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Landslide Evaluation In Parts of Tarmaber District (Debresina), Central Ethiopia; An Expert Evaluation Approach

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ABSTRACT:

The present study was carried out in Tarmaber District, which lies in the Amhara National, Regional state in the North Shoa Zone, Central Ethiopia, about 190 Km from Addis Ababa. The main objective of the present study was to evaluate and to prepare a Landslide Hazard Zonation (LHZ) map of the study area. In the present study to prepare the LHZ map an attempt was made to integrate expert evaluation technique with the statistical method. For this purpose, Slope stability susceptibility evaluation parameter (SSEP) rating scheme was considered. In this technique the rating criteria for various intrinsic and external triggering factors is subjective. Therefore, attempt was made to evolve statistical relation between the past landslide activities in the area and each of the factor class to derive a hazard index. By using this hazard index for each parameter class, the corresponding SSEP ratings were corrected. In an attempt to modify SSEP rating criteria two LHZ maps were thus produced so that a comparison can be made between the LHZ map produced from the SSEP subjective rating criteria and the LHZ map prepared by statistically corrected/modified SSEP criteria. For LHZ map preparation the parameters that were considered are; slope geometry, slope material, structural discontinuities, land use and land cover, groundwater, proximity to streams, seismicity, rainfall and manmade activities. Field observations included inventory mapping of past landslides and facet wise observations and verifications on various parameters. The percent area covered by the high hazard and moderate hazard zones is different in both the approaches. In terms of effectiveness, SSEP method is straight forward and directly it can be applied.

Key words: *Landslides, Landslide Hazard Zonation (LHZ), Evaluated Landslide Hazard (ELH), Hazard Index*

I. INTRODUCTION

A. Background of the study area

Landslide is an important geological hazard that causes damage to the natural and social environment. Landslides can cause significant property loss and human casualties. Moreover, landslides are one of the most devastating geo-hazards which, together with other natural hazards like earthquake, volcanic eruptions and floods, have a major impact on the life and property of the human being. The term landslide is defined by different authors, Varnes and IAEG (1984) defined landslides as 'almost all varieties of mass movements on slope including some, such as; rock falls, topples and debris flow that involves little or no true sliding'. Brusden (1984) considered landslides as a unique form of mass transport and a process, which do not require a transportation medium such as water, air or ice. Further, Crozier (1986) defined landslides as 'the outward and downward gravitational movement of the earth material without the aid of running water as a transporting agent. According to Hutchinson(1988), a variety of external stimuli can be triggered and causes the down slope movement of masses of rock, debris or earth to a landslide. A recent definition by Courture, (2011) simply states that 'landslide is a movement of soil (earth or debris) or rock down the slope'. This concept of landslide is more broaden with respect to the type of material that moves down the slope.

Ethiopia has been frequently affected from such natural hazards, especially in the toe of mountainous area and at the escarpment of rift valley (Kifle Woldearegay, 2013). Ethiopia is mountainous country with great variation in elevations. Ethiopian mountains are susceptible to landslide hazard, especially near or at the escarpment of the rift valley. Intense and prolonged rainfall causes landslides, erosion, and slope failure, especially during rainy season (Fikre Girma et al., 2015; Raghuvanshi et al., 2014; Bekele et al., 2010; Kifle Woldearegay, 2013, Broothaerts, 2012, Lee and Dai, 2001). Landslides are amongst the most damaging natural hazards in the rugged mountainous terrain of the world (Rai1 et al, 2014). Landslide in most parts of the world causes loss in farm production, substantial damage to houses and other properties, besides human injury and fatalities every year (Wang, 2009). The major component that adds to the increase in number of landslides in Ethiopia is the unplanned rural road construction, rapid change in land use and land cover as well as intense rainfall (Henok Woldegeorgis et al., 2014

Currently in Ethiopia landslide is the main problem that has been destroying the topographical features, agricultural product, dwelling house, road, industrial parks and also it is a cause for evacuation and for mortality of people from their residents. The Central Highlands of Ethiopia have been repeatedly experiencing large-scale landslide events. The Tarmaber district area is one of the most affected landslide prone areas located along the western Afar rift margin of Ethiopia, which is frequently affected by large-scale and deep-seated landslides. Despite that, urban and rural development is currently taking place in almost all constricted valleys as well as on the imposing cliffs (Kifle Woldearegay, 2013). Therefore, understanding the major triggering factors and failure mechanisms in this area and surroundings is of critical importance. In order to minimize the loss due to landslide, landslide prone areas should be identified. For this regional and local scale landslide hazard analysis and risk management is essential. The Landslide hazard zonation map can be useful in this regard for estimating, indicating, managing and mitigating landslide hazard.

B. Objectives

a) General objective

The general objective of the present study was to evaluate the landslide hazard in the area and to produce the landslide hazard zonation (LHZ) Map of the study area by using integrated expert evaluation and statistical approach.

b) Specific objectives

- To carry out landslide inventory in the study area
- To assess the causative and triggering factors responsible for landslides in the area.
- To know the possible failure mechanism of the landslides.
- To prepare the landslide hazard zonation (LHZ) map by integrating geological, slope morphometry, Relative relief, vegetation cover, Rainfall and man-made activities. Later, to validate the LHZ map with prepared general inventory of past landslide activities and demarcate areas of possible potential instability.
- To suggest possible remedial and mitigation measures.

C. Description of the study area

a) Location of the study area

The proposed study area, Tarmaber district, is located in the western escarpment of the Main Ethiopian Rift (MER) which lies in the Amhara National, Regional state in the North Shoa Zone, Central Ethiopia (Fig.1.1). The study area is about 190km in the north direction of the capital city; Addis Ababa. Geographically, it is bounded in between 9^{0}48’0”N-9^{0}55’30”N (UTM 1083430m-1097090m) latitude and 39^{0}45’1.5”E - 39^{0}50’42”E (UTM 582287m-592664m) longitude and the total area coverage is 92km^{2}.

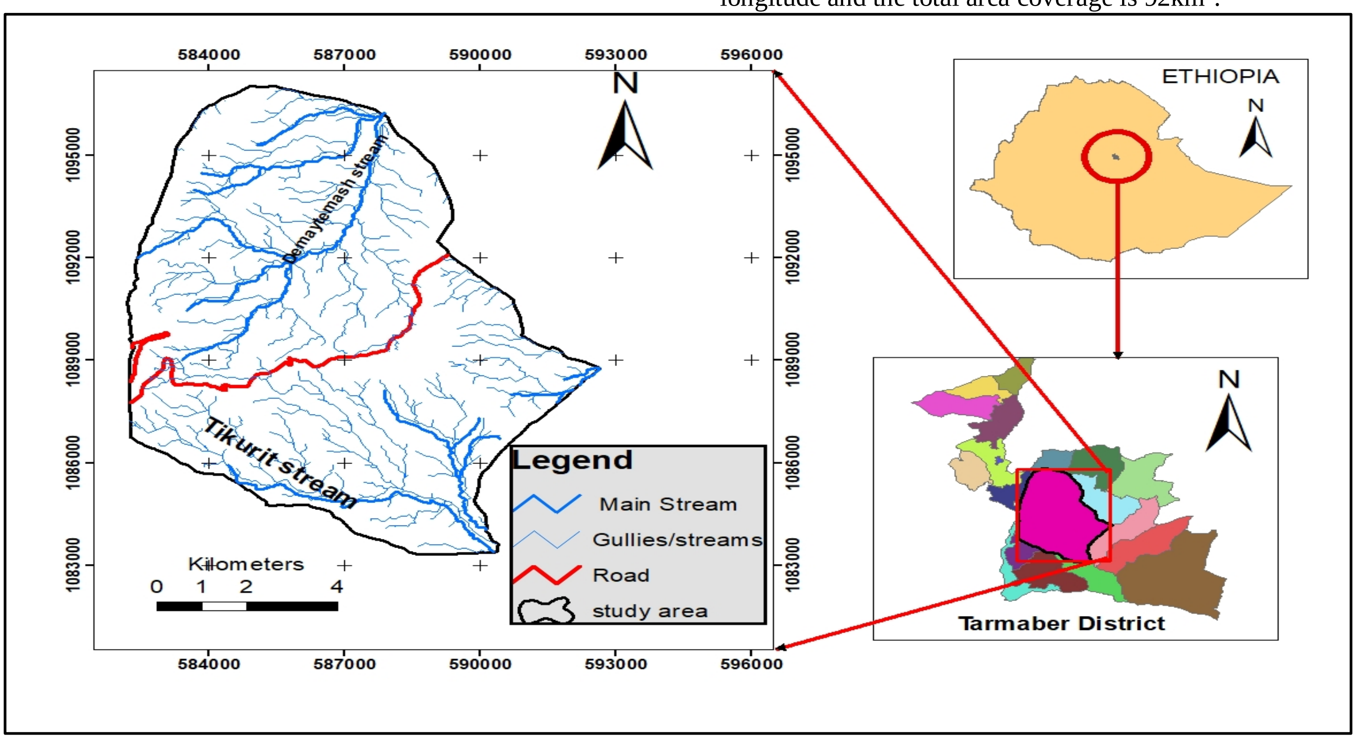

Fig. 1.1 Location map of the study area and its drainage patterns

II. LITERATURE REVIEW

A. Intrinsic causative factors

According to Raghuvanshi et al. (2014) and Anbalagan (1992), intrinsic parameters are inherent or static causative factors which define favorable or unfavorable stability conditions within the slope. Slope geometry (relative relief and slope morphometry), slope material, structural discontinuities, land-use and land-cover and groundwater are the intrinsic parameters which have responsibility for landslide initiating in the specific area.

B. Landslide Analysis Techniques

Methods/ models for ranking slope instability factors and assigning the different hazard levels can be qualitative/ quantitative and direct/ indirect (Guzzetti. et al., 1999).

Qualitative methods are subjective and portray the hazard zoning in descriptive (qualitative) terms. Qualitative techniques depend critically on expert opinions (Marrapu and Jakka, 2014; Raghuvanshi et al., 2014; Fikre Girma et al., 2015). The common types for examining landslide inventory maps to identify sites of similar geomorphological and geological properties are susceptible of material to failure. Some qualitative methods, however, incorporate the idea of ranking and weighting, and it could develop to be semi-quantitative in character. There are two main types of qualitative methods. These are landslide inventory-based approach which is one of the simplest qualitative approaches of LHZ mapping. The other is the heuristic approach, which is based on the a priori knowledge of all causes and instability factors of landsliding in the area under investigation, is an indirect (Chang and Leclerc, 1994). Some of these approaches are as proposed by Raghuvanshi et al. (2014), Guzzetti et al. (1999), Turrini and Visintainer (1998), Sarkar et al. (1995), Anbalagan (1992), Pachauri and Pant (1992); (Raghuvanshi et al., 2015), etc.

Whereas quantitative technique/method of ranking slope instability are based on mathematical and statistical expressions of the relationship between controlling factors and landslide occurrences (Raghuvanshi et al 2015; Carrara, 1983; Wang and Ann-win, 1992; van Westen, 1993; Chang and Leclerc, 1994). Quantitative methods produce numerical estimates probabilities of the occurrence of landslide phenomena in any hazard zone. Quantitative techniques can be classified into two main type approaches. These are deterministic and statistical approaches. Deterministic approaches consist of slope stability analyses depending on the engineering principles of slope instability generally designed to determine a safety factor (Raghuvanshi et al., 2015; Fall et al., 2006). The second one is statistical method. The qualitative and quantitative methods of landslide studies are generally integrated with remote sensing and GIS technique. In these approaches attempts are made to evaluate spatial landslide instability based on the relationship among the active landslide activities, the past landslide and the instability causative parameters (Carrara et al., 1992). In these approaches the general rules are developed statistically with the relative contribution of instability parameters on active landslide and past landslide occurrences (Van Westen, 1994). The landslide hazard can be deduced by applying weights, deduced statically to be applied to each factor subclass (Raghuvanshi et al., 2015; Dai and Lee, 2001).

The second method or model of ranking instable slope is direct or indirect. Direct methods consist of the geomorphological mapping of landslide hazard (Verstappen, 1983). Indirect methods for landslide hazard assessment are essentially stepwise. They require first the recognition and mapping of landslides over a target region or a subset of it. It follows the identification and mapping of a group of physical factors which are directly or indirectly correlated with slope instability (instability factors). They then involve an estimate of the relative contribution of the instability factors in generating slope failures, and the classification of the land surface into domains of different hazard degree hazard zoning (Ghafoori, et al. 2016).

Over last some decades LHZ mapping technique has been adopted in different parts of the world. Four approaches have been developed for LHZ mapping such as inventory based mapping, heuristic approach, deterministic, and statistical analysis (Pardeshi, et al., 2013).

***a) Landslide inventory*:** The landslide inventory (landslide distribution) maps are produced which portray spatial and temporal patterns of landslide distribution, type of movement, rate of movement, type of displaced material (earth, debris or rock), volume of materials dislodged, triggering factors, run out distance, location, date of occurrence, nature and extent of damages and probable causes. Landslide data of inventory are obtained through field survey mapping, historical records, satellite images and aerial photo interpretation. Landslide inventory plays significant role in landslide hazard assessment. The quality and the completeness of landslide inventory influence the reliability of landslide investigation (Pardeshi, 2013).

Further, the analysis of landslide inventories is an indirect and qualitative approach which attempts to predict future patterns of instability from the past and present distribution of landslide deposits (Gemechis Chimidi et al., 2017). This is accomplished by preparing landslide density (''*ISO-Pleth*'') maps, i.e., maps showing the number or percent of the area covered by landslide deposits over a region. The landslide inventory is by far the most important, as it should give insight into the location of landslide phenomena, failure mechanisms, causal factors, frequency of occurrence, volumes and the damage that has been caused (Jordi et'al., 2013). The landslide Inventory mapping technique forms the basis for another landslide hazard zonation mapping techniques.

***b) Heuristic approach**:* The heuristic approach (expert evaluation), mostly qualitative method, that depends on how well and how much the investigator understands the geomorphological processes acting upon the terrain (Guzzetti et al., 1999). It is only based on quasi-static variable to classify landslide hazard (Dai and Lee 2001). Heuristic approach takes into account a hierarchal level and different method for determining weight factors. Next, the hierarchical heuristic model becomes a part of decision support system (DSS) which aims for spatial decisions (Castellanos and Van Westen, 2003). This approach can be classified into two analysis, one is a direct mapping analysis in which the geomorphologist determine the susceptibility in the field directly that is directly based on individual experience, and the second one is a qualitative map combination in which the experts uses their knowledge to determine the weighting values for each class parameter in each parameter (Raghuvanshi et al., 2014; Anbalagan 1992; Bonaventura, 2010).

***c) Deterministic approach*:** Application of deterministic models (mechanical numerical approach), requires detailed Geotechnical and hydrological data and the correct knowledge of the failure mechanisms affecting the investigated slopes. Except for failure mechanisms that can be interpreted through infinite slope models, and deterministic models are suitably applied only to small areas, at the scale of a single slope (Raghuvanshi et al., 2015; 2014; Casagli et al., 2004). This technique provide hazard in absolute values in the form of safety factors, or the probability. The deterministic methods are too detailed and can only be applied to individual slopes (Fall et al., 2006). These techniques require detailed slope geometry, geological and geotechnical data sets.

***d) Statistical approach**:* According to Guzzetti et al. (1999) statistical approaches are based on the analysis of the functional relationships between instability factors and the past and present distribution of landslides. The statistical methods for LHZ can be grouped into two, those are bi-variate statistical analysis and multi-variate statistical analysis. The bi-variate statistical analysis for landslide hazard zonation compares each data layer of causative factor to the existing landslide distribution, whereas multi-variate statistical analysis for landslide hazard zonation considers the relative contribution of each thematic data layer to the total landslide susceptibility (Pardeshi, 2013). However, all the above listed LHZ mapping techniques have their own advantages and disadvantages. For example; heuristic and statistical approaches require the collection of huge amount of data to produce good results and also, contribute in determining the ratings of the factors. The main problem of heuristic methods is insufficient knowledge about the area of interest, which sometimes leads to unacceptable generalizations and it is subjective to decision making. The mechanical numeric approach has also their on limitation for mapping the landslide hazard area. It requires detail Geotechnical and hydrogeological data analysis and it only covers a small area. Each of these approaches has its own advantages and disadvantages over others (Raghuvanshi et al., 2015; 2014; Fall et al., 2006; Kanungo et al., 2006; Casagli et al., 2004; Guzzetti et al., 1999; Leroi, 1997). Each of these methods has some degree of uncertainty owing to parameters considered or methods by which parameter data are acquired (Carrara et al., 1995).

C. Methodology followed in the present study

Landslide hazard zonation has been pursued actively since three to four decades. There are at least three main principles/assumptions that have guided all zonation studies as major researchers use as possible as a principle. The Past and Present are keys to the Future principle, long noted generally useful in geology.

It also means that natural slope failures in the future will most likely consider to identify the geologic, geomorphic and hydrologic situations that have led to past and present failures (Raghuvanshi et al., 2015).

Thus, there is a possibility to estimate the frequency of occurrence, extent and consequences of failures that may occur in future.

In essence, the principle is applicable only to the degree of conditions of the past and present.

The second, the basic causes of slope instability are fairly well known for a wealth of case studies of specific failures, some are inherent in the rock or soil, in its composition or structure; some, like the inclination of undisturbed slopes, are relatively constant and some are variable, such as ground water levels, some are transient (seismic vibration) and some are imposed by new events, like human interferences (building, road, dam and others construction, cultivation). In a given area, most of these could be recognized and their effects-rated or weighed; and some could be mapped and correlated with each other with past failures.

The third, degrees of hazard can be estimated**,** when the conditions and processes that promote instability can be identified, it is often possible to estimate their relative contribution and give them some qualitative or semi quantitative measure, place by place.

Thus, a summary of the degree of potential hazard in an area can be built up, depending on the number of failure inducing factors present, their severity, and their interaction. The processing of data, for instance, at this stage can range from very simple and subjective evaluations to sophisticated processing of extensive data banks with the use of modern computers. There is no standardized methodology or techniques for evaluating landslide hazard and landslide hazard zonation mapping technique. Different methods and techniques to evaluating landslide hazard have been proposed or practiced still now; for example, SSEP by Raghuvanshi et al. (2014).

For the present study, expert evaluation technique slope stability susceptibility evaluation parameter rating (SSEP) technique proposed by Raghuvanshi et al. (2014) was followed. However, the original rating criteria of SSEP were modified through statistical approach in the present study. As a general methodology for SSEP technique, first of all the areas of slopes to be covered has to be divided into individual slope facets. Slope facet is characterized by more or less uniform slope inclination and slope direction (Anbalagan, 1992).

The detail methodology followed during the present study is presented as a flow chart (Fig. 2.1).

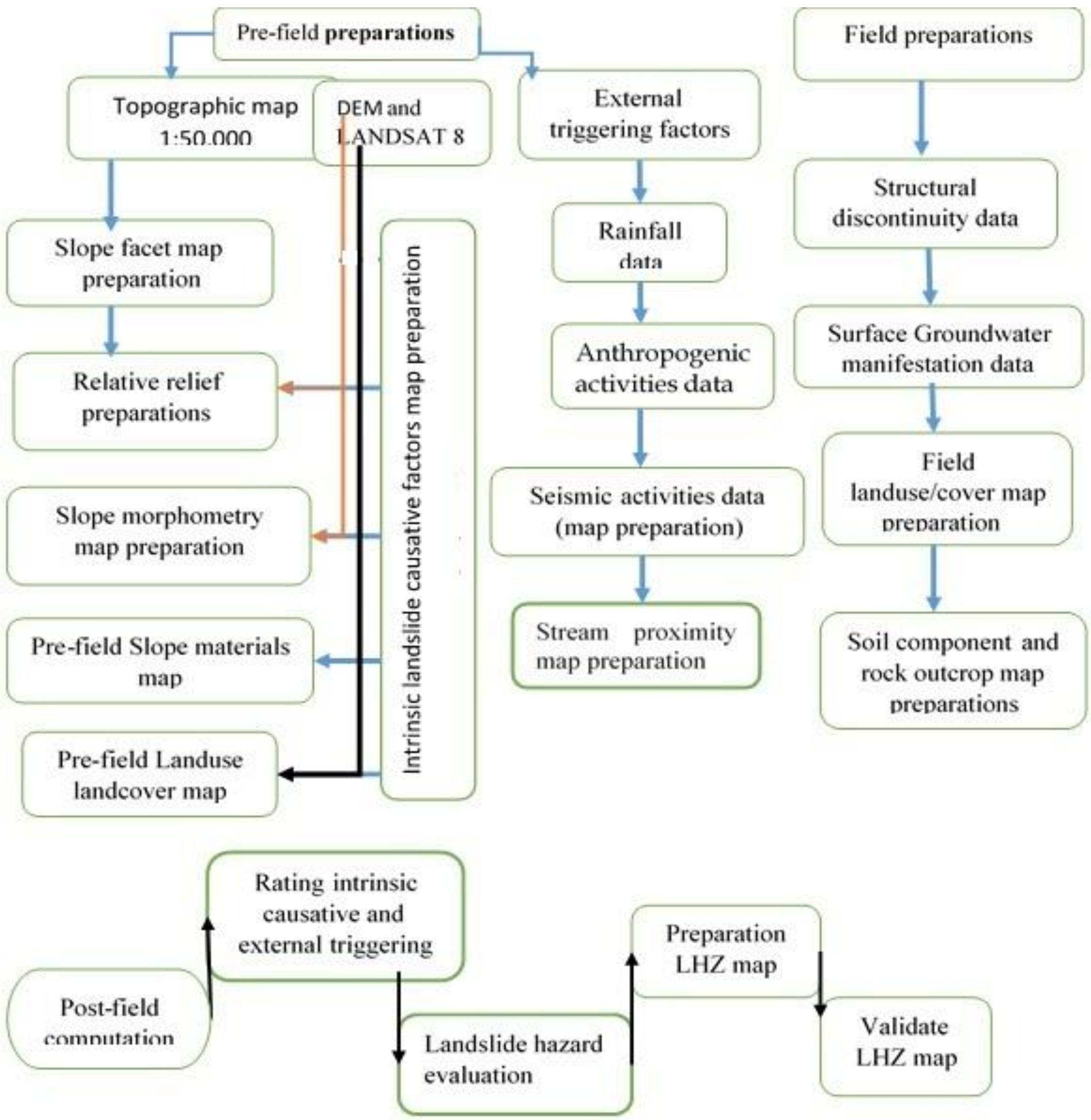

Fig. 2.1 Summarized description of the methodology adopted in the present study (after: Raghuvanshi et al., 2014).

III. GEOLOGICAL SETTINGS

A. Regional geology

The geology of Ethiopia underlies by rock types which range in age from Precambrian to Recent (GSE, 2015) and Ethiopia is blessed by the three rock types. These rocks are categorized into three general groups based on their geological time periods; these are Precambrian rock, Paleozoic: Mesozoic sedimentary rock and Cenozoic volcanic rock (GSE, 2015). The description is as follow;

B. Local geological setup

In this section, the local geology of the study area is presented and the description of the various rock units outcropping in the specific study area is also presented. Two out-cropping lithological units in the present area of study are; namely, Alaje Formation and Tarmaber basalt. Besides, other units present are; alluvial, colluvium-eluvium soils with minor agglomerate (Fig. 3.4) are observed.

a) Alajie Formation

The rocks belonging to Alajie Formation are present in the North-east, south east and southern parts of the study area. These rocks consist of alternating layers of basalt, rhyolitic or trachytic ignimbrites as well as tuffs and agglomerates of different volcanic material (Alajie Formation). These rocks are present in relatively gentle sloping areas.

The ignimbrite forms gentle to steep cliffs, elongated ridges and sporadically distributed isolated hills. It is medium to coarse grained, light/ bluish/ brownish gray to gray (fresh color) to dull/dark gray (weathering color), highly consolidated to shattered rhyolite with altered tuff vertical and horizontal joints, and fractures. It contains rock fragments of trachytic ignimbrite, and vertical joints and overlay by intensively fractured basaltic Alajie Formation rock in a specific area, whereas the exposed volume of rock fragments significantly varies from place to place.

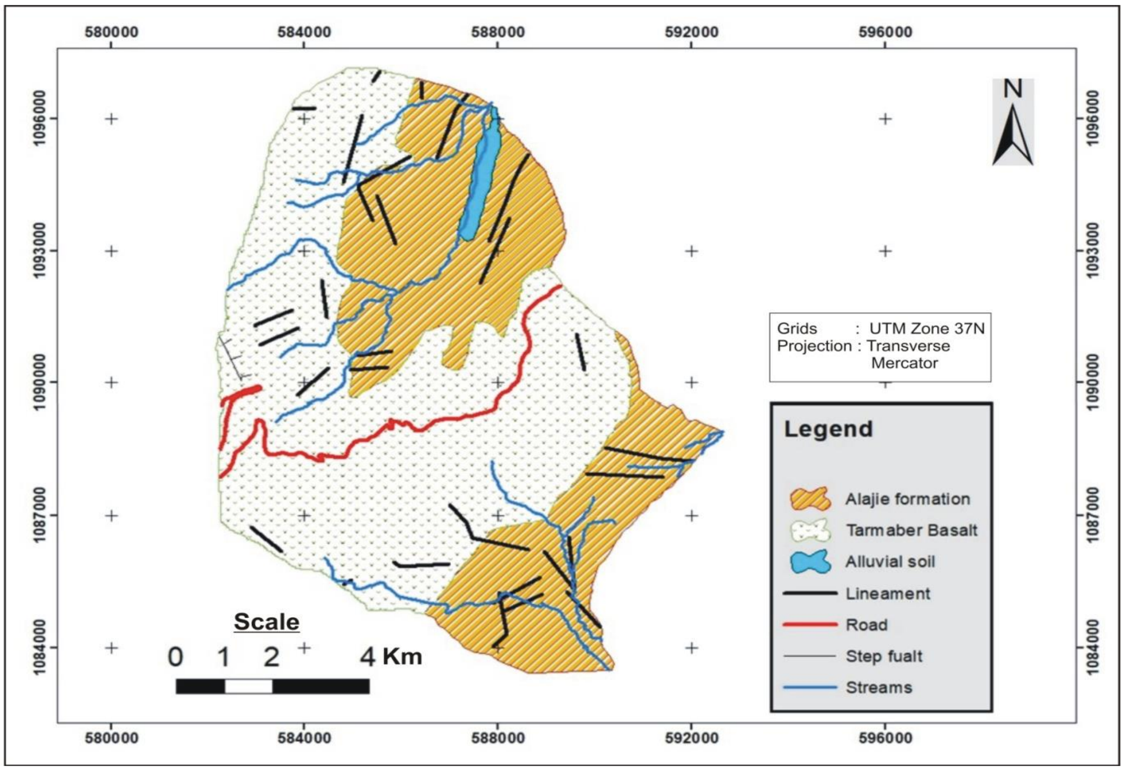

Fig. 3.1 Local geology map extract from 1:250,000 scale Debre-Birhan geology (source: GSE, 2010).

The aphanitic basalt is fine grained, black/dark/gray, irregularly fractured, slightly jointed, slightly weathered and rarely shows a massive appearance that forms a steep morphology.

The moderately weathered rhyolite in 'Nib-Amba' locality shows paleo soil which can facilitate the landslide movements in an expected time. Both the paleosoil and the moderately weathered acidic rocks are decreasing its thickness by falling and erosion of rock fragments and soil particles. The tuff is forming mostly gentle slopes and flat topography. It is white, light yellow, pink and light brown (fresh color) to red, yellowish gray and black (weathering color) and mostly exposed near to the streams and it is susceptible to weathering when the stocks move over it in dry season, and during rainy season due to slope erosion.

Rock and soil sliding are also observed in this lithology. The ignimbrites and tuffs of Alaje Formation, in particular, are highly altered and highly weathered in the present study area.

b) Tarmaber basalt

Tarmaber - Megezez basalt is dominantly exposed in the north-northwest (NNW), west (W), central and south-western (SW) parts of the present study area including its exposures in Debresina town. It forms a series of linear ridges and high/sloppy mountains. It has sharp contact with the underlying Alajie trachytic ignimbrite. The rock is covered by black colored clay soil in different linear ridges or relatively flat topography areas.

The Tarmaber-Megezez basalt includes fine (similar to Alaje basalt formation), medium to coarse grained, dark gray (fresh color) to light/ reddish/ dark/ brown (weathering color) and aphanitic to porphyritic basalts. It is characterized by different phases of basaltic flows separated by randomly exposed reddish palaeo soils and reddish brown scoriaceous basalts. It is dominantly represented by plagioclase phyric varieties (plagioclase phyric and olivine-plagioclase phyric basalts) together with minor olivine phyric, pyroxene phyric, plagioclase-pyroxene-olivine phyric and aphanitic basalts. Plagioclase phyric basalt is the most abundant rock type and mostly occupies the highlands of DebreSina (GSE, 2010).

c) Quaternary sediment

The slopes with lower inclination are covered by Quaternary sediments. The major quaternary sediments that are observed in the study area are alluvial, eluvium soil, colluvial-eluvial deposits and residual soils. The definition and their descriptions are presented in the following paragraphs;

1) Alluvium soil

The alluvium soil is found in the north eastern and southern parts of the study area with relatively very small distribution in the area. The deposition of alluvial is mostly found along the main streams especially, along the Tikurit, Koda Menkeria and Wanzaberet streams. Alluvial soils are formed by different grain size materials (fine to coarse based on transportation force) that are transported over a long distance from its original place by transportation agent such as water. It consists of dominantly fine to medium sand, gravel deposits covered by rare bushes. Fine to medium sand is the most abundant material that covers majority of the area.

Gravel is found in small valleys and gorges (streams). It consists of rounded to sub rounded shaped basaltic boulders. It is derived from the weathering, transportation and reworking of different rocks from the plateau, escarpment and also from the rift area. This indicates that the streams that initiate their flowing from the sloping land are very rich in debris and are with erosive power damaging farmland and other infrastructures.

2) Eluvium Soil

The eluvium soil is mostly found on the plateau and the escarpment of the study area and near to the cliffs, occupying flat and gentle topography. It is formed by the gradual weathering that are derived by in situ weathering or weathering plus gravitational movement or accumulation, of the basalt, ignimbrite (rhyolite) and previously formed soils. There are mixtures of rock fragments of basalt, ignimbrite and rhyolite within the eluvium soil. It is silt to clay sized, light/dark gray to reddish brown fertile soil. It is found in some localities with variable thickness (2-4m). It forms the agricultural land and is used for the cultivation of different cereals, vegetation and fruits.

3) Colluvial-eluvium deposit

The colluviums - eluvium is found at the foot of the stepped cliffs, ridges and flat hill tops and it is distributed relatively over a wide area. These soils are mixed and loose sediments deposited by old landslide, reworked breccia, and sheet floods consisting of fine to boulder sized soils. Most of the time, similarly to eluvial soil, these soils also form cultivable lands. More or less the seepage and/or springs that drain from the highlands disappear in to these thick colluviums and it reappears in the lower morphological breaks or through the stream banks. The colluvium is the most susceptible soils in the study area that results in to both reactivated and new landslides. All soil deposits, found in the present study thickness is variable from place to place. In a specific area the thickness of the soil deposit is thick up to 10m especially, southern, southeastern and central parts of the study area.

Generally, all quaternary sediments found in the present study area are prone for erosion activities and covers 73.8% of the area including residual expansive soil. These quaternary sediments are susceptible for gully erosion, stream bank erosion and slope toe erosion.

d) Geological structures of the study area

Based on the field observations, the principal geological structures that are widespread in the study area include; joints, lineament, surface cracks and faults. These structures create planar weakness surfaces that may give rise to the formation of potential slip surfaces if they are kinematically inclined towards the valley.

1) Lineaments

Based on the digital elevation model (DEM) and the field observation, different lineaments with variable strike length were recognized in the present study area. The most abundant and prominent lineament trends are NW-SE, E-W and NE-SW directions.

2) Fault

The study area is found on the western escarpment of the main Ethiopian rift valley (MER) which is considered as high seismic risk zone. The major faults on the western boundary of the rift can have occasional earthquake tremors leading to activation of unstable ground (Leta Alemayehu et al., 2012). Consequently, the region is more prone for tectonic activities. Based on the field observations and the digital elevation model (DEM) analysis is similar direction step fault was recognized which is a set of parallel, closely spaced faults, oriented in NW – SE, in the western part of the study area, near to Debresina.

3) Joints and Fractures

Joint sets with variable orientation and irregular fractures (few mm to cm in width) were observed in the study area. These joints have a significant variable strike length. Mostly in the silicic rock (rhyolite) differently oriented sets of joints were observed.

4) Surface crack

Surface cracks are common in weathered rock units and clay soil in the study area. Such surface cracks were observed in abundant loose rocks and/or soils and in debris mixture, particularly where vegetation is sparse. This type of surface cracks is abundant in the weathered rhyolite unit and clay soil, especially in the southern, central and north eastern parts of the study area. Surface cracks are abundantly found near to the streams and gully with clay soil coverage. As reported, the cracks in the soils are formed in the dry season. This indicates that the area which is covered by clay soil and weak Alaje Formation rocks is prone for cracking in the dry season. Besides, during intensive rainfall these areas are prone for landslides.

5) Structural geological Discontinuities

Discontinuities with different orientation were observed in rhyolite belonging to Alajie Formation. Other discontinuities were observed in Tarmaber and Alaje basaltic Formation with vertical orientation and having different spacing and separations as well as with different structural conditions. Spacing, separation, degree of weathering, infilling materials, soil depths, angle of joint and slope and other related data of structural discontinuities were recorded in the field.

IV. LANDSLIDE INVENTORY

A. Introduction

Landslide inventories are generated around the world at different scales and for different intents, but special efforts are made to critically evaluate landslide inventories prepared using various techniques or by different investigators (Meena et al., 2019). Landslide inventory is the way of the collection of landslide features in a certain area for a certain period, preferably in digital form with spatial information associated with the fix combined with attribute information. Landslide inventories are either continuous in time, or provide so-called event-based landslide inventories, which are inventories of landslides that occurred as a consequence of a particular triggering event (rain, earthquake, etc.) (van Westen et al., 2012). Inventory lists are essential for any other landslide analysis techniques and susceptibility models that predict landslide on the foundation of past weather. Techniques used to arrange landslide inventory maps depend upon the standard and availability of desired information, the scope and the extent of the survey area, the scales of base maps and the resources available to sway out the work (van Westen et al., 2012).

A landslide inventory map records the location and, where known, the date of occurrence, the mass of the dislodge, dimension of and the types of mass movements that have left discernable traces in an area (Pasek, 1975; Hansen, 1984a; 1984b; Mc Calpin, 1984; Wieczorek, 1984; Guzzetti et al., 2000; Guzzetti et al, 2012). Therefore, in this segment, the locations and characteristics of landslides in the present study area is presented through Fig.4.1. The map was developed by incorporating all slope failures investigated/ identified in the recent field surveys and through Google earth image interpretation.

B. Landslide distribution in the present study area

Because landslides are complex phenomena, determining the spatial and temporal extent of the resulting hazard requires identifying those areas which are, or could be, affected by a landslide.

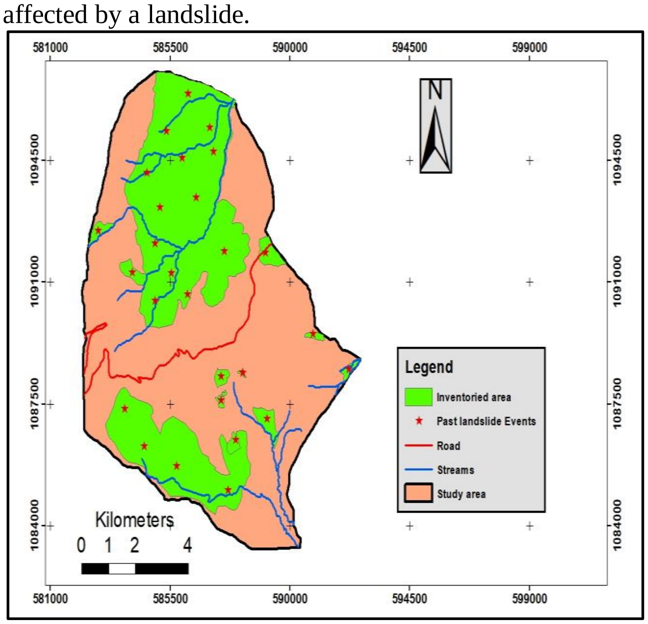

Fig. 4.1 Landslide Inventory map of the present study area

In the present study area, the spatial distribution of landslide clearly reflects internal causative factors and external factors; particularly, type of slope materials and seismic activity. Among the total number of slope instability processes identified and mapped in the study area, about more than 75% of the landslides were found in the north, northeast and south-southwestern parts of the study area (Fig. 4.1). In these areas the curvature and hydro-geomorphic slope is dominantly characterized by convergent or concave hill-slope. Therefore, northern, northeastern and south-southwestern parts of the study area appear to be the least stable areas because it concentrates surface and subsurface water into small areas of the slope, as shown in Fig. 4.1.

The remaining 25% identified landslides are distributed towards the northwestern, east and the central parts of the study area (Fig. 4.1). In these areas the intermittent streams has increased the slope angle and have caused slope instabilities. This scenario is clearly noticeable along the sides of the streams where the risk of landslide occurrence has increased. The factors that have influenced in this regard are; (i) intense rainfall and the presence of thick soil mass, (ii) densely cultivation near and at the top or side of the slopes, (iii) Gully erosion down the slope, (iv) slope erosion, (v) lack of dense vegetation on the side of the stream, (vi) deforestation of the area (vii) gravel road construction over landslide susceptible areas and (viii) high stream bank erosion.

Thus, based on landslide inventory survey, six types of landslides were identified in the present study area. These were further classified according to their failure mechanism namely; debris flow, earth flow, translational, spreading, rock fall and complex modes of failure. Out of total 27 past landslides that were recorded in the study area, 37% (10) as complex type of failures, 18.5% (5) were recognized as debris flow, 18.5% (5) as translational slide, earth flow 14.8% (4), fall 7.4% (2) and the remaining 3.7% (1) is spreading. The total coverage area in which landslide inventory was made accounts to 34km^2 (Fig.4.1).

C. Types of landslides in the study area

The geological and geomorphic conditions in mountainous environment along with the precipitation and human activities as well as stream proximities may influence significantly the landslide occurrences. It was observed that the streams in the present study area have shattering the failed slope material and carried it to long distances. Further, it has resulted into alluvium soil deposition. In brief, material in a landslide mass is either rock or soil (or both); the latter is described as earth if principally composed of sand-sized or finer particles and debris if composed of coarser fragments (USGS., 2008). The type of movement basically describes the actual internal mechanics of how the landslide mass was displaced.

a) Rock falls

The various types of landslides as observed in the present study area were grouped into four different types according to the material and the type of movement. For this purpose classification system developed by Varnes (1978) and later modified by Cruden and Varnes (1996) was followed. These include: (a), rock falls; (b), soil slides; c), spreading flows.

A rock fall (Whittow and John, 1984) is quantities of rock falling freely from a cliff face. A rock fall is a fragment of rock (a block) detached by sliding, falling or toppling, that falls on a vertical or sub-vertical cliff, proceeds down slope by flying and bouncing along ballistic trajectories or by rolling on talus or debris slopes (Varnes, 1978). The volatility of the frequency and magnitude of rock fall potentially endangers human lives and infrastructure. In the present study area, rock-fall is a frequent occurrence activity in the northern part. Even during the field work, rock fall activities were observed occurring randomly in highly fractures rock unit. However, in addition to rock falling there was dry soil sliding in a vertical manner with the same surface of rock fallings. Plate 4.2 presents some of the rock fall and dry soil sliding activities as observed in the study area.

b) Slides

In the present study area, translational soil/rock slides, and debris slides were observed. Most of the parts of the slope that is near to the stream and exposed to gully erosion have failed in a similar manner. gives idea about the translational soil slides occurring on the flat arable land in the study area.

A) Rock fall; B) Slide (translational slide); C), Debris flow, and (D) & (E) Earth flow

Plate 4.1 Types of landslides as observed in the study area

c) Lateral Spreads

Lateral spreads are distinctive because they commonly take place on very gentle slopes or flat terrain. The dominant mode of movement is a lateral extension accompanied by shear or tensile fractures (USGS, 2008). This phenomenon has caused the road to move outward towards the south. The possible reasons for this may be related to the over loading due to vehicles, ground motion, saturation, spring flow and loose cohesion less sediments under the asphalt.

d) Flows

Flows are most common and they often occur due to different mass movement activities as observed in the present study area. The main type of flows observed during the field work in the present study are debris flows and earth flow. As reported by the local respondent earth flow and debris flow frequently occur during the rainy season. These flows mainly erode the arable land, graze land and others economic lands in the area. As a result, the locals residing on such land are at risk in the present area.

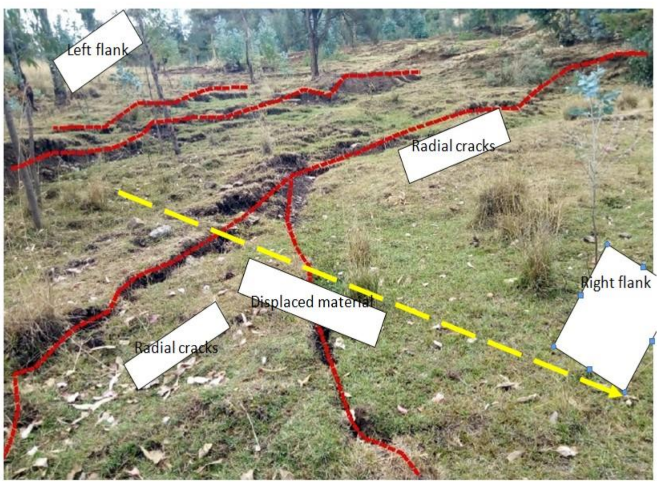

Plate 4.2 Translational slide as observed in the study area

The northern part of the present study area that includes Shoteleamba Kebele, Yizaba wein and around Aynemaryamin and in the southern part including Majetie, Atkuar, disk, Ambo and Diskamba localities have deep seated landslides. As observed and confirmed by the local respondents, the deep seated landslides generally extends up to the stream bank and manifest as toe debris slide, debris flow and earth flow.

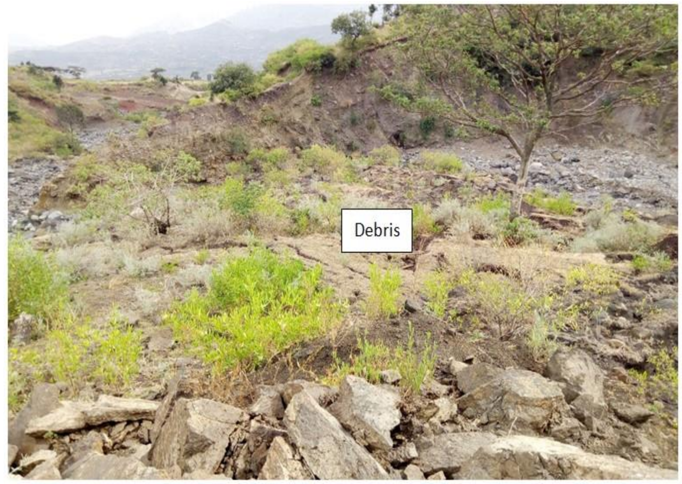

Plate 4.3 Debris flow as observed in the study area

illustrates the deep-seated landslide in Majetie and Diskamba localities of the present study area. This deep-seated landslide is composed of weak materials, rock fragments and unconsolidated sediments. Further, this landslide demonstrates cracking, spreading and a bulged central area. This land is being used for cultivation. As reported by the local respondent that the area was stable and flat land before 1970s.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The present study area is located in the central part of the Northern Ethiopian, in North Showa Zone in parts of the Tarmaber district of the Amhara Regional State. The study area is about 190 km far from Addis Ababa, the capital city of Ethiopia toward the north. The total area covered by the study area is about 92km^2. The area is well known for its landslide hazard and related slope instability problems. Despite the enormous scale of the landslide problem in the study area and related problems not much has been done so far to evaluate the scale of the problem and to workout measures to mitigate the landslide problem in the area. The present research study was thus conceived with an objective to evaluation the landslides in the study area and to prepare a landslide hazard zonation map. In order to prepare the LHZ map of the area, Slope Stability Susceptibility Evaluation Parameter (SSEP) rating scheme proposed by Raghuvanshi et al. (2014) with one additional external factor and little modification was followed. An attempt was also made to modify SSEP technique by integrating it with a statistical hazard index approach and produced a LHZ map with statistically normalized revised SSEP ratings.

For SSEP both intrinsic and external triggering parameters that are responsible for slope instability were considered. The intrinsic parameters that were considered are; relative relief, slope morphometry, structural discontinuity, land-use land-cover, and groundwater surface traces. The external triggering factors that were considered are; rainfall, proximity to streams, seismicity and manmade activities.

Initially, an inventory map was prepared by incorporating the locations and characteristics of all past landslides investigated and identified in the field surveys and through the Google earth image interpretation, as well as those which were registered in the historical and technical documents. Besides, maps were prepared for all intrinsic (except structural discontinuities), and external parameters from various sources and field observations. A facet map was prepared for the study area which was utilized to transfer all required intrinsic and triggering parameter information from various sources including observations made during the field work. Besides, maps on relative relief and slope morphometry were prepared by using ASTER data (30m resolution DEM). The land-use and land-cover map was produced by supervised classification by using LANDSAT 8. The proximity to stream map was prepared by using topographical maps and digital elevation models (DEM) with 30m resolution. All parameter maps, facet map and map of past landslide activities were processed and brought to the GIS environment for further processing and analysis.

In the present study initially LHZ map was produced by utilizing the SSEP subjective rating scheme. Thus, for the purpose of LHZ map preparation, numerical ratings were directly assigned facet wise based on the observations for each parameter sub class. These ratings were assigned to each of the intrinsic and triggering parameters based on the conditions present, as observed on each facet individually. Later, the sum total of all ratings for intrinsic and external triggering parameters provided evaluated landslide hazard (ELH). These ELH values for each facet made the basis to produce the LHZ map.

The ratings assigned to various parameters in SSEP are based on the experience and relative contribution of each factor in inducing instability to slopes. Thus, it was realized that a certain degree of subjectivity exists in SSEP rating criteria. In the present study, therefore, attempt was made to evolve statistical relation between past landslides activities in the area and each of the factor class so that a hazard index can be determined. By using this hazard index for each parameter class, the corresponding SSEP ratings were corrected. Thus, in an attempt to modify SSEP rating criteria two LHZ maps were thus produced so that a comparison can be made between the LHZ map produced from original SSEP criteria and LHZ map prepared by statistically modified SSEP criteria.

B. Recommendation

To mitigate the effect of landslide in the study area it is recommended that slopes must be provided with vegetation cover this will minimize the problem of gully erosion and with strengthen the slope material. Besides, arrangements of proper drainage and directing surface water flowing away from the landslide should also be made, particularly in landslide prone areas. Also, along the road cuts and the stream banks proper slope protection works should be provided. This may control the problem of soil or rock slide, debris flow and slope toe erosion.

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