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Research Paper

Assessment and mitigation of slope stability hazards along Kombolcha- Dessie road- statistical approach.

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Abstract: *The Kombolcha to Dessie Road, linking Addis Ababa with Northern Ethiopia towns traverses through one of the most difficult mountainous ranges in Ethiopia. Slope instability problems in the form of rock fall, rotational failure of colluvial material and debris slides are the common events in the area on the sides of the main road. The presence of loose unconsolidated materials (colluvial materials), highly weathered and fractured basalt rocks high relief, steep natural slopes, nature of geologic formations exposed along the road section, poor drainage conditions, occurrence of high seasonal rains, and seismically active. Slope instability along Komobolcha and Dessie Road is becoming serious problem due to thepresence of loose unconsolidated materials (colluvial materials), highly weathered and fractured basalt rocks, high relief, steep natural slopes, nature of geologic formations exposed along the road section, poor drainage conditions, occurrence of high seasonal rains, and seismically active nature of the region. For these reasons, present study was conceived and detailed slope stability analysis of selected critical slope sections was made nature of the region created favorable condition for slope instability in the area.*

Key words: *Rock fall, Debris slides, Basalt rocks, High relief, Steep natural slopes, Poor drainage.*

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I. INTRODUCTION

1.1 Background

Slope stability problems and associated catastrophes have been faced throughout history when human or nature has disrupted the delicate balance of natural soil and rock slopes (Abramson, 2001). Although, improvement in identification, prediction and mitigation measures is advanced, slope stability problem still triggers economic and environmental crises in mountainous region. This is partly due to the complicity of the processes driving slope failure and our inadequate knowledge for prediction ground condition. Nevertheless, different researchers and experts have been used various slope stability analysis methods and stabilization techniques in order to minimize the problem related to slope failure.

Amongst the several methods, the Limit equilibrium is one of the methods which is most widely used and accepted for analyzing slope stability problems. Therefore, the current study is entirely focused on Limit equilibrium slope stability analysis. For analysis purpose in the present study Slope/W and Slide software has been utilized to analyze the probability of failure along the road cut slopes in the study area. The minimum factor of safety has been computed or calculated by the software's using several parameters and for analysis values were adopted from the soil and rock investigation reports.

terrains experience both deep and shallow excavations in the construction stage, that disturb the inherent nature of rock and soil slopes. Furthermore, rock or soil cut slope along road fail due to various factors such as; seismic activity, high groundwater pressures (after heavy rainfall), geological factors, and human activities can trigger large rock/soil blocks or even larger assemblages of rock to crash down on to the road surface below (Budetta, 2004).

Therefore, assessment of the slope's instability requires comprehensive information about the geology, groundwater, seismicity and engineering geology of the area. Slope stability analysis is often carried out in order to ensure that the analyzed slope can be made safe and probability of slope failure is minimized (Abramson, 2001).

Hence, analysis technique chosen depends on both site conditions and the potential mode of failure, with careful consideration being given to the varying strengths, weaknesses and limitations inherent in methodology (Abramson, 2001). Analyses must be based upon a model that accurately represents site sub-surface conditions, ground behavior, and applied loads (Abramson, 2001).

1.2 Problem statement

Slope failures are always catastrophic due to their large affected areas and great energy, generated by the collapsed soil or rocks with rapid and long run-out movement. This study has very important scientific significance and practical worth.

Most of constructed road in the highland of Ethiopia cross within valleys, hilly and mountainous terrain. Previous studies shown that, the slopes along roads are affected several times by slope instability (landslide) problems (Lulseged Ayalew, 1999; Tenalem Aye new and Barebieri, 2005). The main triggering factors for the instabilities of the areas are the different environmental factors (e.g., intensive rainy summer), variable geological and structural elements (weak rocks, slide debris weak soils, shear zones, and faults) difficult road characteristics (narrow roads with tight horizontal and vertical curvature (Kifle Woldearegay, 2013).

Road plays very important role for development of any country. Kombolcha-Dessie Road is the main route which connects Northern Ethiopian cities (Mekelle, Aksum, Dessie and others) with capital city of Addis Ababa. Like other roads and highways that were constructed on highland areas, the road cut slopes of study area are very susceptible to failures especially during rainy season. The rock falls, debris flows and colluvial material slides hinder the traffic along these road sections. Therefore, in order to provide a safe access for transportation and economic development the proper functioning of this road is very essential. Indeed, construction of road is often accompanied with rock and soil slope cut. For that reason, the stability of the slope is always of paramount importance during the lifetime of the structures (Tenalem Ayalew et al., 1989).

Due to slope instability problem Ethiopian Roads Authority (ERA) used different remedial measures (retaining wall, surface drainage and gabions) in order to prevent damage along the road. Even though, counter-measures applied on some of the critical portions of road cuts, but most of slopes are not mitigated and analyzed. The current study has embarked on a comprehensive evaluation of the stability of all cut slopes along road, with a major objective to identify the most hazardous zones. Besides, the present study is also forwarding the general remedial measures which may be adopted to minimize or to eliminate the possible hazard along the road. This will be accomplished by using different methodologies and techniques based on slope stability result and site conditions.

1.3 Objectives

1.3.1 General objective

The general objective of the present senior project is to identify critical slopes in the study area and to conduct a detail slope stability analysis on selected critical slope sections along the Road, and to evolve appropriate mitigation measures for the potentially unstable cut slopes.

1.3.2 Specific objectives

Delineation and identification of the critical road cut slopes along the road section.

Determination of the Geotechnical and Engineering geological properties of the soil rock mass along critical slope section.

To prepare cross sections along critical slope sections and to deduce slope geometry and geological sections.

Conducting slope stability of critical slope sections along the road for anticipated and adverse conditions.

To develop mitigation strategy for each section of the road and to suggest alternative solutions and designs to minimize future problems.

1.4 Location of the study area and Accessibility

The study area is located in the in Northern Ethiopia, Amhara regional state along Kombolcha to Dessie Road. It connects Northern Ethiopian cities (Mekelle, Aksum, Dessie, Kombolcha and other with capital city of Addis Ababa.

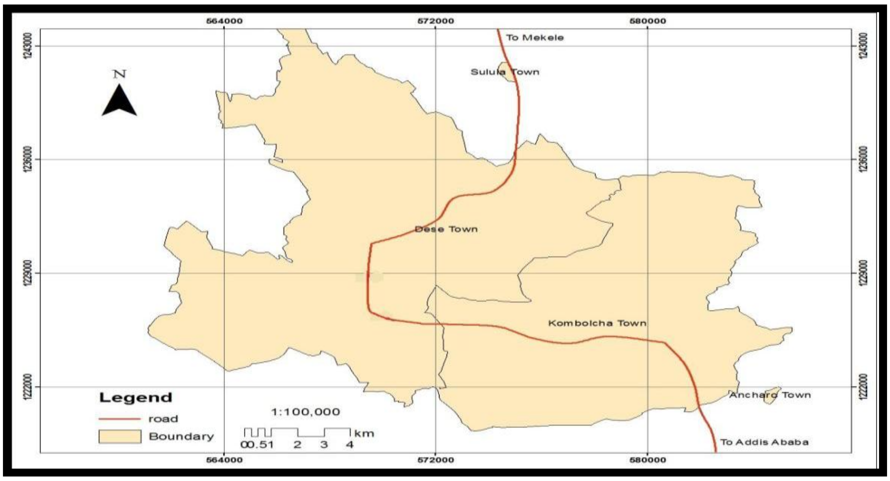

Figure 1: map of study area

1.5 Geology of the study area

The study area comprises different types of lithology such as: Tertiary Trap Series volcanic, Quaternary alluvial–colluvial deposits, and residual soils. Gregnanin et al. (1978) identified the following lithological units as cited by Tenalem Aye new and Barbieri (2005). GSE, (2010) has also prepared a new geological map of the study area.

Quaternary deposits (Colluvial, alluvial and lacustrine)

These include alluvial and residual soils, colluvial or talus deposits, and patchy lacustrine deposits. Alluvial deposits are restricted to low-lying areas close to river courses and deeply incised gullies in the central part of the area. They consist of cobbles and gravels of basaltic origin with a matrix of silty clay soils. The river beds are made of big boulders and cobbles. Residual soils are mostly humus-rich and are underlain by extremely weathered basalt converted to silty clay and clay soils followed by moderately weathered basaltic rock, at places associated with volcanic pyroclastic materials and thin layers of volcanic ash. Colluvial or talus deposits form small fans at the feet of hills and steep slope areas to the south, east, and west. The talus material is often big blocks of basalt associated with weathered friable loose basaltic material that fell from the steep cliffs. Fine-grained lacustrine deposits are confined in the central part of the city of Kombolcha and Dessie. Generally, this chapter emphasize on, types of slope failure, factors that affect slope stability, slope stability analysis methods and different type of slope stabilization methods used currently.

Dessie basalt formation (Stratoid and degraded basalt) Stratoid or layered basalt covers most western part of the study area and is often inter bedded with thin paleo soil horizons; in places, vesicular basalts overlie the stratoid basalt.

1.5.1 Climate condition

Examining the variability of climate that is responsible for the coming effect on an area needs the knowledge of the climatology of that area. This means knowing the long-term mean values of climatic parameters such as; temperature, rainfall, etc. and their degree of variability or deviation from the mean is very important (Guzzetti, et al, 2008). The climate of study area is sub-humid to humid with average annual rainfall of 1385 mm, which is quite high compared to many places in the north-western highlands of Ethiopia (Gebreslassie Mebrahatu, 2011). The long-term average annual temperature of Dessie varies from 12 to 18 °C (Gebreslassie Mebrahatu, 2011). Geographically the area is in bounded between UTM 37 N coordinates of 11° 5' 28'' N to 11° 10' 20'' N latitude and 39° 36' 49'' E to 39° 40' 40'' E longitude. The graph, (Fig.1.2) shows that, from June to September rainfall is high. The road cut slopes become very susceptible to slope instability problems during these months.

1.5.2Physiography and drainage patterns

The study area is generally characterized by highly variable topography features and complex geology, which reflect of the past geological and erosion process. The landscape includes plateaus, steep hill slopes, and deeply incised valleys and gorges. Much of the elevation of the area ranges from about 1800 to 3500m above sea level. Many of the hill slopes are steep enough to reach the limit equilibrium state, whereby external factors such as rainfall infiltration and/or excavations (artificial or natural) could trigger slope failures. The drainage shows well defined with parallel to sub-parallel patterns developed along joints of hard rocks (Tenalem Ayalew et al., 2009).

1.6 Significance of the study

The pervious landslide events were very devastating and it has severely influence transportation activity. In 1977, two people were killed by a seismically induced landslide (Gouin, 1979) and in 1994, landslides triggered by heavy rainfall blocked a segment of the road and destroyed a bridge and buckled the foundations of several houses. Kombolcha to Dessie Road links many important towns of Northern Ethiopia to the central Ethiopia. It has long-drawn-out slope instability problems. Therefore, the present study is very important from the point of view of identifying and understanding the possible causes of the slope instabilities along the road.

In addition to identifying the slope instability causes in the present study an attempt was also made to delineate the areas which are potentially susceptible for future slope problems. Furthermore, for those slopes where the results of the stability analysis indicate that the roadway slope do not meet the factor of safety requirement, both preventive stabilization and remedial measures are suggested on the potential unstable slope sections.

1.7 General outcome of the study

In the present study firstly, it was intended to identify the various causative and triggering slope instability factors and secondly, to achieve the landslide hazard zonation of the study area. Understanding the causative and triggering factors responsible for slope instability may give an insight into the possible mechanism of landslide in the area which may probably be helpful in evolving the possible remedial measures. The Landslide hazard zonation map of the present study area may further help the administrators and planners to take decisions on safety of local people and property. Besides, it may also guide them to locate safe sites forany future developmental activities.

II. LITERATURE REVIEW

2.1. Landslide: an overview

Landslide is a worldwide problem which causes much casualties and economic losses. It is also recurrent and devastating hazard in the highlands of Ethiopia. Therefore, many research studies have been conducted on landslide related issues in the world as well as in Ethiopia in this chapter literature review about the causes of slope instability, classification and types of landslides, different techniques of landslide hazard zonation mapping, and previous landslide studies in Ethiopia and around the present study area has been presented.

Landslide has been defined as a term which comprises almost all varieties of mass movements on slopes, including rock falls, topples, and debris flows, that involve little or no true sliding (Varnes, 1984). It is also defined by WP-WLI (Working Party for World Landslide Inventories), (1993) as a movement of a mass of rock, earth, or debris down a slope. Slope failures (i.e., landslides) occur when the forces generated by the weight of the soil in a slope exceed the shear resistance (strength) of the soil. The force that is responsible for the occurrence of landslide is gravitational force. Gravity is the force that pulls everything towards the center of the earth. Therefore, materials which are on slope are more susceptibility to force of gravity, which causes landslide, than material which is on relatively flat areas (Nelson, 2010). There are many forms of slope failure and it will depend on the types of slopes. For existing slopes, the stability of a slope needs to be analyzed as soon as soil or rock movement in slope is detached.

Gordon and Griffiths (2005) stated that the failure prediction of a soil and rock slope has been long standing geotechnical problems, which attracted a wide variety of solutions. The primary objective of a stability analysis is to determine the factor of safety (FS) of a particular slope, to predict when failure is imminent, and to assess remedial treatments when necessary. Therefore, to apply slope stability principles properly, geology, hydrology and soil and rock properties should be understood well. Site conditions must be applied precisely to the model for analysis.

Engineering judgments must be based on assessing the results of analyses considering acceptable risk or safety factors (Abramson et al., 2001). Nowadays, slope stability analyses are performed by computers and no longer by hand calculations. Several slope stability computer programs are available from public or commercial domains. In the present study, both Slope/W and Slide software were used for the analysis and determination of Factor of Safety (FOS) of slope stability for critical slope sections.

2.2. Types of landslides

Varnes (1978) identifies types of slope movement as falls, topples, slides (rotational and translational), lateral spreads and flows as elaborated below; Fall

Fall, the most rapid type of landslide, originates on cliffs or steep slopes and drop vertically or at a sharp angle. Falls can range in size from a small stream of dirt or pebbles to sudden shearing of a massive section of rock face. According to USGS (United States of Geological Survey) (2004) fall are abrupt movement of masses of geological material, such as rocks and boulders that become detached from the steep slopes or cliffs.

Delano and Wischusen, (2001) added on the susceptibility of rock fall in an area as; rock fall depends mostly on the spacing and orientation of fractures, bedding, and other discontinuities in the rock. Stream banks, highways, and railroad cuts, old mine and quarry areas and other human – made steep slopes are typical settings of rock fall.

Figure 2: FALL

ToppleToppling is the forward rotation out of the slope of a mass of soil or rock about a point or axis below the center of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by material up slope of the displaced mass and sometimes by water or ice in cracks in the mass" (Varnes, 1996)

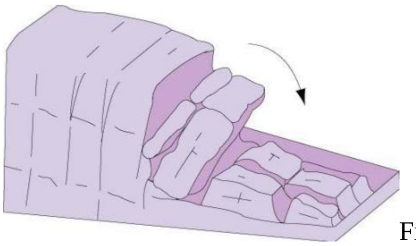

Figure 3:TOPPLE

Slide

Slide is mass movement of soil or rock that occurs as a coherent unit by slipping along one or more failure surfaces. 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 back ward tilting.

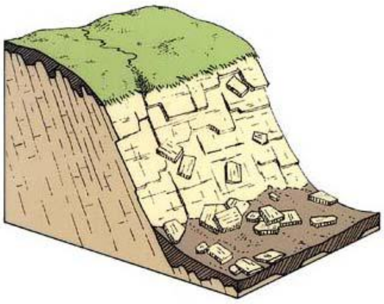

Figure 4:slide

Slump

Slump is a slide having a down ward rotational component along a concave shear surface such that the horizontal movement at the base of the slide zone is greater than that at the top.

Slumps, most commonly are caused by (i) increased moisture content, which decrease strength; (ii) removal of support at the toe of a slope (iii) adding material at the top of the slope; (iv) construction of a cut or filled slope that is too steep for materials involved to be stable. Slump failure commonly occurs in thick, uniform soils and weathered rock, but it may occur also in bed rock hilly planar surface with little rotation or back ward tilting.

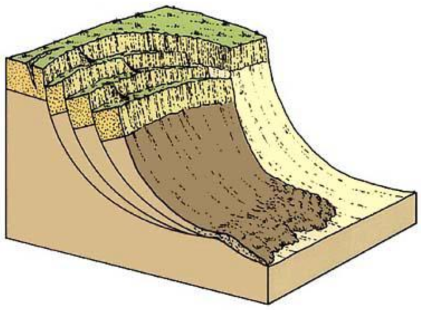

Figure 5: slump

Flow

Flow is a mass movement whose internal structure has become disaggregated, chaotic and turbulent. The rock and /or soil involved in a sediment flow are mixed with water or air which imparts a lubricating effect to the flow. Sediment flows are further categorized as granular flows if they contain both granular flows and slurry flows can entrain debris as they progress down a slope or channel; if sufficient foreign material is accumulated, the flow may be termed as debris flow. According to USGS (2004) there are five categories of flows that are different from one another these are; less than about 20 percent water and slurry flows if they contain between 20 and 40 percent water.

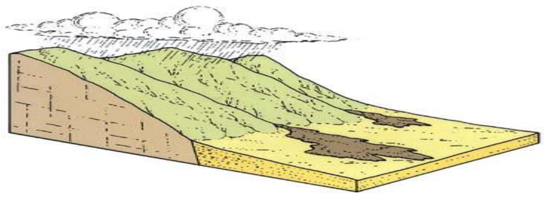

Figure 6: flow

Debris flow: - which is a rapid mass movement which is a combination of loose soils, rocks; organic matter, air and water mobilized as slurry that flows down the slope.
Debris flows are commonly mobilized from other types of landslides that occur on steep slopes, are nearly saturated and consist of a large proportion of silt- and sand- sized material.
(ii) Debris Avalanche: -this is a variety of very rapid to extremely rapid debris flow.
(iii) Earth flow: - This kind of flow is elongated and usually occurs in fine – grained materials or clay bearing rocks on moderate slopes and under saturated conditions.
(iv) Mud flows: - It is an earth flow consisting of materials that are wet enough to flow rapidly and that contains at least 50% sand, silt and clay-sized particles.
(v) Creep: - It is the imperceptibly slow, steady, down ward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation but too small to produce shear failure. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles, or fences, and small soil ripples or ridges.

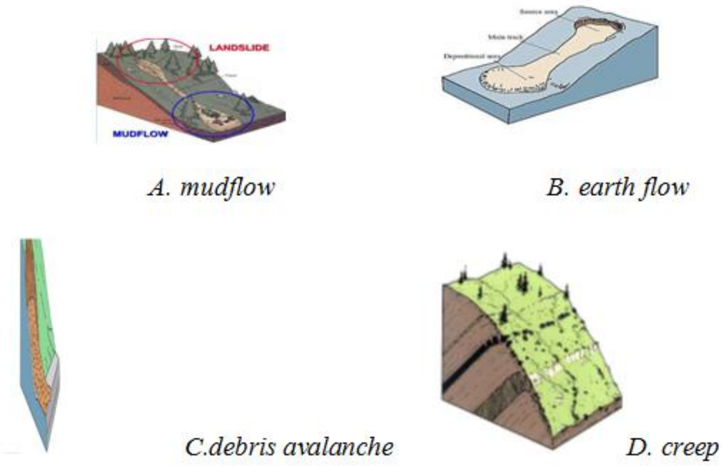

Figure 7: A. mud flow B. earth flow C. debris avalanche D. creep

2.3. Factors influencing slope stability

Force of gravitythe primary factor influencing shear stress is the pull of gravity. Its influence on slope stability is related to the slope gradient. The forces of gravity can be resolved into two components: a component acting perpendicular to the slope and component acting tangential to the slope. On a steeper slope, 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 affected by steep slope angles which increase the shear stress and reduce shear strength. Shear stress of a material can be promoted by undercutting, mining activity, tectonic tilting and removing of lateral support. Shear strength is governed by inherent factors of rock or regolith such as; angle of internal friction, cohesion and binding action of plant roots between particles.

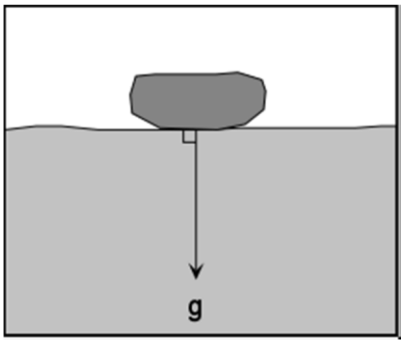

Figure 8: force of gravityHydrologic factor

Water plays major roles in both solid rock and soil mass. Water can reduce shear strength and thereby promoting the movement of rocks and sediment down slope under the pull of gravity. Water reduces shear strength by creating positive pressure in the pore spaces of earth materials. Water infiltrating into slope materials can saturates the soil particles at depth by filling the pore spaces. The weight of water lying above creates water pressure that drives soil particles apart (Sidle, 1982).

Slope failures often occur after heavy rainfall over a prolonged time period (Long, 2008). This is a triggering factor which is usually considered for dynamic models of slope failure. Besides rainfall, erosive action of streams also contributes to slope instabilities. Streams erode the lower valley slope by undercutting which leads to increased slope gradient and local slope instability.

Geomorphic factors

Geomorphic factors have significant influence on slope instability initiation. These features are directly related with the topography and slope of the area such as; gradient, aspect and shape of the slope.

Slope gradient; with increasing slope gradient, the shear stress increases due to the effect of gravity thus, down slope movement of material is enhanced. According to Carson and Petey (1970) slope gradient is taken as the main driving forces of mass movement, especially for shallow landslides. In most cases of landslide assessment, slope gradient is taken as main causative factor (Swanston and Dryness, 1973).

Slope stability is affected by many factors. A change in any one or in the combination of these factors can alter the steady state condition of the slope, decreasing its stability and leading to slope failure. When the slope is in a critical state of stability the destabilization can be generated by a relatively sudden triggering event of natural (such as an earth quake, soil saturation) and human events (undercutting slope for construction purpose). The most important factor controlling slope stability is explained here after (Duncan and Wright 2005).

2.4. Landslide causative factors

The environmental factors are a collection of data that are expected to have an effect on the occurrence of landslide, and can be utilized as causal factors in the prediction of future landslides (Raghuvanshi et al., 2014; Van West net al., 2008; A balagan, 1992). The landslide causative factors including slope angle, slope material, aspect, elevation, LULC and NDVI

2.4.1. Elevation

Elevation is a significant landslide conditioning factor because it is controlled by several geological and geomorphological processes (Ayalewet al., 2005). The elevation is considered to be an important causative factor which may possibly affect the slope material by weathering process (Raghuvanshi et al., 2015; Ahmed, 2009).

2.4.2. Aspect

Aspect is defined as the direction of maximum slope of the terrain surface with reference to north (Xuet al., 2012). The aspect of a slope can influence landslide initiation, because it affects moisture retention and vegetation cover, and in turn soil strength and susceptibility to landslides (Raghuvanshi et al., 2015).

2.4.3. Slope angle

Slope angle is one of the major factors in landslide hazard. Slope inclination has direct effect on landslide process because the driving force of mass movement increases with increasing slope; therefore, it is frequently used in landslide zonation map (Ayalew and Yamagishi, 2004; Ayalew et al., 2005). As the slope angle increases, shear stress in soil or other un-consolidated material generally increases. Gentle slopes are expected to have a low frequency of landslides because they possess lower shear stresses associated with low gradients (Raghuvanshi et al., 2015; Ahmed, 2009).

2.4.4. Slope material

Slope material plays an essential role in the slope instability and it is correlated with the properties of the slope forming material. The erodibility of rock is highly influenced by the strength of the rock. Rocks which possess high strength are relatively more resistant to erosion (A balagan, 1992, Raghuvanshi et al., 2014).

2.4.5. Land-use/land-cover

Land-use and land-cover is a key factor for landslide occurrence. Regions with dense vegetation are found to be prone to landslide than sparse vegetation, agriculture and urbanization (Raghuvanshi et al., 2014; Kifle Woldearegay, 2013; A balagan 1992; Varnes, 1987).

2.4.6. Normalized Difference Vegetation Index (NDVI)

Vegetation provides both hydrological and mechanical effects that are beneficial to the stability of slopes, partly due to the root retaining strength and controlling of rainfall runoff movement (Chauhan et al. 2010).

2.5. Landslide hazard zonation approaches

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).

2.5.1 Inventory based mapping approach

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).

2.5.2. 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).

2.5.3. 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).

2.5.4. Expert Evaluation 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 Western, 2003).

III. METHODOLOGY

3.1. General

Several approaches have been developed for LHZ such as inventory-based mapping, heuristic approach, probabilistic assessment, deterministic approach, statistical analysis and multi criteria decision making approach (Gemechis Chimindi et al., 2017; Tilahun Hamza and Raghuvanshi, 2017; Raghuvanshi et al., 2014; Cruden, 1991; Guzzetti et al., 2005).

3.2. Methodology adopted for landslide Hazard Zonation

3.2.1Information value model

Information Value (IV) model is a bivariate statistical analysis method that was developed from information theory. In this model, information values of predisposing factors are used to characterize the possibility of landslide occurrence. The information values are determined for each subclass of landslide related parameter on the basis of presence of landslide in the given mapping unit. The causative factor maps were combined with landslide map in order to get weight of each class. The Model has the advantage of assessing landslide susceptibility in an objective way. The method allows for the quantified prediction of susceptibility by means of a score, even on terrain units not yet affected by landslide occurrence. Each instability factor is crossed with the landslide distribution, and weighting values based on landslide densities are calculated for each parameter class, as it happens with all bivariate statistical methods. Negative values of IV mean that the presence of the variable is not relevant in landslide development. Positive values of IV indicate a relevant relationship between the presence of the variable and landslide distribution (Yin and Yan, 1988):According to Yin and Yan (1988) weight mathematically obtained by:

Conditional probability=$\frac{\text{Number of landslide pixels with in factor class}}{\text{Number of factor class pixels}}$ (4.1)

Prior probability=$\frac{\text{Sum of landslide pixels of the whole study area}}{\text{Sum of pixels of the whole study area}}$ (4.2)

Weight of factor class=$\frac{\text{Conditional priority}}{\text{Prior probability}}$ (4.3)

Information value = log (Weight of factor class) (4.4)

Information values are assigned to each factor class to obtain weighted factor maps. These factor maps are then summed up using the raster calculator to obtain a landslide susceptibility index value for each pixel (Eq. 4.5):

LSI= $IV_{\text{Slope Angle}} + IV_{\text{Elevation}} + IV_{\text{Aspect}} + IV_{\text{Slope Material}} + IV_{\text{NDVI}} + IV_{\text{LULC}}$ (4.5)

Finally, the landslide hazard zonation map was classified into five ranked classes very low, low, moderate, high and very high hazard zone.

3.3. Methodology adopted for Slope Instability Assessment

3.3.1 In SAR time series analysis

Advanced in SAR methods such as Persistent Scattered (PS) (Greif and Vlcko, 2012) and Small Baseline Subset (SBAS) (Lanari et al., 2007) which can overcome objects arising from atmospheric noise and temporal and spatial baseline decorrelation, enable us to benefit from displacement time-series analysis using a stack of SAR data. Both techniques work better in urban areas because of the high density of man-made objects, which increase the probability of discovery coherent pixels in a stack of SAR data over time. Because of the non-urban nature of the landslide area in Gi dole, it is covered moderately with forest and other permanent vegetation, PS technique was used for surface displacement time-series analysis.

Long term deformation monitoring works with a special form of in SAR that is known as Persistent Scatterer Interferometry Synthetic Aperture Radar (PS-in SAR). PS-in SAR finds objects in the area of the image that produces a constant and characteristic radar reflection over time in a stack of many radar images. The PS-in SAR method was initially developed by Ferretti et al. (2000) used to estimating the time series displacement of each detected PS pixels. The Stamp’s Method, developed by Hooper et al. (2007) came as an improvement the capable of finding PS pixels in urban as well as non-urban areas and also a smaller number of interferograms is sufficient to map the surface displacement. PS-in SAR is a multi-temporal differential in SAR technique, which analyzes long temporal stack of satellite SAR Data and provides mean velocity and time series of ground deformation on dense grids of point-wise targets, the so-called Persistent Scatterers (Ferretti et al., 2001). PS-in SAR work by identifying image pixels in a stack of interferograms generated with the same master that persistently backscatter the radar signal over long time interval. The detail schematic flow chart of the methodology followed in the present study.

3.4. Pre-field Investigation

A review of previous works in the study area about landscape, geology, hydrogeology and so on will carry out. Collection of rain fall, humidity and temperature data from Dessie town water bureau was carried out before going out for field work.

3.5. During Field Investigation
A series of field investigation will be done in order to identify landslide hazards prone areas and to collect soils and rocks samples. Determinations of different geological structures that may be responsible for the triggering of landslide in the study area will be carried out. Identify intrinsic and extrinsic factors of land slide.
3.6. Post field Investigation
After the field work, different tasks were performed following various approaches. Data wereorganized in such a way, so that it can be accessed and used easily when needed. The tasksperformed include: primary and secondary data, was analyzed andprocessed to get the required information and input for further detailed stability analysis.
3.7. Materials
For the successful of this project, the following materials will used during field. These include: GPS, Topographic map, compass, Geological hammer, Note book, pen and pencil, Samples bags and Computer.

IV.CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

The roads, which passes on the hilly and mountainous terrains is characterized by variable topographical, geological, hydrological, and land-use condition. All such conditions make such roads to frequently affect by the slope failures. This is because the road which crosses through hilly and mountainous terrains experiences both deep and shallow excavations at the construction stage that disturbs the inherent nature of rock and soil slopes. The main objective of the present study is to conduct detailed slope stability analysis of critical slope sections and to evolve and suggest appropriate remedial measures to stabilize the critical slope sections.

Slope instability along Komobolcha and Dessie Road is becoming serious problem due to the presence of loose unconsolidated materials (colluvial materials), highly weathered and fractured basalt rocks, high relief, steep natural slopes, nature of geologic formations exposed along the road section, poor drainage conditions, occurrence of high seasonal rains, and seismically active nature of the region.

4.2. Recommendations

As we have done this senior project, the area which is Kombolcha - Dessie is highly affected by different landslide types like, rock fall, sliding, earthflow and other types. But we did not get the chance to visit, collect and record data from this area to do the senior project due to limitations of resources and this is one of the drawbacks of college of natural sciences or Wollo University and shortage of time because of covid-19. we strongly advice for the coming senior project working students who have a chance to do in this area, college of natural sciences or Wollo university should fund budget for students in order to visit and collect data and also for well understanding their study area.

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