmental activity or proper remedial measures has to be adopted if forced to undertake any developmental activities in these landslide hazard prone areas.

Finally, through the present study general remedial measures such as; proper management of drainage, reforestation, supporting critical slopes, constructing catch walls, avoiding quarry sites activities on slope instability etc. has been forwarded. Moreover, applying integrated approach of remedial measures may be helpful to minimize the landslide hazard in the area. However, more detailed studies would be required to work out specific remedial measures for individual critical slopes.

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7.1 Conclusion

The main objective of the current research study was to evaluate landslide hazard in Hagereselam, Wereda Degia Tenben, Tigray Regional State in Northern Ethiopia which is about 828 km far from Addis Ababa and 45 km far from Mekelle town towards west. The total study area investigated during the present study is 58 km^2. It is characterized by rugged topography with maximum elevation of 2900 m above sea level. The area falls in semi arid climatic zone and it receives 670 mm mean annual rainfall. The economic activity of population in the study area is mainly based on farming. The area is being affected by repeated landslide problems for the past several years therefore seeing the severity of landslide and related instability problems in the area the present research study was conducted. In the present study landslide hazard zonation (LHZ) of the study area was carried out. The LHZ map was prepared by following two different approaches; one by Slope Susceptibility Evaluation Parameter (SSEP) approach and other by integrating SSEP with statistical approach. The two methods were attempted mainly to see the effectiveness of new integrated approach.

The general methodology followed in the present study was based on thorough literature review, field investigations, data collection, analysis and evaluation of various causative factors in inducing instability to slopes in the present study area; Finally, LHZ maps were produced by SSEP approach and the integrated approach. For landslide hazard zonation purpose, the area was first divided into 30 slope facets. Later , data for nine required causative parameters namely; relative relief, slope morphometry, slope material, structural discontinuity, land-use/land-cover, groundwater surface manifestations, rain induced manifestations, seismicity and manmade developmental activities have been generated through facet wise field observations, secondary sources and image interpretations. Later, as per the observations made for each causative parameters on each facet ratings were assigned to get the evaluated landslide hazard (ELH) value. This ELH value formed the basis to generate LHD map by SSEP approach.

In the integrated approach the methodology followed was based on the calculation of the corrected normalized value of the SSEP. For this hazard index value was first computed for each of the parameter class. For this density relation between past landslides in the area and each of the parameter class was established. This hazard index value is a ratio between landslide did occurred to landslide did not occurred within each parameter class. It implies if hazard index value is more than ‘1’ corresponding parameter class has a strong relation with the landslide occurrence.

Later, corrected normalized value was calculated based on relative influences of causative factors on past landslides. The landslide inventory mapping for this study has been prepared through field investigation, from previous works in the area, and using Google earth image. The distribution of landslide over each of the factor maps have been obtained and analyzed in GIS environment. Modified ratings for each of the classes within these factor maps have been obtained using the hazard index value.

Inventory landslide investigation was made to know the areal distribution of past landslide events. In total 39 past landslides were investigated and recorded during the field investigation, through literature review and other secondary data. The past landslide events in the study area were categorized in to ten types; debris and rock slide, debris fall, debris flow plateau layer, earth slide, earth slide and debris fall, earth slide belt, landslide depletion area, creep, landslide belt, and slump. During the field investigation a thorough inventory was made for the past landslide activities to record the locations, dimension, type of failure and material involved in the landslides.

In the integrated approach the entire study area was overlaid by a total of 53890 pixel counts. To intersect all the causative factors maps within a facet geo-processing was done in GIS environment. Later, for each facet total landslide hazard index was computed by summing up all the causative factor values within each facet. On the other side the computation landslide class in the SSEP approach was done by the original ratings assigned by SSEP approach.

Based on the SSEP approach out of 39 past landslides 20% falls under moderate hazard zone, and 80% falls under high hazard zone, whereas, in the integrated approach 91% falls under high hazard zone and 9% falls under moderate hazard zone.

The results by two methods distributed HH zone in almost comparable area coverage. When compared validation of two LHZ maps; LHZ map produced by integrated approach show about 91% validation, whereas LHZ map by SSEP shows about 80 % validation with the past landslide activities (table 5.5). Thus, it may be concluded that both methods produced almost similar type of LHZ maps. However, LHZ map produced by integrated approach showed better validation with the past landslide activities.

The choice of selection of either of methods depends on area to be covered and capability of an evaluator to handle large data in GIS environment. With good software skill integrated approach is more preferred as it utilize more real objective data and the rating criteria thus used may provide more realistic LHZ map.

7.2 Recommendation

To avoid or reduce the landslide hazard in the study area, various general remedial measures such as; proper management of stream bank erosion and drainage system, reforestation, supporting critical slopes, constructing catch walls, avoiding quarry sites along steep slope at nearby distance from settlement and mine road etc. have been proposed.

The general recommendations based on the present study are;

- Integrated approach of remedial measures may be more appropriate to mitigate the possible landslide hazard in the area.
- Improvement in drainage and stream bank condition will be an effective measure to stabilize the slopes in the area.
- Unplanned manmade activities such as; quarrying on slopes and dumping excavated material down the slope can induced instability in the slopes to certain degree. In this regard awareness among the local residents and construction agencies should be made by the local administration.
- High hazard zones, as delineated during the present study, are probable susceptible landslide prone areas. Thus, such high hazard zones in the area should be avoided for any settlements and investment activities or if required appropriate remedial measures must be adopted.

- The local government is required to create awareness among the local residence of the study area to provide information on the landslide condition in the area and make them aware about the hazardous area.
- Further, more detailed studies are mandatory to investigate individual slopes for its instability, possible causes for such activities and to work out appropriate remedial measures for critical slopes.

Despite some constraints on technical support for analysis, resource, and time all efforts were made to perform this research in a systematic manner. All these constrain might have affected on the quality of result and certain component of imprecision may not be eliminated. Therefore, it is strongly recommended that more detailed systematic study must be undertaken before applying the results from the present study.

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ANNEXURE

A. appendix for SSEP approach

facet	Develop-mental	structural	rain fall	slope morph-ometry	groundwater	land use	Slope material	Seismic	Total
1	1.3375	2.14	1.18125	2.3	0.06	1.04	1.4	1	10.45875
2	0.8375	1.99	0.91125	1.6	0.06	0.845	1.6	1	8.84375
3	1.3375	1.51	1.25625	1.6	0.32	0.51	1.2	1	8.73375
4	1.0875	1.87	1.15625	2.3	0.7	0.84	1.2	1	10.15375
5	1.0875	1.87	1.15625	1.2	0.7	0.84	1.2	1	9.05375
6	0.975	1.74	0.9125	1.2	0.7	0.84	1.4	1	8.7675
7	0.975	2.02	0.847	2.6	0.4	0.89	1.42	1	10.152
8	1.3375	2.01	1.41	2.5	0.385	1.2	1.4	1	11.2425
9	0.7625	1.51	0.96875	0.4	0.925	0.715	1.4	1	7.68125
10	1.3375	2	1.03125	1.9	0.7	0.96	1	1	9.92875
11	0.975	1.82	0.728125	2.5	0.15	1.2	1.025	1	9.398125
12	0.8375	1.23	1.295	0.5	0.42	0.52	1.6	1	7.4025
13	1.3375	1.88	0.825	1.6	0.12	0.76	1.4	1	8.9225
14	0.8375	1.66	1.215	1.6	0.125	0.8	1.4	1	8.6375
15	1.3375	1.74	1.36125	1.6	0.17	0.8	1.4	1	9.40875
16	1.3375	1.68	1.140625	1.6	0.17	0.8	1.4	1	9.128125
17	0.8375	1.92	0.953125	2.5	1.1	0.96	1.4	1	10.67063
18	1.0875	1.91	0.9875	2.5	0.102	0.715	1.4	1	9.702
19	0.975	1.79	1.01875	2.5	0.6	0.825	1.4	1	10.10875
20	0.8375	1.78	1.430625	0.8	1.25	0.56	1.4	1	9.058125
21	0.475	1.56	1.003125	2.5	0.024	1.2	1.6	1	9.362125
22	1.0875	1.21	0.971875	2.5	0.542	0.56	1.4	1	9.271375
23	1.3375	1.21	0.971875	0.8	0.078	0.48	1.4	1	7.277375
24	0.74	1.13	0.971875	1.2	0.622	0.5925	1.4	1	7.656375
25	0.7625	1.13	1.525	0.4	0.126	0.59	1.2	1	6.7335
26	0.975	2.17	0.7975	3	0.58	1.2	1.2	1	10.9225
27	1.0875	1.91	1.459556	1.2	0.054	0.56	1.4	1	8.671056
28	1.0875	1.27	1.21875	1.2	0.126	0.56	1.6	1	8.06225
29	0.7625	1.13	1.525	0.4	0.126	0.59	1.2	1	6.7335
30	0.975	2.17	0.84125	0.7	0.078	1.05	1.425	1	8.23925

B. appendix for integrated approach

sub of adjustment from manmade	A
multi of cultivation adjustment	B
slope	C
Discontinuity as rain fall	D
rock mass condition	E
slope material as rain fall parameter	F
slope*adjustment R	G
Slope material for soil	H
relief value	I
rain induced manifestations	J
Land-use/land-cover	K
Surface Ground water Manifestations	L
seismicity	M
rain fall	N
other structural discontinuity values	O

A	B	C		E	F	G	H	I	J	K	L	M	N	O	Total	Facet
0.7	0.0225	1.212722	0.220559977	0.22056	0.25	1.377819	0.688909	0.057072	0	0.728593	0	1	0.2	2.14	8.482276	facet 1
0.7	0.15	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.035249	0.097213	0.2647	0.128155	1	0.2	2	8.482276	facet 10
0.6	0.0225	1.212722	0.25	0.25	0.25	0.719946	0.359973	0.118632	0.097213	0.748766	0	1	0.2	1.82	8.464118	facet 11
0.7	0.075	0.18626	0.220559977	0.22056	0.25	0.719946	0.359973	0.035249	0.097213	0.728593	0.128155	1	0.2	1.23	6.348912	facet 12
0.7	0.075	0.18626	0.109386334	0.109386	0.25	0.719946	0.359973	0.057072	0.097213	0.2647	0.128155	1	0.2	1.88	6.798308	facet 13
0.7	0.0225	1.212722	0.109386334	0.109386	0.25	1.377819	0.688909	0.057072	0.310271	0.748766	0.128155	1	0.2	1.66	8.734025	facet 14
0.7	0.0225	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.057072	0.097213	0.2647	0.128155	1	0.2	1.74	7.644693	facet 15
0.7	0.075	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.057072	0	0.2647	0.128155	1	0.2	1.68	7.9776	facet 16
0.7	0.075	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.057072	0	0.2647	0.128155	1	0.2	1.68	7.9776	facet 16
0.7	0.0225	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.118632	0.097213	0.728593	0.576678	1	0.2	1.92	8.094709	facet 17
0.6	0.0225	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.118632	0.097213	0.2647	0.128155	1	0.2	1.91	7.713868	facet 18
0.6	0.0225	1.212722	0.109386334	0.109386	0.25	0.719946	0.359973	0.118632	0.310271	0.2647	0	1	0.2	1.79	8.1	facet 19
0.7	0.075	0.583076	0.25	0.25	0.25	1.377819	0.688909	0.057072	0.097213	0.728593	0	1	0.2	1.99	7.991	facet 2
0.7	0.15	0.583076	0.220559977	0.22056	0.25	2	0.359973	0.035249	0.097213	0.2647	0.128155	1	0.2	1.78	8.614536	facet 20
0.7	0.0225	0.583076	0.220559977	0.22056	0.25	2	0.688909	0.118632	0.097213	0.748766	0.128155	1	0.2	1.56	8.265121	facet 21
0.7	0.0225	0.583076	0.220559977	0.22056	0.25	0.719946	0.359973	0.118632	0.097213	0.748766	0	1	0.2	1.21	6.476162	facet 22
0.7	0.0225	0.583076	0.109386334	0.109386	0.25	1.377819	0.688909	0.035249	0.097213	0.2647	0.128155	1	0.2	2.04	7.749502	facet 23
0.7	0.075	1.212722	0.25	0.25	0.25	0.719946	0.359973	0.118632	0.097213	1.5	0.128155	1	0.2	1.55	8.808636	facet 24
0.7	0.075	0.18626	0.109386334	0.109386	0.25	0.719946	0.359973	0.000609	0.097213	0.728593	0	1	0.2	1.11	6.712864	facet 25
0.7	0.075	2	0.109386334	0.109386	0.25	0.719946	0.359973	1	0.097213	0.2647	0	1	0.2	2.17	10.81489	facet 26
0.7	0.075	1.575	0.220559977	0.22056	0.25	1.377819	0.688909	0.035249	0.097213	0.728593	0	1	0.2	1.91	8	facet 27
0.7	0.15	0.18626	0.109386334	0.109386	0.25	0.719946	0.359973	0.035249	0.097213	0.2647	0.128155	1	0.2	1.27	5.898672	facet 28
0.7	0.075	0.18626	0.109386334	0.109386	0.25	0.719946	0.359973	0.000609	0.097213	0.2647	0	1	0.2	1.13	5.423032	facet 29

1.25	0.075	0.18626	0.220559977	0.25	0.25	2	0.688909	0.057072	0.097213	0.2647	0	1	0.2	1.51	8.140963	facet 3
0.94	0.0225	2	0.109386334	0.109386	0.25	0.719946	0.359973	0.035249	0	0.2647	0.128155	1	0.2	2.17	8.711045	facet 30
0.7	0.075	1.575	0.109386334	0.109386	0.25	0.719946	0.359973	0.057072	0.310271	0.728593	0.128155	1	0.2	1.87	8	facet 4
0.7	0.075	1.575	0.25	0.25	0.25	0.719946	0.359973	0.035249	0.310271	0.2647	0.128155	1	0.2	1.74	8.295482	facet 6
0.7	0.15	1.575	0.109386334	0.109386	0.25	0.361379	0.180689	0.035249	0.310271	0.728593	0	1	0.2	1.87	8.217455	facet 5
0.6	0.0225	1.575	0.25	0.25	0.25	0.719946	0.359973	0.057072	0.097213	0	0	1	0.2	2.02	9.321157	facet 7
0.7	0.075	1.212722	0.220559977	0.22056	0.25	1.377819	0.688909	0.118632	0.097213	0.2647	0	1	0.2	2.01	8.364023	facet 8
0.7	0.15	0.18626	0.220559977	0.22056	0.25	0.361379	0.180689	0.118632	0.310271	0.2647	0.128155	1	0.2	1.79	6.234811	facet 9

MSc THESIS ORGONALITY TEST REPORT

School of Earth Science
Addis Ababa University

Name of Student:	Searom Gebremicheal
ID No:	GSR/0457/08
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S.No	Particulars	Originality/Percent	Plagiarism (%)	Remarks
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2	Chapter 1	100	0	Excellent
3	Chapter 2	100	0	Excellent
4	Chapter 3	100	0	Excellent
5	Chapter 4	100	0	Excellent
6	Chapter 5	100	0	Excellent
7	Chapter 6	100	0	Excellent
8	Chapter 7	100	0	Excellent
9	References	100	0	Excellent
10	Annexure	100	0	Excellent
Average (%)		100	0	Excellent

Signatures

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