



ADDIS ABABA UNIVERSITY
SCHOOL OF EARTH SCIENCES

**GIS-BASED STATISTICAL ANALYSIS FOR EVALUATION OF LANDSLIDE
SUSCEPTIBILITY MAPPING: A CASE STUDY IN WACHA-MIZAN ROAD
SECTION, SOUTHWESTERN ETHIOPIA**

**A Thesis Submitted to School of Earth Sciences for Partial Fulfillment of the
Requirements for the Degree of Master of Science in Engineering Geology**

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This is to certify that the thesis prepared by **Wegderes Tena**, entitled “**Landslide Hazard Susceptibility Using Bivariate Statistical Analysis Approach: The Case Study in Wachamizan Road Segment and Its Surrounding Area in South West Ethiopia**,” submitted in partial fulfillment of the requirements for the degree of Master of Science in **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

This study was undertaken in the Bench Maji Zone along the Mizan Wacha-Mizan roadway in southwestern Ethiopia, approximately 562 km from the capital, Addis Ababa. This region is notably susceptible to landslides, causing significant risks to road infrastructure, agricultural lands, and residential areas. The primary aim of this research was to develop a landslide susceptibility map using the Information Value Model a bivariate statistical method. This approach evaluates the influence of historical landslides on each factor contributing to slope instability. Key causative factors identified include slope morphometry, aspect, curvature, soil composition, groundwater seepage, land use, and proximity to streams.

Data were meticulously gathered through field investigations and corroborated with secondary sources. The integration of these seven causative factors culminated in a comprehensive landslide hazard susceptibility map. Statistical analysis of the information value revealed that certain classes of causative factors such as colluvium deposits, convex slope curvature, groundwater flow traces, slopes ranging from 25-35 degrees, north-facing aspects, Built up Areas, and proximity within 100m of stream exhibited the highest correlation with landslide occurrences.

The resultant landslide susceptibility map delineates the study area into various degrees of risk categories: 20.7 km² (24.92%) of the study area falls in low susceptibility, 28.7km² (34.49%) of the area falls in moderate susceptibility (MS) class and 33.7km² (40.59%) of the study area falls in high susceptibility (HS) class.

In general, the susceptibility classes derived from this study are consistent with historical landslide data and the causative factors examined. The findings from the Information Value Model provide a reliable basis for informed infrastructure planning, ensuring enhanced safety within the study area.

Key words: Bivariate Statistical Approach, Information Value Model, Landslide Susceptibility

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LIST OF ACRONYMS

AUC	Area under curve
CF	Certainty Factor
DEM	Digital Elevation Model
FR	Frequency Ratio
GIS	Geographic Information system
GSE	Geological Survey of Ethiopia
GPS	Global Positioning System
HS	High Susceptibility
JICA	Japan International Cooperation Agency
IV	Information Value
IVM	Information Value Model
LHZ	Landslide Hazard Susceptibility
LS	Low Suceptibility
LHEF	Landslide hazard evaluation factor
LULC	Land Use Land Cover
LSI	Landslide Susceptibility Index
MS	Medium Susceptibility
SRTM	Shuttle Radar Topographic Mission
VHS	Very High Susceptibility
VLS	Very Low Susceptibility

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Geohazard such as landslides have the potential to damage public infrastructure such as buildings, roads, and railroads in addition to affecting the environment. The movement of rocks and other soil materials from an upslope to a downslope due to gravity is known as a landslide, and it is a naturally occurring hazard.

The cause of the Landslide disasters were classified into Triggering and Causative Factors. Triggering factors of slope instability includes Rainfall which causes landslide through surface erosion of the given slope mass by the action of water, Earthquakes which cause landslide by liquefaction and lateral spreading of geological slope materials, volcanic activity associated with lahar slides flows in slopes, Human made triggers such as excavation and quarrying of slopes for mining or construction purpose. The predisposing factors of landslides includes weak geological slope materials including geological structures or faults in the slope, Topography of the terrain associated with steepness of the slope, Drainage of the slope related with the stream distance. The geological landscapes of mountainous regions and rift margins in Ethiopia are characterized by constant mass movements that level or continually adjust the land surface due to gravity.

The landslide type which is found in most of the south western part of Ethiopia is related to Rainfall-induced landslides caused by an increase of ground water level due to the area gets high cumulative rainfall . Landslides are associated with a movement of earth's material caused by gravitational force due to the shear strength of the slope materials were decreased. According to the JICA 2015, Landslide Handbook for Road Engineers, there are five different forms of landslides : debris flow, slope failure, rock fall, rock mass failure, and slow mass movement. Landslides are classified based on their types of slopes forming materials as falls, topples, spreads, flows, slides; based on the mechanism of sliding movement were classified as rotational, translational as well as Complex mode of movement.

The Landslides fail in the form of deep seated rotational slumps, massive translational slides and slow progressive creep movements. The wacha-mizan road is found in south west region which is characterized by complex geomorphological, geological and hydrogeological environment.

As a result, mass movement which affect the road way and drainage structure apparent in the gentle to moderately steep mountain ridges of the slopes of this road stretch. The Wacha Mizan asphalt road corridor plays an important role in terms of socioeconomic development for the local peoples in the area as well as for the country in which the main agricultural commodities such as Tea, coffee, honey, maize, banana and other products were exchanged across the region as well as to the country. Furthermore, by suggesting potential landslide remediation projects and ground improvement strategies, this study contributes to the enhancement of the condition of the road pavement in the Wacha Mizan Road section and lowers any damage caused by the road slope.

1.2. Statement of problem

The study area is located in the south western part of the western Ethiopian highlands, which are characterized by undulating landforms and mountainous terrain. The area is affected by a variety of earth flow, debris slides, and rock falls, which can disrupt the transportation network, cause landslides to fail, and harm residential settlements and the environment. There has been no previous landslide susceptibility mapping in the Wacha Mizan road segment that categorizes or rates the locations based on their level of susceptibility to landslides. As a result, I am motivated to do landslide susceptibility mapping for the Wacha Mizan area in order to lessen the existing mass movement problem.

The existing Wacha-Mizan road lacks adequate landslide countermeasures, hindering connectivity, accessibility, and mobility. Despite the prevalence of landslides and slope failures in the study area, local communities and the road administrative bodies or managers have not yet prioritized effective landslide management. As a result, comprehensive susceptibility mapping is required for the identification and mitigation of landslide-prone areas, which can be used as a guideline to inform engineers, urban planners, decision makers, or managers for the future construction of infrastructure projects such as roads, Residential settlements, and other civil structures.

1.3. Objectives

The main objective of the study is to develop a comprehensive landslide susceptibility map for a designated section of the Wacha-Mizan Road project, employing a GIS-based information value method within a bivariate statistical framework.

1.3.1. Specific objectives

The specific objectives which are outlined to achieve the general objectives are as follows:-

- To identify the main causative factors responsible for landslides in the area
- To evaluate the causative factors and conduct a GIS-based information value within a bivariate statistical analysis
- To recommend possible remedial and mitigation measures for landslide-prone areas of the wacha mizan road segment.

1.4. Significance of the study

The main significance of the present study is to determine each causative factor map and its parameter classes of the factor map to produce detailed landslide hazard Susceptibility map of the study area using GIS based information value modeling landslide hazard technique.

The primary landslide causative characteristics for the road slope that functions as a trigger for landslides must thus be determined by this study. In addition, taking into account landslide hazards while planning future actions for the local government and interested parties that manage the road disaster might assist to reduce or minimize the impending consequences in landslide prone areas.

This research is important to improve the status of road pavement condition which is affected by landslide problems in the critical slope sections and used as a reference for further future research study in other south west regions which are affected by recurrent landslide problems. The final susceptibility map allows for the formulation and recommendation of suitable mitigation landslide works also enables to decrease the maintenance reformation cost incurred by landslide problem.

1.5. Scope and Limitations

The scope of this study includes the determination of main causative and triggering factors responsible for landslide in this area. The scope is limited to describing the main causative as well as triggering factors that have an impact on causing land mass movement hazards in the road slope or pavement structure from the Wacha to Mizan Teferi area. The main landslide causative parameters were calculated using the Information value statistical method to determine the relative degree of Hazard or susceptibility of a road from landslide and mass wasting process as well as earth flow and debris flow movement.

The lack of availability of appropriate data as well as the inaccessibility of the terrain were considered as one of the limitations for completing the research thesis as per the planned time during the study. The area is covered with large natural trees or forests as well as thick vegetation crossed by medium to small streams.

In addition to this, undulating nature of the terrain makes the area inaccessible to map the landslide features that are found far from the road slope sections. Therefore, to characterize landslides a combination of field survey as well as Google Earth method of identification was used for the present study.

1.6. Future Extensions of the study

The landslide for the wacha mizan road segment which is found in the south western highlands could be caused by different landslide causal factors responsible for the activation of mass movement in the area. Thus, future studies on this road segment includes detail investigation of the slope problems using various investigation techniques such as mapping investigation of groundwater on the slope surface using geophysical investigation techniques through recommending suitable structural and ground improvement remedial measures on the slope. Thus, further investigation study involves other slope stability techniques such as finite method and limit equilibrium techniques of slope analysis to understand more about the behavior of the slope that helps to formulate necessary landslide countermeasure works.

CHAPTER TWO

2. LITERATURE REVIEW

Landslides were triggered by different natural and anthropogenic casual factors. The main natural factors which were categorized as landslides causative factors includes higher cumulative precipitation or rainfall, erodible or weathered colluvium slope materials, geomorphology and topography of the study area. The study areas topography, geomorphology, drainage or groundwater conditions, and erodible or weathered colluvium slope materials are among the primary natural factors that were classified as causative factors. Human-induced causes of landslides include the construction of roads and slope cutting, undercutting the toe of slopes, Vibration from Road traffic and unsuitable agricultural practices such as clearing of forest for agricultural expansion and irrigation activity as well as settlement on the top of slopes. In the southern west highlands of Ethiopia, the resulting damage to infrastructure and agricultural lands of mountainous slopes by landslides shows an increasing trend due to various anthropogenic and natural causative factors. The wacha to mizan terrain were part of south western Ethiopian highlands that experiences landslide problem caused by cumulative high prolonged amount of Precipitation as well as weak paleosoil thick overburden slope materials. Therefore, identification of landslide causative factor helps in suggesting appropriate landslide remedial works that could alleviate the landslide problem in the long term through applying statistical bivariate method.

2.1. Classification of Landslides

Crude and Varnes (1996) classified landslides as spread flows, falls, topples, slides, and complex types of movement based on the nature and velocity of movement as well as the geological material invoved in the sliding process.

The Landslide types in wacha-mizan road were classified as rotational landslide, translational landslide, complex landslide, rock fall. The rock fall areas were found at the road cut section triggered by inappropriate slope cutting for road construction purpose. There are minor rock fall areas which are found at the road slope cut section triggered by inappropriate slope cutting for road construction purpose.

Whereas the rotational, translational and debris flow type of landslides occur in unconsolidated soil and weathered weak volcanic rock units of the rhyolitic or basaltic origin. A combination of topographical, geological, geomorphological, and human-induced factors can result in landslides (Varnes, 1978).

2.1.1. Falls

According to Varnes (1958), it begins with the separation of rock or soil from a steep slope along a surface where there is little to no shear displacement. Rock falls, soil falls, debris falls, and falls involving a combination of two or more materials are all examples of falls, which are by their very nature Sudden and Rapid. In our study area there is a minor rock fall observed in the rock cut slope of wacha mizan road but has less hazard onto the road and it is not active during field observation.

2.1.2. Slide

A slide is the downward movement of a mass of soil or rock that happens on relatively thin zones of significant shear strain or on surfaces where there is a surface rupture. A translational slide has minimal rotation or rearward tilt as the landslide mass travels along a relatively planar surface. A rotational slide has a surface of rupture that is concavely curved upward and moves nearly in a rotational direction along an axis that runs transversely across the slide and parallel to the ground. According to Highland and Bobrowsky (2008), slides are widespread in loose, unconsolidated soils and can travel at a rate of extremely slow to relatively fast. If they are left uncontrolled, they can cause damage to infrastructure.

2.1.2.1. Rotational slide

It is the movement of slope forming materials on a curved upward surface of rupture (Highland 2004). The movement results from forces that cause a turning moment about a point above the center of gravity of the unit. A rotational slide with multiple parallel, curved planes of motion is referred to as a slump. The complex type of slide occurred in this road segment is the largest inventoried landslide among the total past landslides. Weathered geological rocks as well as earth slides occurred in the road from wacha to mizan segment.

Table 1 Types of landslide Varnes' classification of slope movements (Varnes, 1978)

Types of movement		Types of materials		
		Bedrock	Soil	
			Coarse	Fine
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slides	Rotational	Rock slump	Debris slump	Earth slump
	Translational	Rock block slide	Debris block side	Earth block slide
Lateral spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow	Debris flow	Earth flow
Complex of slope materials (e.g., combination of two or more types)				

2.1.2.2. Translational slide

It is the movement of slope forming materials formed along a relatively planar surface of rupture (Varnes, 1978). It occurs on the slope formed by extensive slabs of rock, or loose, unconsolidated soils, or both. Translational slide can occur along joints, faults, bedding surfaces in rocks or unconsolidated soils, or the contact between rocks and soils .

2.1.3. Earth flow

According to Highland (2004), earth flow is the flow of viscous or plastic slope-forming materials that have undergone significant internal deformation. Earthflow is among the type of slide movement that consists of a highly weathered fine grained material which have a potential to occurs on the flat to moderately sloping terrain. The soil involved in landslide activity is weak geological material of with large soil thickness of residual and colluvium portion of our study area, an earth flow slide was observed.

2.1.4. Debris flow

This type of movement occur during rainy season in the slope side of the stream banks through the action of surface water flow which results in the accumulation of geological soils and rock materials in the flat lying lower valleys or gentle slopes.

2.1.5. Complex landslides

A Complex landslide is characterized by multiple separate forms of movement that occurring on the unstable slope of the given slope terrain. Therefore, it is possible for rotational and translation movement to take place within the same geological soil and rock material.

The station at 195+000 km or the largest slide near to wacha town is considered as a complex type of landslide which shows a mixture of soil, rock and earthflow debris deposited especially on the toe part of the landslide block section.

2.2. Previous Landslide Hazard Zonation Studies in the Country

Ahmed Abdikerimet al. (2020) produced a landslide hazard zonation map for Funyan Biro Town in the Gursum District of Eastern Ethiopia by using the information value approach. The primary causative factors found in the study were aspect, elevation, slope materials, land use and cover, and groundwater conditions. An overlay analysis describes about 97% of past landslides have occurred in high-hazard and very-high-hazard zones. Thus, the model produces good results for landslide hazard assessment and zonation.

Alembante Genene (2021) used information value (IV) and frequency ratio (FR) statistical methods to create a landslide hazard zonation map for Gindeberet West Shewa zone, Ethiopia. The causative factors includes lithology, rainfall, land use classifications, slope, aspect, curvature, and distance from lineaments or streams. the landslide validation findings from the Area under curve, which demonstrate a good performance of both models with success rates of 0.836 and 0.835 and prediction rates of 0.817 and 0.818 for the IV and FR models, respectively.

The landslide susceptibility mapping for the Goncha Siso Sene area in northwest Ethiopia was carried out by Azmeraw Wubalem et al. (2020) using the Information Value and Logistic Regression (LG) approach. The primary factors that contributed to the landslide were rainfall, land use/cover, lithology, slope, curvature, aspect, and distances to streams, lineaments, and springs. AUC accuracy for the information value model is 88.9% success rate and 85.9% prediction rate, while for the logistic regression model it is 81.8% success rate and 80.2% predictive rate, according to the validation results of the model.

In the Uatzau catchment basin in northwest Ethiopia, Azmeraw Wubalem et al. (2021) also carried out landslide susceptibility mapping by utilizing the frequency ratio (FR), information value (IV), and certainty factor (CF) techniques. According to validation data, the model's accuracy in terms of area under the curve (AUC) is 88.83% for the FR model, 87.03% for the CF model, and 84.83% for the IV model.

Abinet Addiss et al. (2022) used bivariate statistical models of frequency ratio (FR) and information values (IV) to map the susceptibility of landslides in the Chemoga watershed upper Abay basin. The main landslide considered causative factors classes were slope, elevation, aspect, curvature, Topographic Wetness Index, Normalized Difference Vegetation Index, road, river, land use, and rainfall. The AUC validation findings indicate that the FR and IV models had success rates of 0.870 and 0.901, respectively, and prediction rates of 0.880 and 0.923.

2.3. Previous Landslide Hazard Studies in the Study Area

In 2016, SG Consulting Engineers Plc conducted a geotechnical report on a slope stability analysis using the limit equilibrium method at the profile of the landslide at 197+000 km from Jimma. The results of the analysis from the two investigated drilled geotechnical boreholes shows the distribution of subsurface material variation and the slip surface position of the landslide. The overlying layer is 0 to 5.5 meters deep and is made up of compact, medium-plastic, silty clay that ranges in color from brown to reddish brown and contains occasional broken pebble materials.

The next layer is composed of medium-sized, compact, grayish-brown silty gravel with pebbles that range in thickness from 3 to 8 m. The third unit is underlying gray to pink grayish brown, highly weathered rhyolite. The slip surface is located between 8 and 11 meters, and the water level was discovered to be between 0 and 5.5 meters, according to the borehole SPT data. Based on the groundwater data and the slope section geometry, the landslide is classified as a shallow form of landslide failure.

The depth of groundwater is shallowest and occurs close to the ground's surface, according to data from secondary boreholes and field observations. Because of this, according to their research, the experts believe that one of the main factors reactivating the landslide problem is the rise in shallow ground water levels. The Ethiopian Geological Survey also carried out laboratory testing to ascertain the geotechnical characteristics of four (4) typical soil samples for the largest landslide failure section at 195+170 km, including grain size distribution, moisture content, and dry density.

Since the top soil serves as a sliding surface for the bottom soil, which is composed of 70% sandy gravel and 30% silty clay, the test's data analysis indicates that the top soil includes approximately 58% sandy gravel and 42% silty clay.

2.4. Landslide Hazard Susceptibility

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). Landslide inventory mapping is a technique for identifying the area affected by landslides and recording the location, dimension, causative factor, frequency of occurrence, and mode of failure of the landslide.

The heuristic approach is a subjective landslide hazard susceptibility mapping method that classifies and determines the type and degree of hazard based on the detailed knowledge and experience of the researchers in preparing various landslide causative factor maps. In this technique, individual thematic map layers (causative factor maps) are combined to produce a landslide hazard map (Dai and Lee, 2002). According to Highland and Bobrowsky (2008), landslide inventory maps can show the spatial distribution of previous landslides and provide information on their geomorphological characteristics, such as scarp and accumulation zones, type of movement, activity, geological age, and rate of movement.

These and other characteristics are thought to be helpful in creating and validating potential landslide hazard analysis maps. The quantitative approach combines landslide inventory and landslide governing components in statistical and deterministic modeling of landslide susceptibility (Leulalem Shano et al., 2020).

2.5. Statistical methods

Statistical approach is a quantitative way of evaluating area with landslide susceptibility. This method has been developed mainly to correct high level of subjectivity in connection with expert judgments evaluation (Dai and Lee, 2001). All possible causative terrain parameters are weighted and integrated using GIS for landslide susceptibility analysis. This method is important to determine the degree of influence of individual causative factors responsible for landslide occurrence (Kanungo et al. 2009).

Statistical method evaluates landslides in the particular area by combining causative factor with the past landslide events to predict the degree of future landslide hazard which might have the potential to occur in the future (Carrara et al., 1992). The disadvantages of using statistical method is the collection of data at an optimum cost over large area is difficult .

Therefore, the result depends on the quality of input data. The statistical methods were classified as Bi-variate and multi-variate statistical methods (Kanungo et al., 2009).

2.5.1. Bi-Variate Statistical Method

In bivariate statistical analysis, each landslide causative factor map that causes landslide activity is overlaid with the landslide distribution map, and weighting values are calculated for each causal factor class (Soeters & van Westen, 1996; Suzen & Doyuran, 2004) according to their contribution to the cause and occurrence of landslide activity.

In bivariate statistical analysis, the occurrence of landslides is considered a dependent variable, whereas environmental causative parameters that cause landslides are considered an independent variable (Aleotti and Chowdhury, 1999; Suzen and Duyuran, 2004). Landslide density is used to calculate the weight or contribution of a causative component to the landslide hazard. The bi-variate approach compares the causes of current landslides with those that could cause landslides in the future. Based on landslide severity and distribution, the weights are assigned to the landslide-causing factors.

There are many types of important bivariate statistical methods, such as the information value model (IVM), weighted overlay method, Bayesian probability model, fuzzy logic method, certainty factor method, statistical index, and density area method (Aleotti and Chowdhury, 1999; Kanungo et al., 2009). The final output map based on the information value modeling method was classified into five hazard zones, such as very low, low, medium, high, and very high. The information value modeling method (IVM) was used to calculate the weighting values for each class of the causative factors considered. The landslide density within each class is the basis for calculating the weighting values.

2.5.2. Multi-Variate Statistical Method

This approach takes into account the relative contributions of each theme data layer or causative factor to the overall susceptibility within a certain area. The multivariate statistical modeling techniques that were frequently used were conditional analysis, multiple regression models, artificial neural network analysis, and logistic regression (Lulalem Shano et al., 2020). The combination of parameter maps and the presence or absence of landslides are compared in multivariate analysis. Parameter maps are merged and contrasted with the presence or absence of landslides in multivariate analysis. 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, 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.

Multivariate statistical analyses related to landslide study determine the weights of landslide causal factors based on the relative contribution of each in the presence or absence of past landslide events within a defined land unit (Dai et al. 2010; Ayalew and Yamagishi 2005; Nandi and Shakoor 2009).

2.6. Deterministic Method

The deterministic method necessitates in-depth knowledge of geology, geomorphology, and probable mechanisms of slope failure. This approach assesses the risk of landslides by understanding the mechanical and physical mechanisms that contribute to their vulnerability. This method primarily takes rainfall, slope values, and ground water statistics into account (Varnes, 1984). This method does not consider the effects of causative factors that are linked to environmental and human induced factors, which are considered to be significant causative factors for landslides. Deterministic approaches are becoming increasingly popular in the hazard analysis of larger areas because they can handle large numbers of calculations with the aid of GIS tools (Soeters & van Westen, 1996).

The limitation of the deterministic method was the lack of proper slope-specific geotechnical and hydrological data for slope analysis over wide areas, and therefore this approach can only be effectively applied to small areas (Ayalew & Yamagishi, 2005; Almaz, 2009). Therefore, deterministic methods are considered a geotechnical engineering approach that utilizes slope instability analysis to evaluate a factor of safety based on mathematical models of physical mechanisms that control landslides as well as slope failures (Ayalew & Yamagishi, 2005).

2.7. Genesis Methodology and Gap of the present study Area

The methodology followed in the present study is part of a bivariate statistical approach. Thus, the techniques are based on the general assumption that “the past and the present are the keys to the future” (Dai and Lee, 2001). A statistical approach, the information value method, which is classified under bivariate statistical analysis, was followed in the present study of the Wacha-Mizan landslide road section (Raghuvanshi et al., 2014a; Lulalem Shano et al., 2020). Landslide studies done with other statistical methods don't show the probability of occurrence with an inventory of past landslide correlations.

Therefore, many authors agree that statistical methods, such as the information value method, are more appropriate for hazard zoning because they have a minimum degree of subjectivity (Lulalem Shano et al., 2020). In this method, the results of the inventory data are compared with the causative factors that influence landslides.

The information value method is based on the statistical determination of landslide density within a given causative factor class. Based on the analysis of the relations between causative factors and the inventoried landslide activities, quantitative estimations are made. For statistical information value analysis, each causative factor class information value is decided through the combination of a landslide raster and a causative factor raster based on the presence of a landslide in a given thematic map.

After the statistical IV is obtained, the weight of each landslide causative factor class is assigned. These weighted factor maps were rasterized by using the lookup tool in the spatial analysis of the Arc Toolbox. Then, after rasterization, the landslide susceptibility index (LSI) maps were produced by adding up all the raster maps using a raster calculator in Map Algebra. Finally, a landslide susceptibility map for the given study area could be produced. Thus, from the literature so far reviewed and considered in the country, the information value statistical method has better accuracy for landslide prediction than any of the other bivariate methods. Therefore, for landslide susceptibility mapping purposes, this study was applied to the Wacha Mizan road segment.

CHAPTER THREE

3. THE STUDY AREA

3.1. Location and Accessibility

The Project Jima-Mizan Road is an existing asphalt road connects the cities of Jima and Mizan that forms part of Addis-Jima-Tepi main road network providing access to the south western part of Ethiopia. The Wacha-Mizan road corridor is part of Jimma-Bonga-Mizan road and the landslide prone stations were located between wacha and mizan Teferi towns.

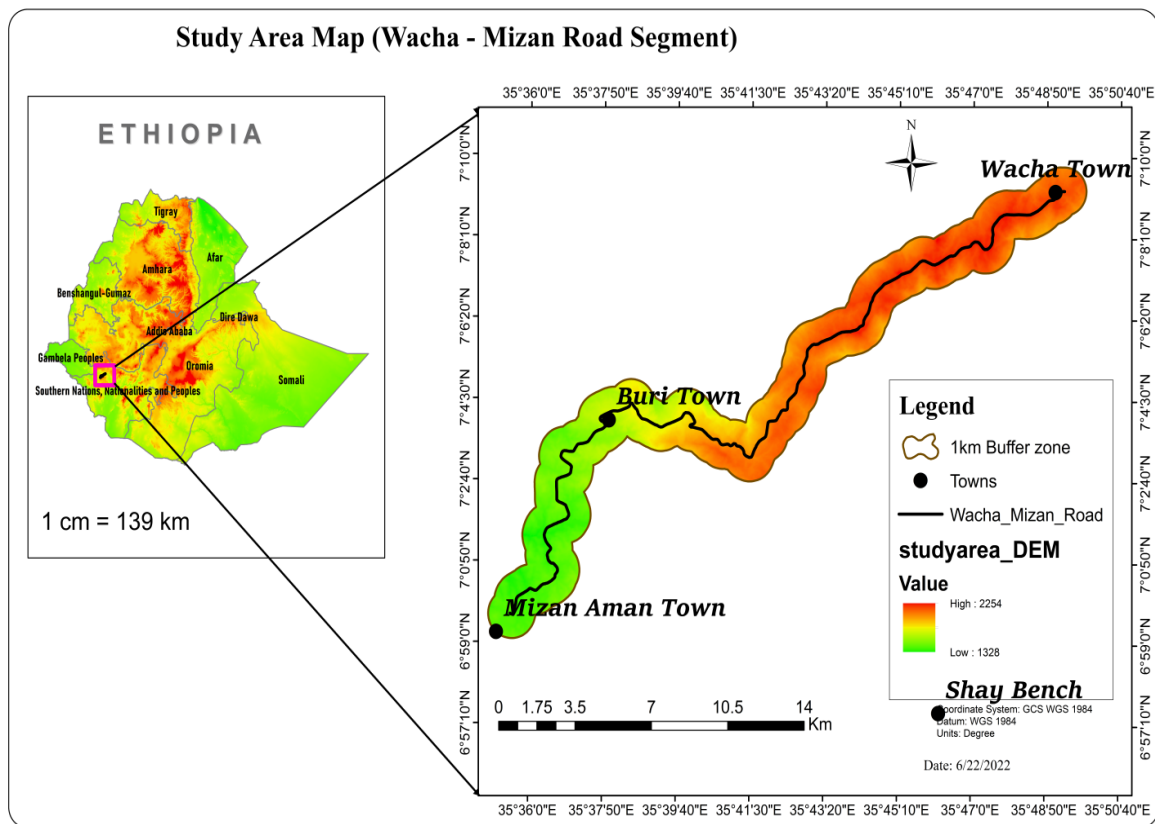


Figure 1 : Location map of the Wacha-Mizan Road

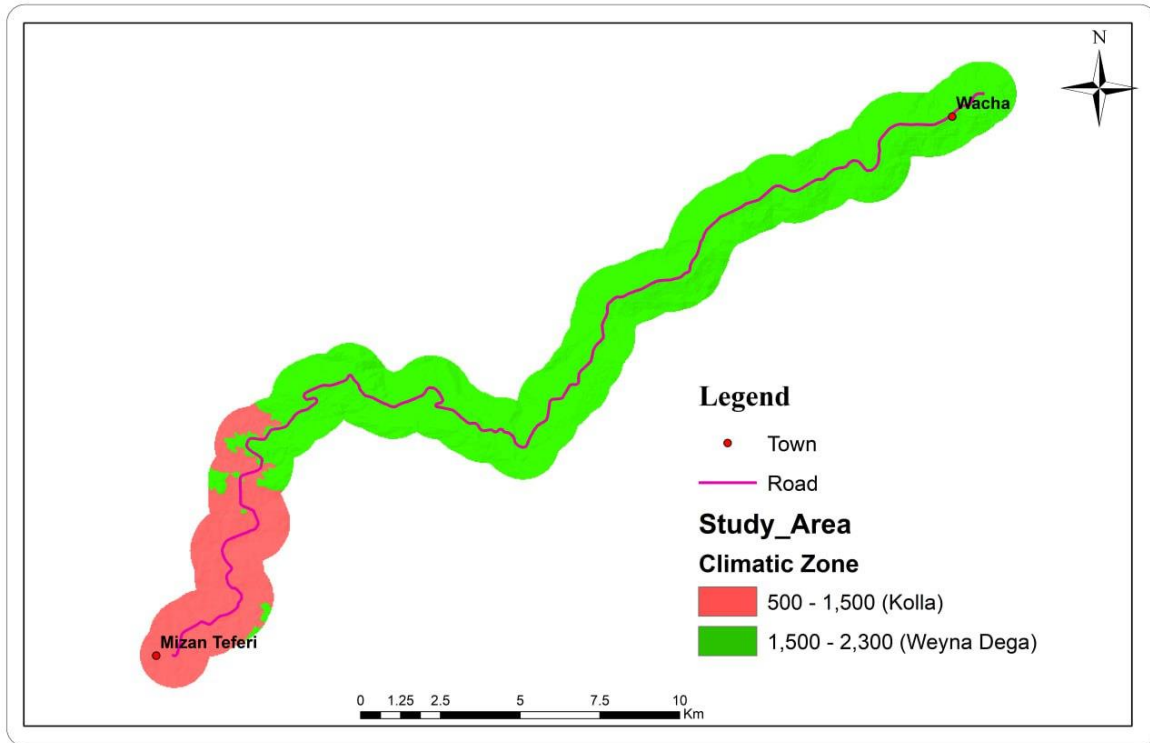


Figure 2: Figure Climate Zone Map of the Study Area Based on Elevation

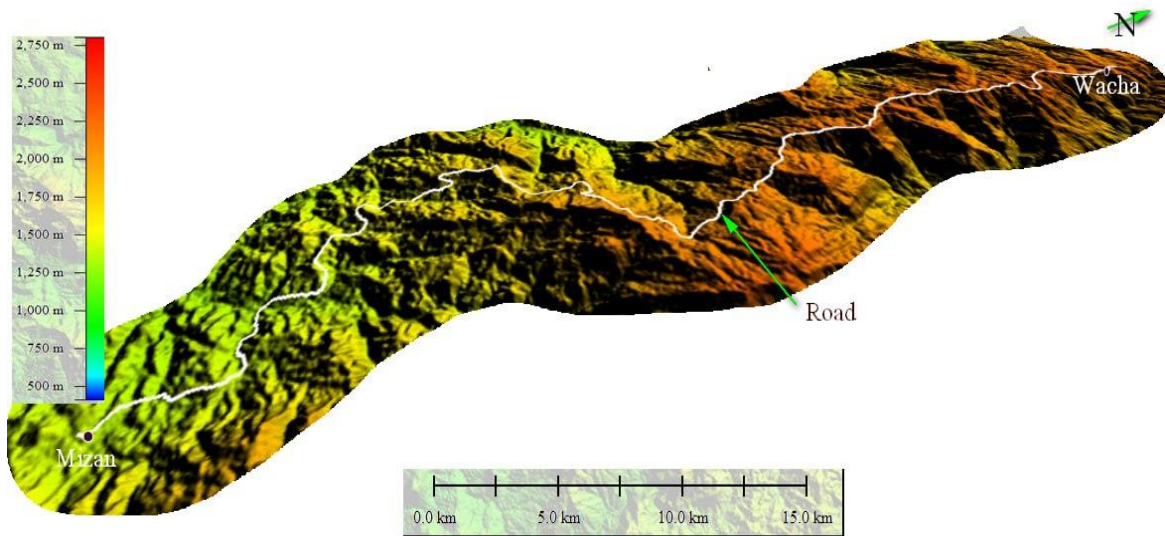


Figure 3: Physiographic map of Wacha-Mizan Road

3.2. Climate

According to Koppean classification, the elevation ranges that determine the climate of Ethiopia are as follows: higher than 3300 meters in the Alpine (Kur), between 2300 and 3300 meters in the Temperate (Dega), between 1500 and 2300 meters in the Subtropical (Weinadega), between 800 and 1500 meters in the Tropical (Kola), and lower than 800 meters in the Desert Climate Zone (Berha). Thus, it is reasonable to determine from Ethiopia's climate map and classification that the majority of the Wacha Mizan climate falls under the Woinadega climate classification, which has an elevation range of 1320 to 2300 meters and suggests a humid, warm tropical climate.

3.2.1. Precipitation or Rainfall

The physiography and geomorphology of the study area, together with the vegetation, influence the relationship between precipitation over the area and water drained out from the slope. Rainfall increases the failure of landslides and slope failures through decreasing the shear strength of soils and rock units. The study area is situated at the water divide between Omo-Gibe basin and Baro-Akobo Basin within young streams of dendritic nature characterized by formation of steep gullies due to the surface water flows following the topography of the slope from high relief to low relief areas.

The study area receives prolonged bimodal type or pattern of rainfall which occurs from April to May as well as in the predominant summer Ethiopian rainy season from June to August with the maximum rainfall. The area experiences an average mean rainfall of more than 1500mm in the highest rainy season or in the month of august.

Rainfall results in increase the water content of slope material, which can increase pore water pressure above the optimum condition and results in landslide or slope failure (Dai and Lee 2000). Shallow debris-flows or gully slope erosion were observed triggered by highest amount of cumulative rainfall.

The project area gets maximum rainfall during the months of April through September, and it gets minimum rainfall during the months of December through February. The mean annual rainfall of the project corridor is ranging from 1500 to 1800m. Therefore, this high amount of rainfall during the major rainy Ethiopian season is considered as one of the main triggering factors that can have an impact for the slope by facilitating erosion and landslide problem for the study area.

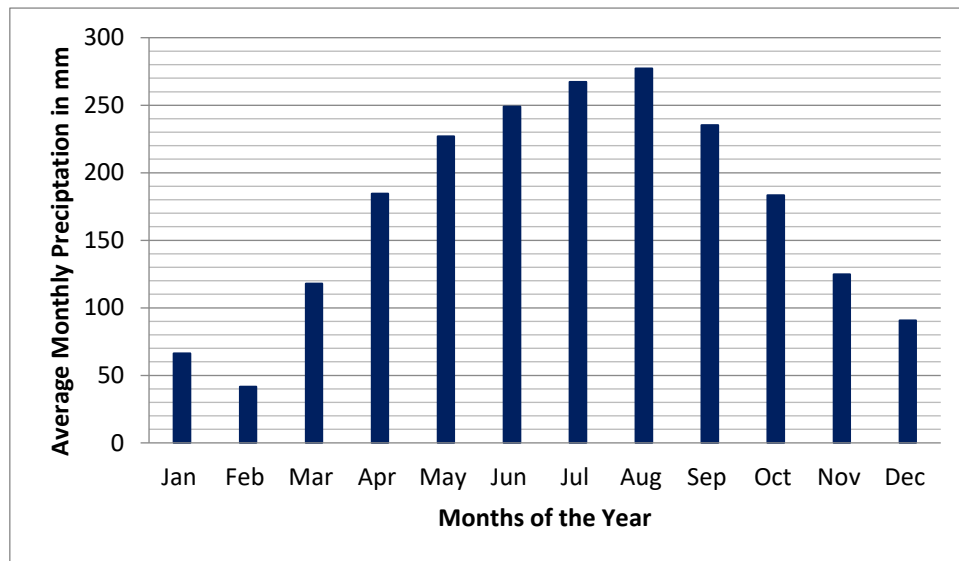


Figure 4: Average Monthly precipitations from 1990 to 2019 for Mizan Teferi station

In general, the cumulative monthly and annual amount of precipitations in the wacha-mizan Teferi area was higher especially in the month of June to September. This indicates that rainfall plays a major role for triggering landslide activity in the study area through increasing groundwater level in the slope or storage capacity of the soil is exceeded which ultimately results in the erosion of colluvium and residual materials that are exposed in the slope surface.

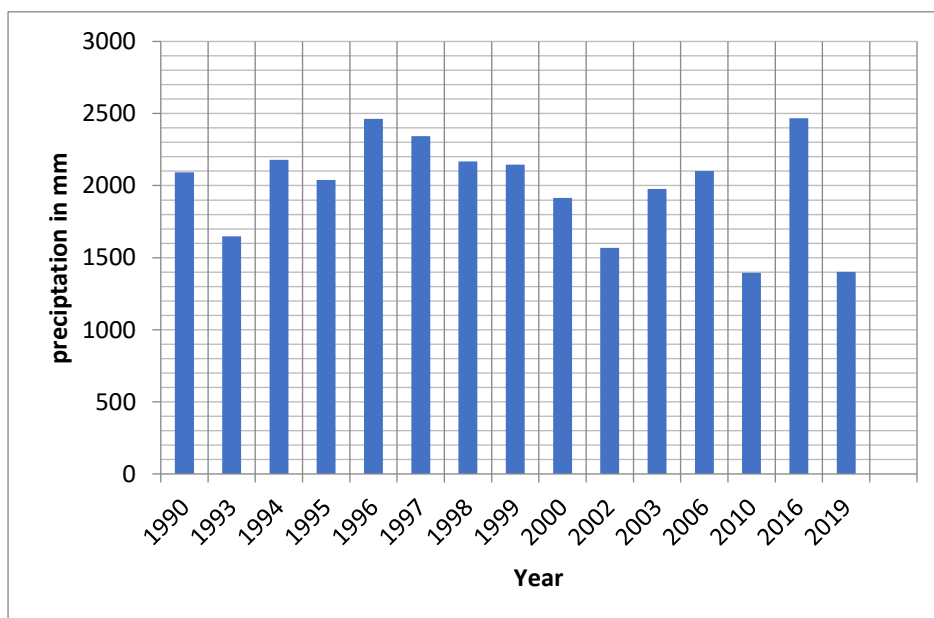


Figure 5: Annual precipitation from 1990 to 2019 for Mizan Teferi station

3.2.2. Temperature

Temperature is dependent on solar radiation and has a direct influence on the rate at which water molecules leave the water surface and enter the overlying air. Since the area is humid and found in the tropics, it has a high evaporation and Evapotranspiration rate, depending on the precipitation and soil moisture content of the study area. As a result, temperature plays an important role in the weathering of volcanic rocks because the area is located in the tropics, and variation in the annual climate or temperature of the study area results in residual soil formation due to the abundance of rainfall.

Most areas in this region were comprised of deeply weathered volcanic rocks due to the wet and warm climate, which promotes rapid deep weathering results in the formation of disintegrated unconsolidated type of soils. The climate of the study area has a characteristic elevation from 1500m to 2300m and classified as humid temperate regions with more than half of a year experiences rainfall in the region.

The climate of the project section is classified as cold climatic nature or low temperature zone, high rainfall and low Evapotranspiration. Minimum temperature is 4.5°C and maximum temperature is 41°C . There is a large variation in the minimum and maximum temperature as well as annual average temperature condition of the study area.

Therefore this variation indicates that lowest temperature during rainy season and highest temperature during the dry season period creates a favourable condition for promoting the disintegration and weathering of the given geological slope material of the volcanic rock unit of the slope that can have a potential to trigger slope instability in the form of Colluvium and earth flow of sliding materials. Mountainous terrain in tropical environments is characterized by high rainfall values and deep weathering profiles in saturated or humid field conditions. This is the reason for the superficial landslides triggered by rainfall in tropical environments were controlled by the weathering profile and storage capacity of the water in the soil.

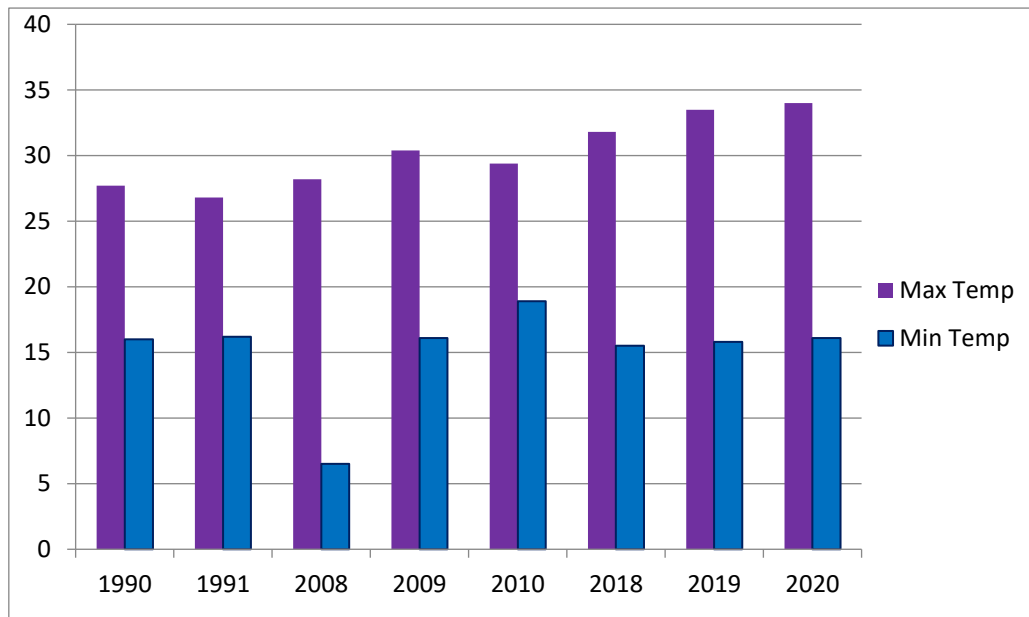


Figure 6: Annual maximum and minimum Temperatures of the study area

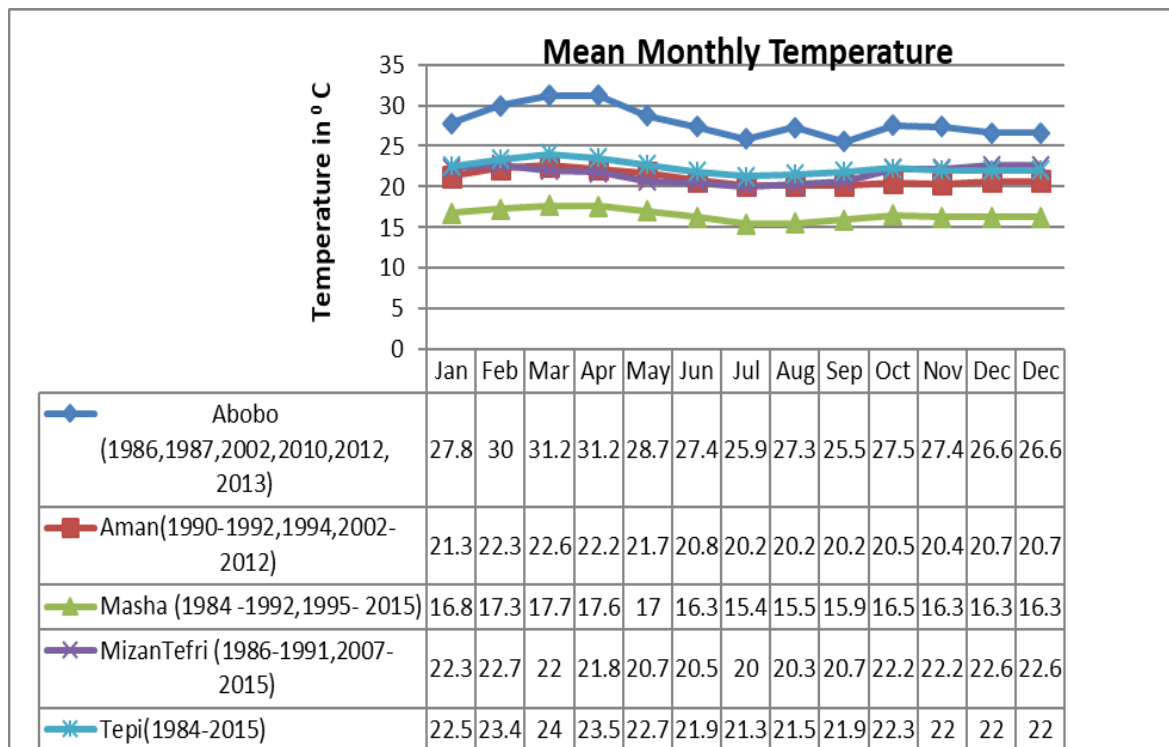


Figure 7:Min, average & max Temp for Gecha meteorological stations

3.3. Seismicity

The wacha-mizan Road project is found in the southwestern regional states of Ethiopia. Earthquake is a natural hazard resulting from seismic waves that may damage natural and manmade structures around the epicenter. Ethiopian Building Code Standard (EBCS, 1995) classified the country into four major seismic hazard zones.

According to this seismic hazard map, the present study area falls in zone 0 which is seismic free, which implies that the present study area lies in no seismic hazard zone. The ground acceleration that should be considered in each seismic zone is described here under in Table 2. Therefore, it is considered that Earth quake have no effect on triggering landslide activity in wacha- mizan road segment.

Zone	4	3	2	1	0
g (cm/sec²)	0.1	0.07	0.05	0.03	Seismic free

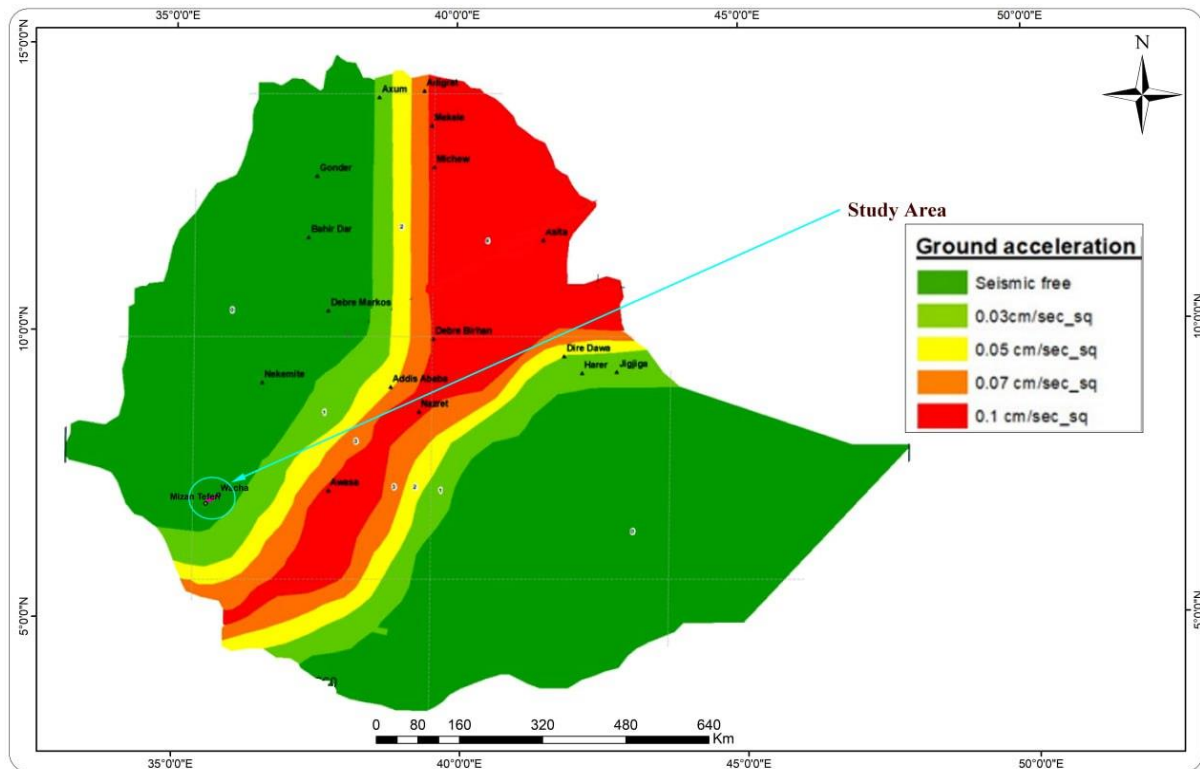


Figure 8: Seismic zone map of Ethiopia for 100 year Return period from EBCS

3.4. Topography

Topography determines the geographic variation of hydrological conditions and slope stability. It influences the spatial distribution of soil moisture and groundwater flow, which is determined by the slope's surface topography. The slope of the ridge is categorized as undulating to dissected tough morphometric terrain, which produces an ideal environment for

landslide mass movement. The Wacha-Mizan road is largely made up of clusters of hills with ridges ranging from moderately steep to gentle to level terrain.

During road construction, the steepness of the slope geometry or alignment influences the land mass movement of the area's slope. The topography of the route corridor ranges from steep undulating clusters of several minor mountainous ridge terrain surfaces to a smooth gentle slope. The topography of the road's downslope ranges from fairly steep to gently steep up to the bottom of the river valley.

The undulating topography causes perennial and intermittent streams to flow along the surface gradient from upslope to downslope locations. The rolling terrain on the hill in the vicinity serves as a recharging zone for the flat slopes. The topography on the down slope of the road is moderately steeping to gently steeping terrain up to the bottom of the valley of the land surface. The undulating nature of the topography makes perennial and intermittent stream to flow following the surface gradient from the upslope to down slope areas. The rolling terrain of the area is acts as a recharge zone for the flat slopes.

3.5. Drainage and Groundwater

The rainfall triggers surface runoff for the slope in the wacha mizan road. There is a perennial as well as an intermittent stream flow that flows following the terrain of the slope surface through modifying the geomorphology shape of the ridge surface. The Surface flow of shallow spring water on the slope flows from the upslope to downslope area infiltrating into the ground surface. Streams have the potential undercut the slope terrain, which may cause slope erosion in stream valleys and result in the development of gully surfaces in the river's valley.

The rivers actively eroding the stream bed courses by carving out the undulating morphology of the stream valleys, resulting in the deposition of alluvium slope materials. Downstream slope erosion of the embankment surface and deep gullies were observed caused by flow of spring water underneath the drainage structure.

In general, surface drainage is considered to be one of the factors that affect slope instability hence it is associated with erosion of the old landslide material through the action of surface water runoff caused by rainfall most importantly at the time of rainy season.

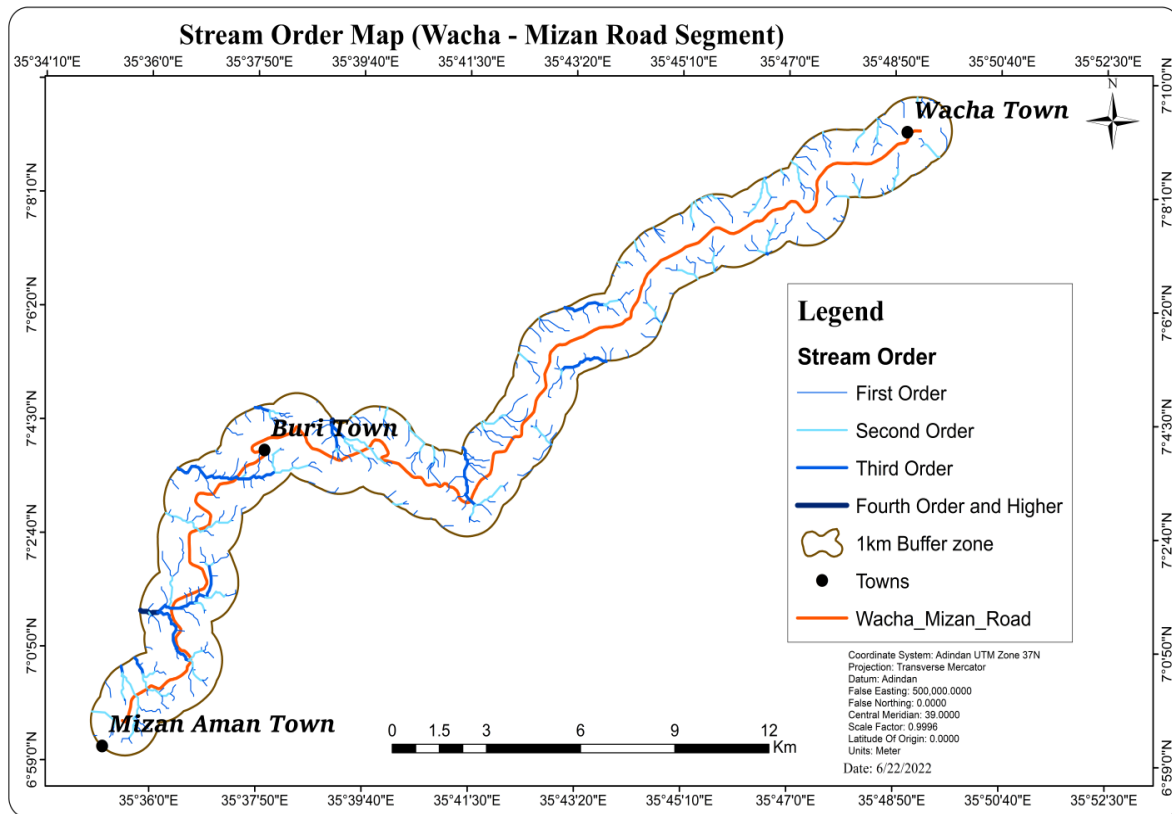


Figure 9: Stream order or Drainage map

3.6. Geomorphology

The geomorphology of the terrain was defined by morphological features of previous slide scarps as well as erosional surface features that transport soil masses during extended rains with uncontrolled surface runoff. The dissected form of the plateau, which is characterized by slope subsidence, enables lithological volcanic rocks to move from upward to downward areas by river or stream transport.

The geomorphological nature of the area makes the slope vulnerable to erosion and denudation of the mountain ridge surface because the area receives the most rainfall over 5 months of the year, and as a result, percolation and infiltration of surface water to the ground are considered to be relatively high. The dissected nature of the volcanic plateau allows for the formation of colluvium and denudation slopes of the terrain becomes unstable especially when the rainfall of the area is highest at the month of summer season.

Therefore, side slope erosion of the slope terrain results in slow mass movement and landslide activities. The slope ridge surfaces, when cut at a sharp, steep gradient, aggravate the slope mass's stability because the slope's weak geological rock and soil units slide due to the action of surface and ground water.

The landscape in the project corridor has altered as a result of uplift, incision, volcanism, weathering, mass movement, erosion, deposition, and land use change. The depletion of geomorphic mountain land mass through mass wasting or slope deterioration upon the slope surface is considered to be a contributing factor to the slope's mass movement.

The denudation geomorphological processes involve in the landscape reduction processes or changing the geomorphology of the terrain surface at the upper slope part of volcanic rock unit. during the construction of a road, improperly cut slope angles can destabilize the slope materials, reduce the suction between soil particles, and ultimately weaken the natural shear strength of the soil. The various mountain ridges and hill clusters at the volcanic plateaus are characterized by the gully and rill kind of erosion that deteriorates the slope materials on the mountain ridge surface.

Retrogressive landslides move along the river or stream path of the slope gradient, beginning at the upper slope surface and progressing towards places with moderate gentle slopes. Slope morphometry is considered to be one of the primary intrinsic causal variables that can initiate slope instability. Therefore, As the slope steepness increases the strength forces that hold the slope material decrease and shear stress increases, resulting in colluvium soil mass failure due to gravity forces.

3.7. Geology

3.7.1. Regional Geology

The Jima volcanic rocks consists of two main rock units; the lower Jimma volcanics are mainly basalts and the upper Jimma volcanics, are mainly, trachytes, rhyolites, ignimbrites and pyroclastic rock units are known which shows a conformable relationship.

There are younger valley deposits of quaternary stratified tuffs and alluvial deposits follow events of rifting and subsequent downwarping and different graben formation to which they have accumulated. The project area's volcanic rocks consist of mainly upper part of Jimma Volcanic of rhyolite, trachyte flows , tuff and basalts. By influencing changes in the discontinuities of geological structure and material quality, lithology has a significant role in controlling the occurrence of landslides, according to Ayalew and Yamagishi (2005).

Therefore, different lithological slope units are linked to different levels of landslide vulnerability (Dai et al. 2001). According to (Haro, et. al. 2012) Geological map of Jimma area shows most part of mizan town and surrounding area is covered by mainly trachyte intercalated with minor ignimbrite and rare basalt and some part is covered by mainly basalt with rare intercalation of trachyte. The basalt unit overlies the lower pyroclastic unit and it is fine grained, dark grey and slightly to deeply weathered and fractured basalts which are separated by paleosoil. The pyroclastic rock contains a combination of boulders, blocks, cobbles and gravels cemented by fine grained material. The other geologic formation is middle trachyte flow which is mainly trachyte intercalated with minor ignimbrite and rare basalt.

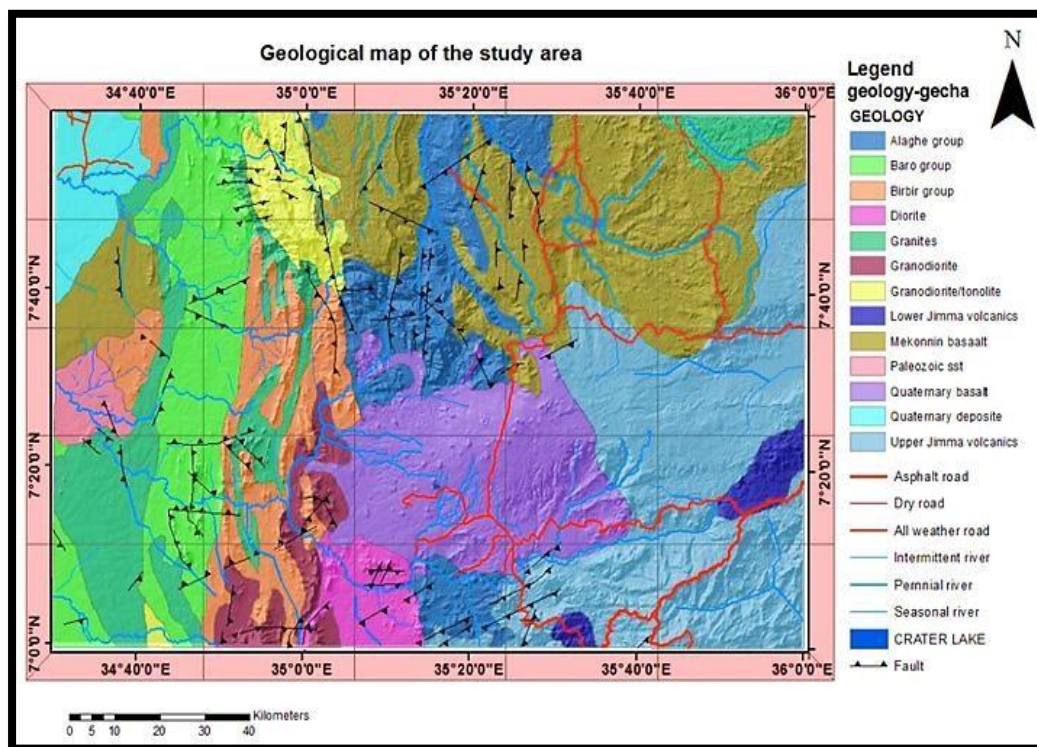


Figure 10: Regional Geology of Gecha map sheet

3.7.2. Local Geology of the Area

The type of soil in this area, as described in the generalized Gecha soil map sheet, was categorized as Distric Cambisols, which are a type of soil derived from the decomposition of wide range of rocks characterized as mostly alluvial and colluvium deposits.

The main lithological materials involved in the past landslide deposits include a mixture of basaltic colluvium material with different types of grain sizes, ranging from silts and clays to gravel, as well as a sand portion of boulder materials.

The colluvium landslide deposits scattered across the road section includes a mixture of different types of granular materials that range in size from cobbles to boulders as well as sand and gravels with silty sand soil mixture. The material type on this road stretch consists of transported colluvium materials, which comprise a wide variety of intercalation of pebble, boulder, and gravel size material intercalated with silt sandy clay soil.

There are geological structures such as faults that acts as a weak zone by making geological rock units into unstable lithological slope condition. The local geology of the study area was exposed along the road cut and the natural hill slope of the terrain. The rock units which are mostly observed in the study area include basalt, rhyolite and trachyte which undergone different degree of fracturing and intensive weathering that creates favorable condition for the slope mass movement. The dominant soil type in this area includes reddish to dark brown Silty clay lateritic soil mixed with weathered volcanic rock such as basalts and rhyolites. Geological material involved in the study area includes the unconsolidated heterogeneous materials such as colluvium deposit, alluvial deposits and paleo soils or residual soils.

Most of the typical features of the local geology consist of brownish reddish to reddish silty clay rich soils. Silty gravel soils of derived from colluvium soils were the main geological materials of the study area derived from weathered basalt and pyroclastic rock units.

The other type of soils which are exposed in the area includes weathered volcanic rock such as basalt, trachyte with the underlying soil unit that acts as a contact zone for the activation of land mass movement. Gully geological surface features were formed on the soil slopes by stream lateral erosion of the slope through the action of streams and spring water.

The geology of the area is mostly colluvium materials such as Silty clayey gravel soils intercalated with boulder basalts scattered in the midway slopes and residual soils in gentle slopes. Geological fractures or faults play a great role in the activation of the old landslide material by storing water as a temporary perched layer or aquifer in terms of groundwater storage. Tension cracks develop retrogressively dipping from the upper head part of the landslide towards the toe of the old past landslide area following the topography of the slope. The upper parts of the cut slope are inclined and dip towards the road.

The rhyolite rocks when weathered lose the strength or binding forces b/n the particle which makes the rock slope more susceptible to surface erosion by land mass movement. The colluvium materials embedded in reddish clay soil matrix units have low frictional forces and lose cohesion during high rainfall seasons

Failure of past landslide geological materials accumulate in the form of debris type of sliding of colluvium slope deposits. There are manifestations of active landslide progress due to the slope cracks developed retrogressively longitudinal to both sides of the road slope section. Colluvium materials such as Silty clayey gravel soils intercalated with boulder basalts scattered in the midway slopes . However, residual soils occur in relatively gentle slopes of the area.

3.7.2.1. Shishinda Trachyte rock

The type of rock unit found from Wacha to Mizan is a trachyte volcanic rock unit, which has a weathering degree ranging from moderately weathered to slightly fractured. However, when the trachyte rock is disintegrated and fractured it loses the structure of a rock and more susceptible to landslide and slope instability problem.

3.7.2.2. Weathered Basalt

The weathered basalt outcrops in the moderately sloping terrain of the wacha mizan area. this rock unit outcrops in the side slope as well as along the gentle slope of the study area . the lithology of weathered degree ranges from moderately to highly weathered basalt that results for the formation of colluvium fractured boulder basalts scattered along the slope terrain. The rock is susceptible to erosion and mass movement by the gravity during rainy season when the ground water table is higher near to the surface.

3.7.2.3. Alluvium soil

Such types of soils are found along the flat to gentle terrain of the slope, at the stream channel courses, and at the base of the river valley. The soils are poorly graded particles, and the majority of the particle size includes silty and sandy clay particles, with a proportional percentage of coarse-grained materials of gravel size. Such soils are unstable debris slope materials and are prone to erosion and flooding by the action of surface water.

3.7.2.4. Colluvium Soil

This type of soil is found mostly at the base of the slope-cut sections of the road, which contain a well-to-poorly graded mixture of silt sand and gravel soils. This soil unit has a mixture of cobble, pebble, gravel, sand, and silty soil that results in slope mass movement when it occurs above the underlying rock slope unit.

3.7.2.5. Residual Soil

This soil unit outcrops on the flat to gentle slope of the study area, which is derived from the weathering of parent volcanic rocks. Further, this soil unit has characteristics of a reddish to reddish brown color and contains mostly clay to silt fine-grained material. Therefore, such soils are easily eroded through the action of surface water, especially during the high rainy season.

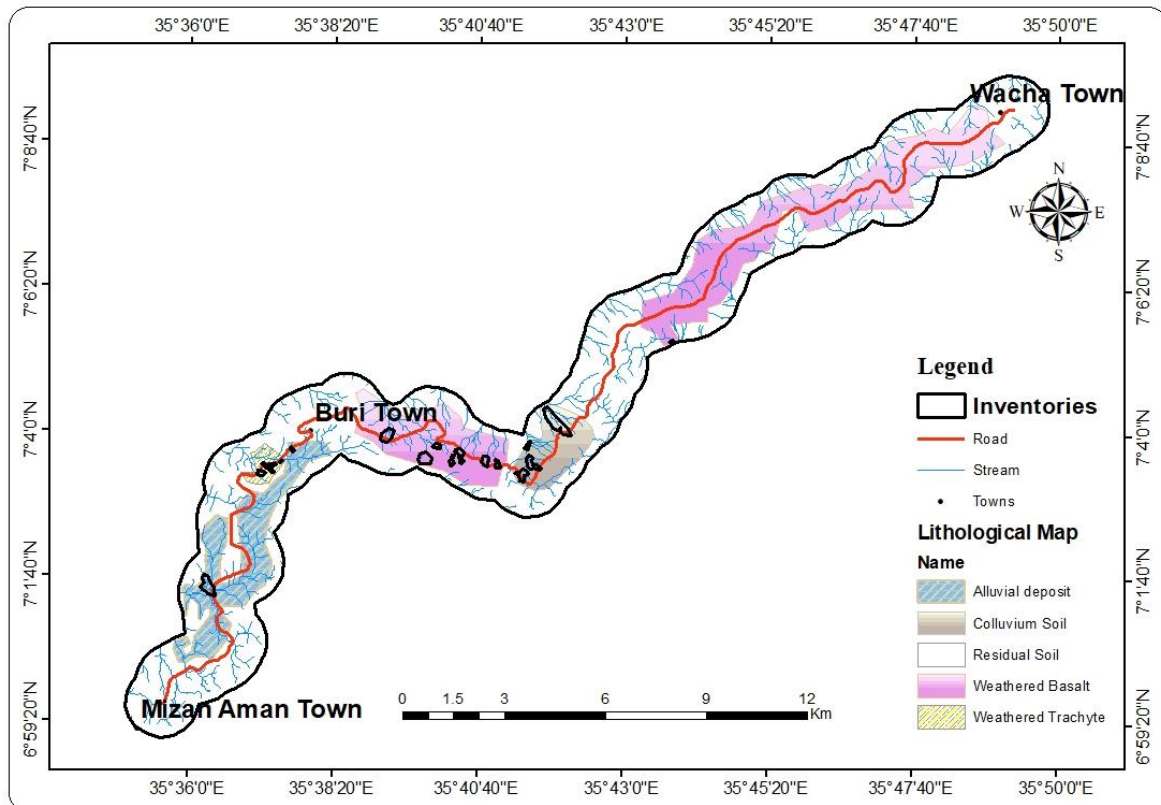


Figure 11: Lithological map of the study Area

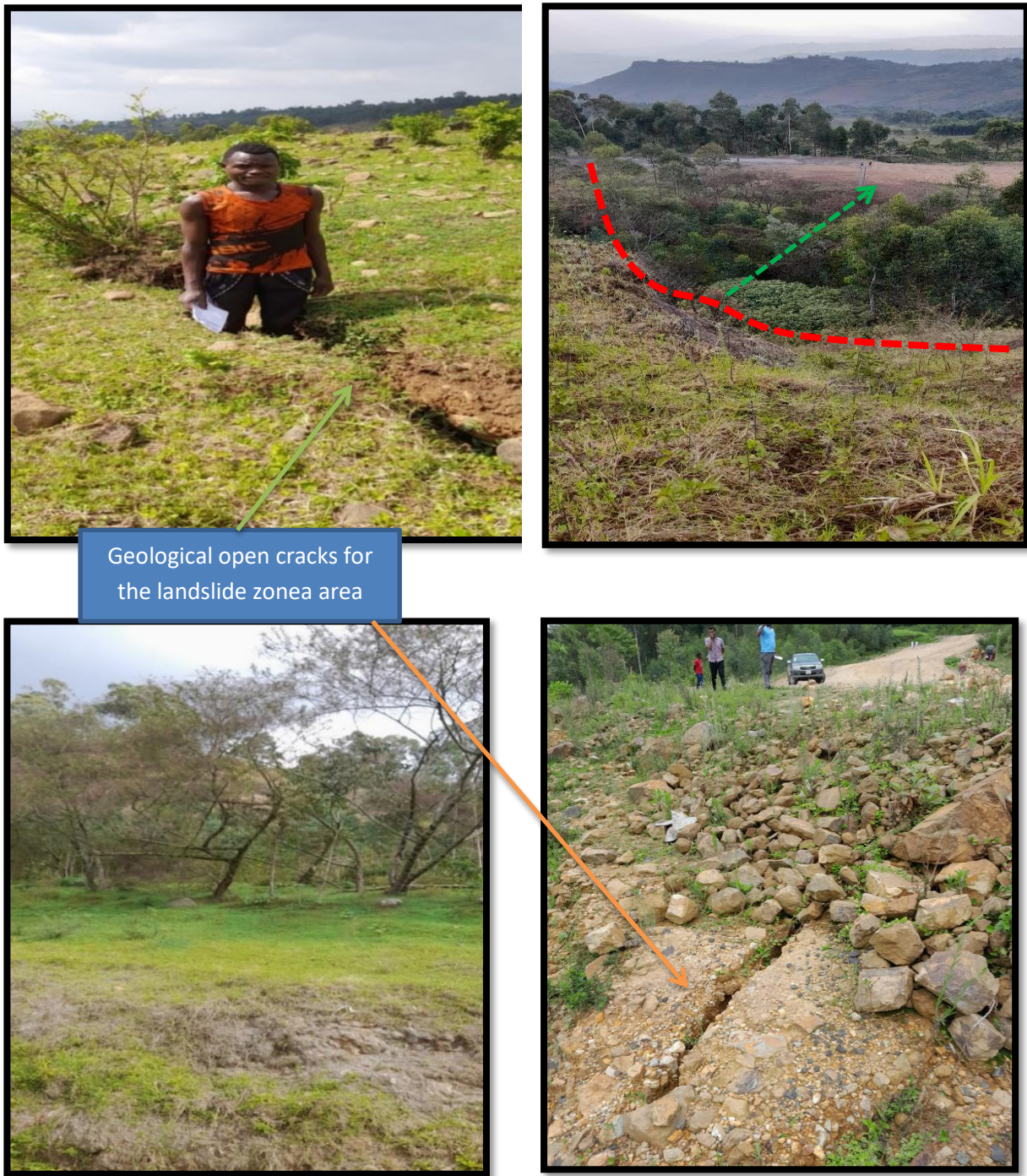


Figure 12: Landslide Hazard of the past landslides in the study area

CHAPTER FOUR

4. METHODS AND MATERIALS

Among the various techniques which have been used for landslide susceptibility mapping statistical approach is widely used (Leulalem Shano et al., 2020). Statistical methods are preferred by many authors for hazard zoning, because of having minimum degree of subjectivity. In statistical method the inventory data from the past landslide coverage were compared with the causative factors which influence the final susceptibility value of landslides. Statistical analysis techniques are determined based on the combination of causative variables and past landslides in a given area. According to the statistical analysis for the relations of the causative factors and the invented landslide activities quantitative estimations are made.

4.1. Methodology

4.1.1. Information value model

Landslide susceptibility mapping is a crucial task for assessing the potential risk of landslides in a given area. One effective method for achieving this is the statistical information value model, which integrates causative factors with landslide distribution.

In this model, statistical information values are used to characterize the likelihood of landslide occurrence based on relevant parameters. The key components of the statistical information value model are causative factors and parameter relations and their relevant weighing factors. The model relies on causative factors that influence landslide susceptibility. These factors include rugged topography, slope morphometry, aspect, curvature, geology, soil, and drainage.

The statistical information values are determined for each class of landslide-related parameters. These values are based on the presence or absence of landslides within specific mapping units. Then to assess the impact of each causative factor, the model combines causative factor maps with the landslide map using weighting factors.

Weighting values are calculated for each parameter class, similar to other bivariate statistical methods. When the statistical information value is negative, the variable does not significantly contribute to landslide susceptibility. Conversely, a positive value indicates a relevant contribution.

In this study, seven causative factors for landslide susceptibility mapping are considered. These factors were categorized into two groups, predisposing causative factors and external inducing causative factors.

The predisposing causative factors include rugged topography, slope morphometry, aspect, curvature, geology, soil, and drainage, while the external inducing causative factors encompass rainfall, earthquakes, and human activities (such as road construction on slopes, quarrying, and excavation). Based on the landslide inventory, thirty-four classes of landslides are mapped considering their topographic conditions, geology, and land cover types.

Specific causative factors like curvature, slope, aspect, groundwater, and proximity to streams, determined for each class based on topographic conditions and spatial relationships. Moreover, land use/land cover classes were defined according to the slope unit's covering in the study area, and lithological classes were derived from the type of slope material units found within the study area.

The choice of causative factors was based on their relative importance in inducing instability in slope terrains obtained from the study on the natural conditions, existing literature, field investigations, and local interviews. According to Yin and Yan (1988), IV can be computed using equations (eq. 4.1 to 4.3).

Conditional probability (calculated using eq. 4.1) indicates the likelihood of landslide activity for each individual class. Prior probability (eq. 4.2) represents the overall area probability for landslides, obtained by dividing total landslide pixels by the total area pixels.

This value remains fixed for each class within the study area. Weight of factor class and statistical information values are used to calculate by substituting the values obtained from eq.4.1 and eq.4.2; and calculated by dividing conditional probability with prior probability.

$$(\text{Con_prob}) = \frac{\text{Number of landslide pixels within the factor class (Nslpix)}}{\text{Number of factor class pixel (Ncpix)}} \dots\dots\dots \text{eq 4.1}$$

$$(\text{Prior_prob}) = \frac{\text{Sum of landslide pixels of whole study area}}{\text{Sum of pixels of the whole study area}} \dots\dots\dots \text{eq 4.2}$$

Statistical information values are assigned to each factor class to obtain weighted factor maps. These weighted causative factor maps were rasterized using look up tool in the spatial analysis of Arc Toolbox.

After rasterizing all causative factor maps the landslide susceptibility index map for each pixel were formed by sum up of individual factor maps using a raster calculator in Map Algebra (eq.4.3):

Information value = $\log (\text{Con_Prob}) / (\text{Prior_prob})$ -----eq 4.3

LSI= IV Slope Material + IV Curvature + IV Slope + IV Aspect + IV LULC + IV Ground Water+ IV Proximity to Stream---- (eq. 4.5). Where; IV = information value

Finally, the landslide susceptibility map was classified into five landslide susceptibility class levels such as very low, low, moderate, high and very high.

4.1.2. Data Collection and Processing

This is the first basic step in landslide susceptibility mapping. In this step relevant landslide conditioning factors are extracted to construct a spatial database. In order to achieve the aforementioned objectives of the present study, it needs to have the necessary information from various data sources. These various data are collected from field visit, remote sensing image analysis Sources and types of data are presented in Table 3.

Table 3 Sources and types of data

Type of data	Source of data
Literature	Published and unpublished paper
DEM (SRTM) and Landsat8 (30m*30m resolution)	USGS
Geological map	GSE
Metrological data	NMAE
Google Earth image	Google Earth

4.1.2.1. Pre-Field Investigation

Pre-field investigation stage comprises the compilation of secondary data and gathering of the necessary required materials from various organizations to understand the general overview of the study area. Those tasks conducted during this phase of investigation includes:

- Literature review, articles and websites related to landslide hazard susceptibility, both
- unpublished and published papers were collected and reviewed in order to have a general background and a conceptual framework about the study area.

- Previous maps such as lithological map for understanding the geology of the study area collected from geological survey of Ethiopia. Hydrogeological data describes about groundwater of the study area collected from the ministry of water Resources .
- Meteorological data were collected from Ethiopian meteorological agency to acquire general understanding about climatic conditions of the study area.
- Slope, elevation, aspect, curvature, and proximity to the stream were prepared from the Digital Elevation Model (DEM) at a resolution of 30 m by 30 m obtained from the Aster DEM data set by using Arc GIS v 10.8.

4.1.2.2. Field Investigation

During the field visit, validation of the pre-field work and relevant data collection for the present study were conducted. Field investigations were conducted to confirm the necessary data collected from the secondary sources. A field investigation was mainly undertaken to have all relevant information about past landslide activities in the area and to verify various causative factor maps prepared during the prefield works. This stage of investigation is important to validate the causative factor maps that were prepared during the prefield investigation stage.

The activities that were carried out during field investigations are: -

- GPS locations about the type, mode of failure, and volume of past landslides were collected using topographic maps and GPS.
- Taking photographs of the past landslides, geology, and geomorphology of the area
- GPS point data of spring sites for the surface manifestation of groundwater were collected from the slope surface to characterize the effect of groundwater on the slopes.
- Data on artificial man-made activities like road or building construction, quarrying, slope stabilization, and excavation were observed and recorded.
- The previous geological map has been verified and revised during field investigation.
- Land use and land cover maps were observed and validated through field excursions.

4.1.2.3. Post-Field Investigation Data Processing and Analysis

After compilation of both pre field work investigation and field observation, the data has been systematically analyzed using available techniques like GIS software's. The following activities were done during post field investigation stage.

- The process of creating a landslide inventory polygon involved demarcating the boundaries of landslides for inaccessible areas and overlaying field GPS failure point data on Google Earth images for the accessible areas. An inventory of landslides was created using GPS bounds for places that were reachable.
- Thematic map layers of causative factors were prepared using secondary and primary data in Arc GIS v 10.8. Later, all these maps were converted into raster form by using look- up tool analysis of Arc GIS v 10.8.
- Using overlay analysis on inventory maps, all factors contributing to previous landslides have been quantified. The landslide susceptibility index (LSI) maps are produced by adding up all of the raster causative factor maps using a raster calculator in Arc GIS version 10.8, following the rasterization of the factor maps using the look up tool. Five maps representing the class levels that are susceptible to landslides (very low, low, moderate, high, and very high) were created. Finally, landslide susceptibility map was validated through inventoried landslide map.

4.1.3. Materials and Software's

4.1.3.1. Materials

Different materials were used before, during, and after field investigations. Those various types of materials include cameras for capturing photos during field investigation, laptops and desktop computers, topographic maps, GPS, and stationery materials, including a note book, pen, and pencil. GPS was utilized to pinpoint landslides, lithological boundary contacts, and springs on a topographic map.

Table 4 Descriptions of causative factor layers and source

Causative factors	Data	Data type	Data source
Slope, aspect, Curvature and proximity to Stream	SRTM DEM	30m grid	USGS
LULC	Sentinel 8 Image 2021	10m grid	USGS
Lithology	Geological map 1:250,000	Polygon	GSE
Ground water	Springs	point	GPS Inventory

4.1.3.2. Software's

Different types of software's were applied for this thesis work such as Microsoft office Excel 2010 and Microsoft office Word 2010 version for data processing as well as for report writing purpose. In order to process data and write reports, various software packages were used for this thesis project, including Microsoft Office Word 2010 and Excel 2010.

ESRI Arc GIS version 10.8 was utilized to create different thematic maps and prepare their layout. ArcGIS version 10.8's supervised classification technique was also used to create the LULC map of the study area.

The Digital Elevation Model (DEM) from the Shuttle Radar Topographic Mission (SRTM) was processed using Global Mapper 15 to create a 3D model physiographic map of the research area using a 30m*30m resolution DEM. Slope, aspect, curvature, maps of the study area are prepared using the general technique of the study, which involves downloading aster DEM satellite image data. Ground water map delineated by surface groundwater indicators such as springs to rate as dry, wet and flow.

A field work investigation was conducted to verify the nature and extent of landslides and create an inventory map of the landslides using Google Earth. In order to determine the causes and triggers of the landslides that happened in the study area, the bivariate statistical method known as Information Value Modeling statistical method was used in this study.

Based on the presence of landslides in the specified mapping unit, the statistical information values are determined for each class of landslide related parameter.

To determine the weight of each class, the landslide map and the causal factor maps were combined. In the statistical modeling of landslides, the assumption is based on the rule "the past is the key to the future". For the present study six prominent causative factors are considered for the landslide hazard susceptibility. These causative factors are i) slope material, ii) slope, iii) land use and land cover iv) groundwater and v) aspect vi) curvature.

Pre-field works include secondary data collection related to previous field reports, topographical maps, satellite images, and Digital Elevation Model (DEM) data. The landslide hazard causative factors were processed using Arc-GIS built in software and ratings were given based on the contribution of each factor for the occurrence of mass movement of the slope and landslide hazard index of the study area were calculated.

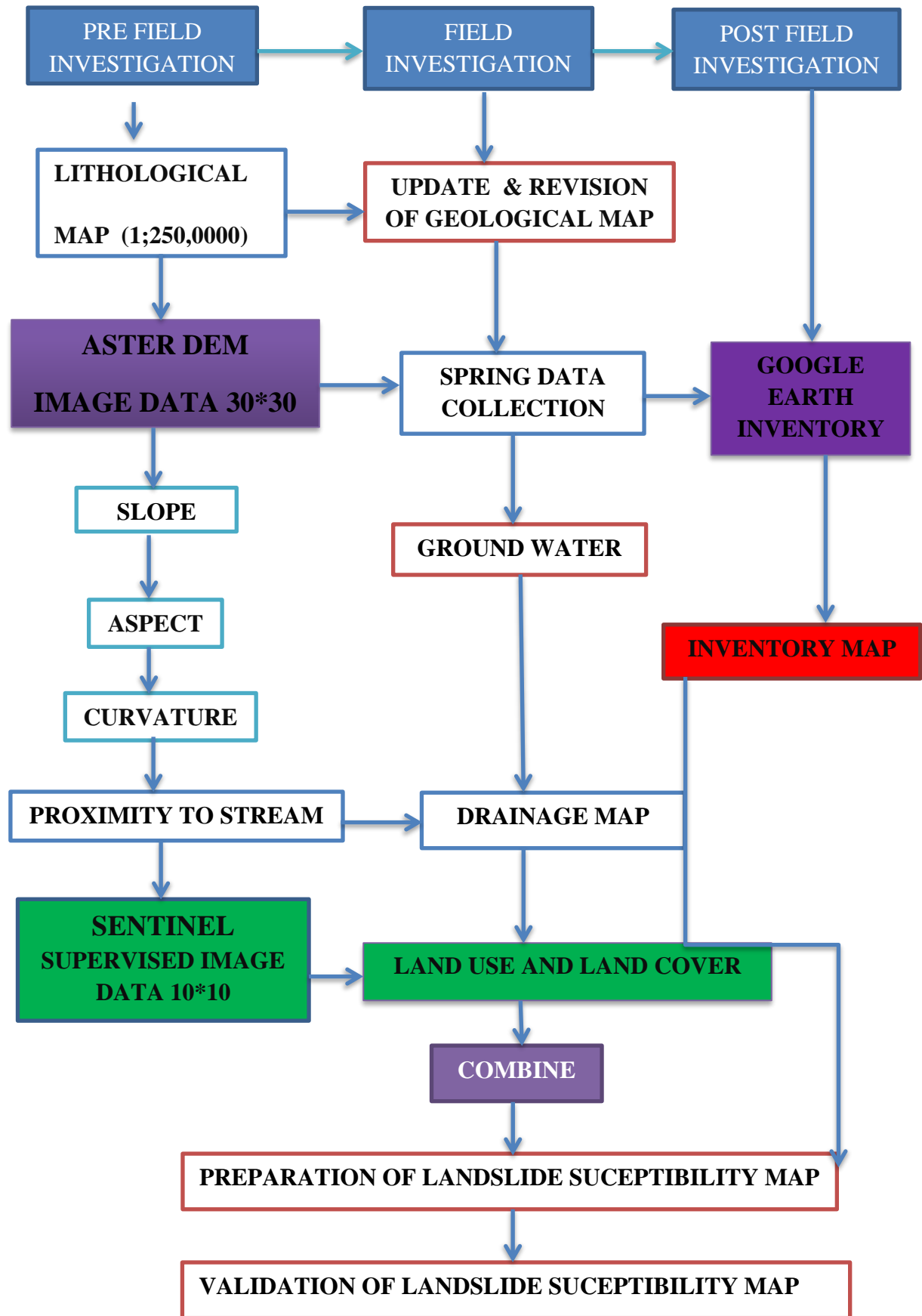


Figure 13: Flow chart of general methodology adopted for the study

CHAPTER FIVE

5. LANDSLIDE CAUSATIVE FACTOR EVALUATION

The previous landslide data is necessary to assess landslide susceptibility and to create the landslide inventory map. The distribution of past and present landslides in a given area must be identified, located, and understood in order to estimate the likelihood of landslides occurring in the future (Guzzetti et al., 1999). The landslide inventory determines the likelihood of a future landslide, which indicates the probability that landslides will occur in the future and will be similar to those that have occurred in the past (Lee and Talib 2005).

5.1. Landslide Inventory Mapping

The Wacha-Mizan road is located in an area with difficult terrains with a high and long rainfall season. The road section has a history of landslides due to the geological, geomorphic, and climatic conditions. These conditions make the road highly susceptible to instability problems. The instability is caused by various factors including poor drainage, high seasonal rains, and geomorphological active conditions.

The studied road section has suffered from multiple and recurring landslides that seriously affected the road's sustainability. This is due to the nature of the geomorphological conditions and extreme climatic conditions characterized by high and long-duration rainfall. The mapped instabilities include deep and active landslides; slope failure of soil and rock mass; failure of colluvial-alluvial hills and slopes; creeping, settlement, and subsidence of residual formation; erosion and saturation of pyroclastic slopes that caused slope and hills instability; rockfall sections; side slope instability caused by erosion of culvert outlets; and spoil piling or damping of reworked earth material deposits that triggered landslides and instabilities on saturated residual soils. Some of the major manifestations of landslide problem on this segment includes:-

- There are deep-seated rotational failures that are affecting the back slope, the roadbed, and the side slope. These landslides are active and intensifying that are results of either reactivated from old landslides due to modifications in the road slope geometry, or due to deep slope cuts within weak residual formation, or interface of soil mass with the underlying rock when saturated with surface and groundwater.
- There are also shallow earth slide translational failures that are caused by improper management of surface and subsurface water flow.

- The soils during rainfall season are prone to sliding by surface water flooding due to losing of grain to grain contact of their shear strength property found within the soil mass.

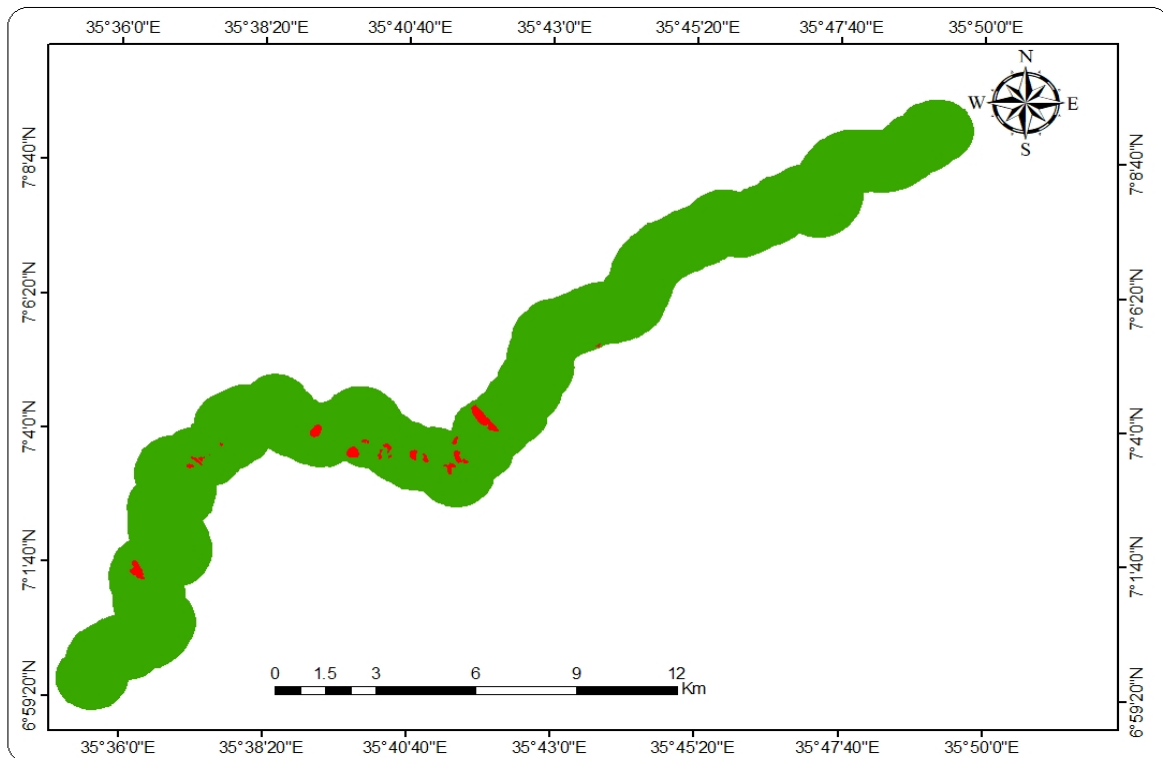


Figure 14 : landslide inventory mapping

5.2. Causative Factors

5.2.1. Slope Map

The slope layer is an important topographic parameter in slope stability analysis which comprises five parameter classification classes.

According to Raghuvanshi et al. (2014) and Anbalagan (1992) slope morphometry map can be classified into 5 classes: very gentle slopes ($<15^\circ$), gentle slopes ($16-25^\circ$), moderate steep slopes ($26-35^\circ$), steep slopes ($36-45^\circ$) and escarpment ($>45^\circ$). Therefore, most of the landslides were concentrated on the gentle to moderate slope classes of 0-15 and 15-25 slope degrees. As the slope angle increases the frequency of landslide activity decreases.

This indicates that the landslides are also prevalent in the moderate slope to gentle terrains of the wacha mizan area due to the reason that more than half of the slopes of the study area is found in the slope class of $0-25^\circ$.

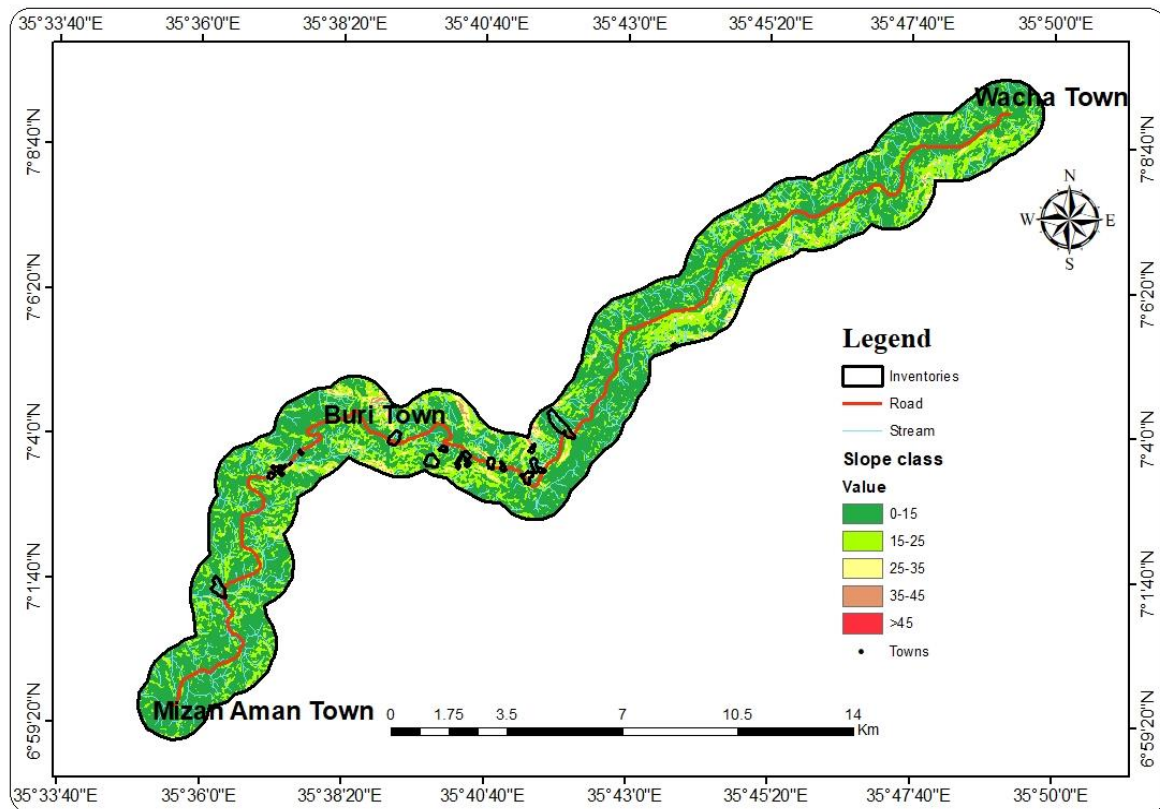


Figure 15: slope map of the study area

5.2.2. Aspect Map

Aspect represents the direction of the mountain slope face concerning solar radiation. Exposure to incident solar radiation, rainfall and discontinuities which are related parameters of aspect that can have the potential for the control of the occurrence of landslides.

Aspect map is the map that shows the ground slope direction for a terrain with respect to North. It indicates that the degree of inclination of the slope with respect to the wind and solar radiation which side of the slope is facing sliding movement. Although there is a relation between the aspect and the mass movement, no general criteria have been described regarding the aspect landslide relationship (Ercanoglu et al. 2004). The aspect maps in our study area were divided into 10 categories. Aspect direction which are inclined towards north, north west and north east are more prone to landslide activities.

This could be due to the slope directions dipping towards north may receive more solar radiation and rainfall humidity. As a result the slopes facing towards north are more affected with weathering conditions which is responsible for the sliding activity.

In addition, from the aspect orientation it is possible to deduce that the south facing slopes are more covered with forest vegetation where as the north facing slopes have asparse vegetation cover with bare agricultural lands. As a result, the landslide activities are more concentrated towards north facing slopes due to the overlay analysis of slope aspect causative parameter.

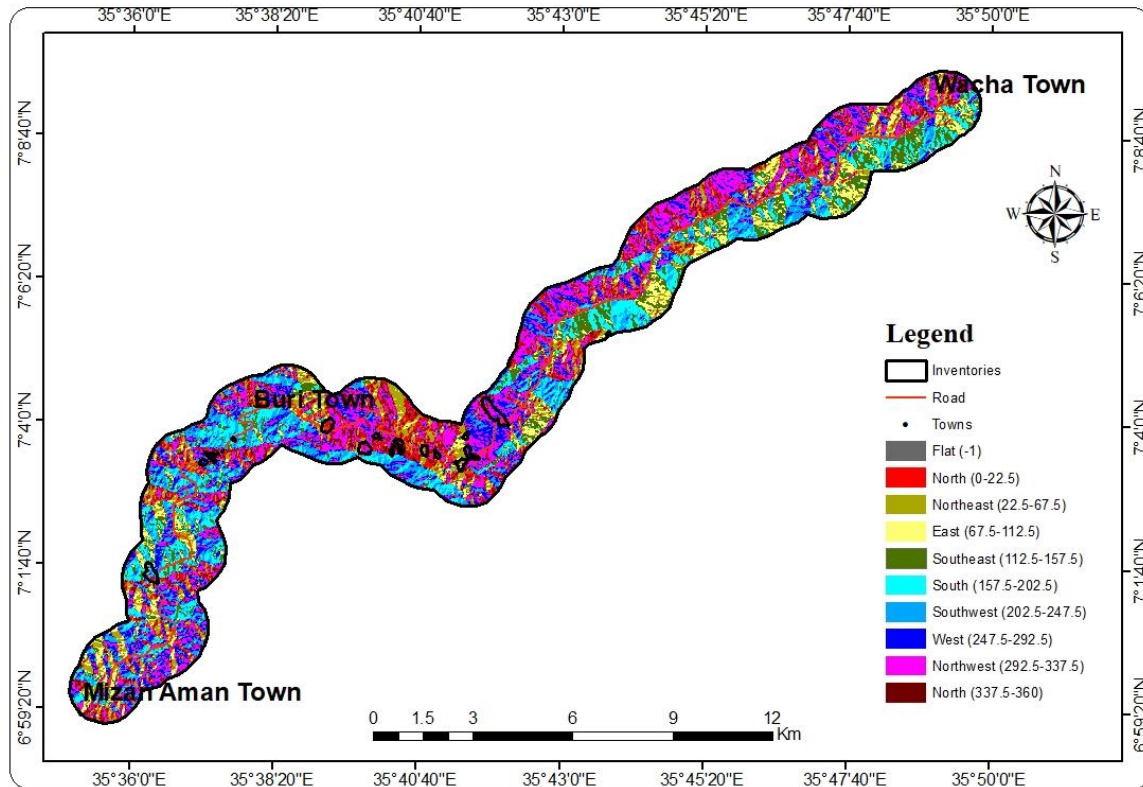


Figure 16: Aspect map of the study area

5.2.3. Curvature Map

According to Fikre Girma et al. (2015), curvatures are topographical causative factors that represent the shape of the mountain terrain surface. Curvature parameter have an impact on landslide due to the flow of surface and ground water accumulation on Earth.

As a result, they are thought to be one of the conditioning causative factors for slope stability and landslide occurrences. From the topographical DEM analysis slope convex class have derived which comprises an area of 18.7% indicating that earth flows have the probability to occur in such slopes. However, concave classes have an areal coverage of 41.9 % indicates that it is more prone to surface erosion or landslide activity. The rest of 39.4% class is covered by flat curvature class.

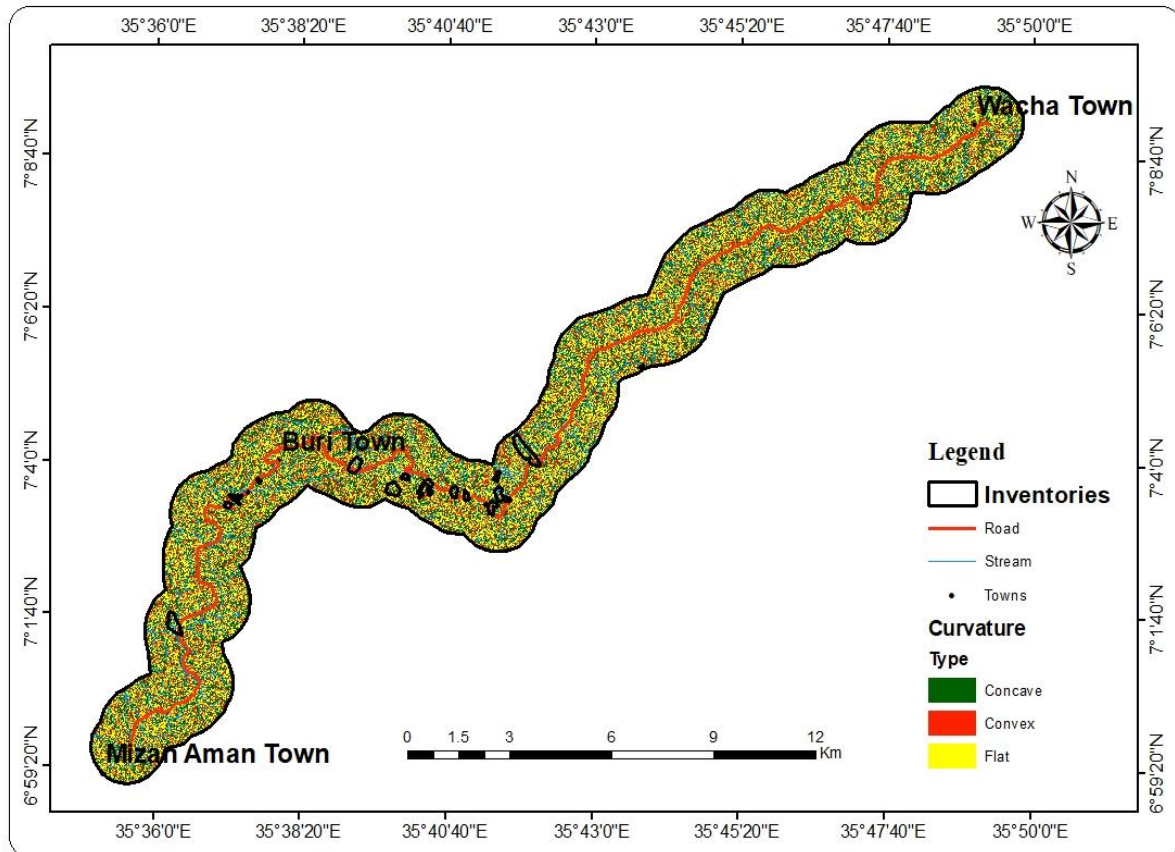


Figure 17: Curvature map of the study area

5.2.4. Groundwater

Groundwater is considered as one of the main causative factors of landslide due to the development of pore water pressure in soil and rock masses of a given slope material. Groundwater is considered to be one of the primary causes of landslides because it creates pore water pressure in the rock masses and soil of a particular slope material.

Increased pore water pressures, increased saturation of the rock and soil units, and an increase in the groundwater table in the saturated zone can also be caused by infiltrated water in the unsaturated zone of the slope, which can lead to mass movement and slope failures. In the mountainous areas of southwestern highlands of Ethiopia, the ground water level is considered to be shallower in depth. due to this reason, the rise of groundwater at those areas contributes for the saturation of the slope mass by decreasing the strength of the slope material and the cohesion binding forces that holds the slope material or soil mass together.

According to (Chowdhry, 2010), water reduces the apparent cohesion due to capillary forces, which results in the reduction of shear strength slope materials of a given slope that binds the slope materials in place.

The moderate slope mountainous terrain acts as surface water drainage that divides areas of the ridge slopes to recharge the groundwater into relatively low gentle slope areas. Streams can affect the stability of slopes by erosion or saturation of the lower part of the slope-forming material (Dai et al. 2002).

The primary cause of landslides for the slope can be increase of groundwater table on the side slope of the road at the crown part or upper part of landslide block during the time of high precipitation or rainfall. When the infiltration rate capacity of ground water for the slopes is lower than the given amount of rainfall it results in an overland flow through saturation or erosion of colluvium residual lithological materials by the surface water. Therefore, the areas near to the stream which have weak geological slope materials were more prone to erosion of the slope materials by the surface and subsurface water.

When unconsolidated colluvium material overlies more impermeable slightly weathered bedrock, the ground water becomes confined and perched due to the reason that surface water flows laterally into the ground by gravity until it reaches the less permeable geological stratum. This is manifested in the form of emerged spring or seepage of water near the lower part of the slope surface of the landslide block.

Groundwater builds up above the impermeable stratum that flows laterally to the slope face where it emerges as a line of seepage or spring. Perched ground water develops in colluvium materials and builds up pore water pressure on the colluvium materials of the slope which were considered to be medium to high permeability that causes saturation for the mass slope of the given material. Because of the high groundwater level and constant recharge from rainfall, particularly during the rainy season, erosion of lithological colluvium materials and weathered rock debris by surface and springing water causes mass movement of slopes in the study area. Since the ground water level is rising on the slope surface during the rainy season, the formation of permanent to intermittent streams produces gully erosion of the slope surface. Perennial springs which were observed during field visit indicates that the ground water is a perched type of aquitard hydrogeological layers that exist between the bedrock and the upper shallower colluvium soils. Those spring flows have the potential to create gully and erosional surfaces at the slope sides of the stream surface.

Therefore, this hydrogeological formation or unsaturated soil surface acts as a slip surface for the landslide block through inducing instability to the slope by lubricating the underlying soil and increasing the weight of the slope mass. most of the spring water flows have a characteristic of perennial or ephemeral type of flows.

This indicates that the seepage of groundwater is the main reason for causing slope mass movement by scouring action of erosion of the side support of the slope surface in which the stream water is flowing. Ground water recharge is limited by the topography in the mountain area. However, tectonic activities such as fracturing and weathering of the volcanic rock of the highlands enhance both infiltration and the depth of groundwater circulation.

Infiltration in the highlands is mainly through direct percolation of rainfall through the soil to the porous rock aquifers. This zone is also partly recharged by groundwater flow from the highlands and by bank infiltration from permanent and intermittent rivers through floods during rainy season, which is an important recharge mechanism.

The relatively undulating as well as flat morphological character of the area causes shallow circulation of groundwater in the aquifers. The groundwater flow direction coincides with the topography, following the surface water flow direction because small intermittent and particularly perennial rivers form local drainage levels for shallow and deep aquifers. Groundwater is mostly under confined water table conditions.

However, surface water flows in the form of springs were observed in the trachytic and rhyolitic rock aquifers. For the delineation of homogenous ground water zones Ground water surface trace indicators such as Dry, Wet and Flow spring surface traces were considered. Dry areas characterized as no water traces along structural discontinuities, dry rock face surfaces. Flowing areas showed presence of spring on slope faces.

Wet areas indicated water marks on rock surface, some droplets along structural discontinuities, algal growth in shadow areas. Springs emanate from the base of the ridge slope and where the flow laterally towards the side slope of the road and result in piping and erosion of thick overburden and colluvium soil deposits.

Therefore, most of the perennial springs were found in the wetland surface and in the form of discharging flows responsible for the mass movement and washout of debris materials. However, in dry classes where there are no evidence of groundwater landslide does not occur.

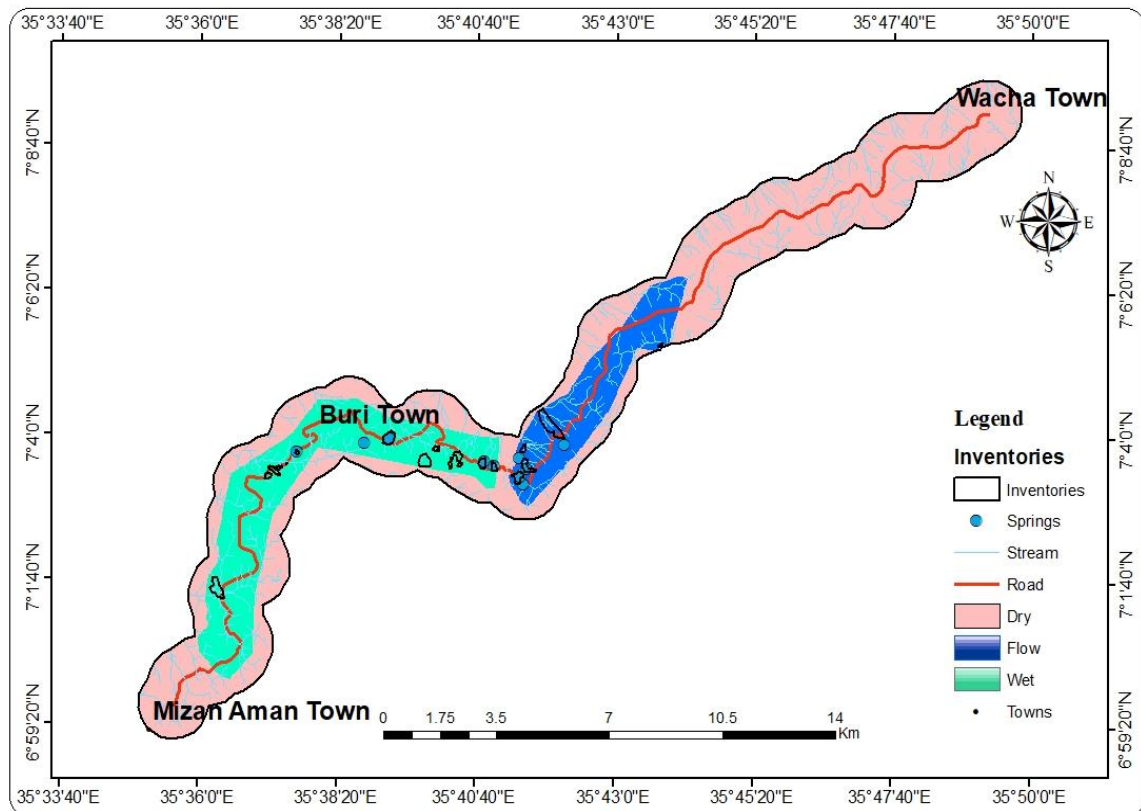


Figure 18: Ground water map of the study area

5.2.5. Proximity to Stream

The area is found at the water divide or drainage lines of Baro Akoboo basin and Omo Ghibe basin. Therefore, the stream characteristics have different types of drainage flow lines in the study area. The drainage pattern of the study area is characterized by a dendritic drainage pattern, which is mostly the gradient of surface water flow converging from the upper slope part of the study area towards a slope direction to gentle down slope areas. The dendritic drainage water flow pattern follows the topography of the slope by cutting and eroding the sides of the meandering river valley of the slope.

A proximity to drainage map was constructed based on the field observation findings, which indicates that landslide disasters occur more frequently near the streams as a result of the undercutting action of streams and groundwater flows moving towards the base of the stream. Surface water has the potential to erode the sides of the upper mountain ridge slope through the formation of gully surfaces on the side scarps of the landslide, especially during the high rainy season. Due to the higher flooding activity that is triggered by rainfall, the study area is affected by recurrent landslide activity.

According to the local people's explanation, the landslide activity has been frequent for more than 15 years and can affect their agricultural fields through lateral erosion of the upper soils by the action of surface water. The erosion of the slope mass is caused by streams carrying erodible soils from the upper slope to the flat plain areas deposited by the surface water gradient. Examples of these soil transported and eroded by surface water includes Colluvium, reddish silty clay, and sandy gravel soils.

Gully surface on the study area is manifested in the form of open tension cracks at the sides of mountain slopes through the action of streams and rivers. Infiltrated water percolation in the cracks of the ground surface leads to saturation of the slope by the surface water that has the potential to induce slope movement in the area.

Streams adversely affect stability of slope masses through saturation of the lower part of the slope material by developing pore water pressure which creates favourable condition for mass movement through increase of ground water level in the slope.

At the time of field observation streams are categorized as intermittent to perennial type of stream have a potential to erode the weathered part of Colluvium slope materials and create favourable condition for the landslide prone segment in moderately steep ridge slopes particularly when there is high amount of cumulative rainfall. Infiltrated water percolation into the ground surface leads to saturation of the slope by surface water that has the potential to induce slope movement in the area.

Steeper slopes transport more Colluvium and soil debris material into gentler slopes as the potential of slope gradient decreases starts to deposit coarser materials first followed by fine residual soil materials in flat to gentle slope areas.

Therefore, as the rainfall increases the possibility of landslide or mass movement increases due to the scouring action of the stream course becomes higher that ultimately results in gully erosion of upper Colluvium and residual soils. During the hydrological cycle of the given slope terrain, parts of rainfall other than the surface and groundwater flow were intercepted by vegetation before reaching the ground surface. The surface water infiltrates into previous soils and rock units that lie in ground depressions or flows as runoff.

Runoff is strongly influenced by the infiltration capacity and topographic setting of the study area. during field visit, There is a stream flow of water observed at the lower part of the landslide failure block infiltrated through tension surface cracks that acts as a groundwater conduit to infiltrate the subsurface water that comes from the the head or upper part of the landslide slope.

The rivers flow out from the upper part of the slope to downward part of the slope following the topographic gradient or slope pattern of the study area. Therefore, proximity to stream is calculated by buffering the drainage lines. The more the stream distance from the drainage the less effect on the erosion of the slope and hence its effect to the creation of landslide and slope instability problem. there is seepage of water observed under the manhole culvert structure and flows towards the lower stream channel of the river.

The flow of stream order or discharge flow rate increases in magnitude in the down slope direction due to the convergence of streams occur from low to high order following the surface topography of the slope towards gentler slope areas of the main river channel. Colluvium slope materials and alluvium deposits such as gravels, silts and sands intercalated with clays materials were deposited in the slope side as well as at the bottom of the stream river valley. The more the stream distance from the drainage the less effect on the erosion of the slope and hence its effect to the creation of landslide and slope instability problem.

There is seepage of water observed under the manhole culvert and flows towards the lower stream channel of the river.

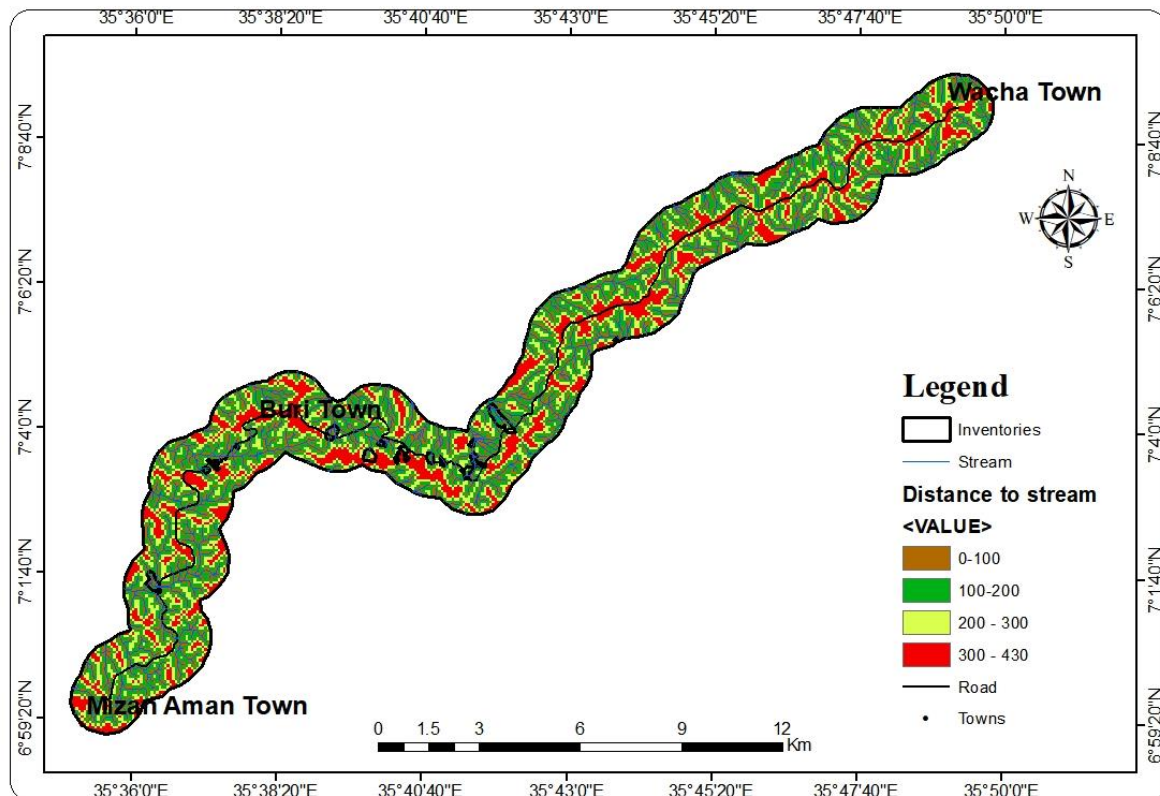


Figure 19: Proximity to stream map of the study area

5.2.6. Lithology Map

Thus, geological features such as tension open cracks that runs from the crown part of the road cut of the hill slope section towards the lower part of the landslide block section were considered as a medium of channel to transport the infiltrated water into the slip surface of the landslide block thereby making the slope mass into a marginally stable state.

The geological materials involved in the past landslide deposits include a mixture of basaltic Colluvium material with a different type of grain sizes such as silts , clays ,sands, gravel and boulder slope materials. Thick Colluvium soils have a thickness of more than 5 m in some of the studied areas of the slope section. The proportion of the mixture of Colluvium soil in the study area characterized by coarse grained soils such as large sized boulder gravel and sand particles intercalated with appreciable amount of clay and fine silt soils.

As a result of the geological parent material type in the area being highly decomposed and weathered, as well as being affected by fracturing on the slope, there are manifestations of active landslide progress, and those manifestations develop on the landslide area of the ridge slopes topography. The upper parts of the cut slope are inclined and dip towards the road.

Due to this reason, the fracturing of rocks on the slope and formation of cracks play a great role in the activation of the old landslide material by storing water as a temporary perched layer or aquifer in terms of groundwater storage.

The weathering degree of a trachytic rock as observed during field observation is from moderately to highly weathered as well as higher fracturing degree that can lose their shear strength and more susceptible to surface erosion which results in slope instability problem. The dominant rock types in the study area include moderately to highly weathered basalt; light Gray colour rhyolite and Trachyte which undergone different degree of fracturing and intensive weathering that creates favourable condition for the slope mass movement.

The rhyolite rocks when weathered lose the binding forces b/n the particle which makes the rock slope more susceptible to failure. The dominant soil type in this area that includes reddish Gray to dark brownish silty clay rich thick overburden residual soils which are found at the contact of weathered volcanic rock such as basalts and Trachyte rocks.

The soil materials involved in landslide includes the mixture of unconsolidated heterogeneous materials such as Colluvium deposit, alluvial deposits as well as residual soils. Silty gravel soils of Colluvium type of soils were the main geological materials of the study area derived from volcanic rocks such as weathered basalt and pyroclastic rock units.

The presence of clay derived from weathering of volcanic rock contributes to the tendency of soil masses to fail in shear. The main type of geological units found in the study area includes Colluvium materials, alluvium soils and transported basaltic and silty gravel soils.

Gully scarp surface features were formed on the ridge of the terrain of the slope by stream lateral erosion of the rock soil interface layer through the action of gravity and surface water.

Colluvium geological materials such as Silty clayey gravel soils intercalated with boulder basalts scattered in the midway slopes and residual soils in gentle slopes.

The material type observed on this road segment includes transported Colluvium materials which includes a wide range of intercalation of pebble, boulder and gravel size material intercalated with sandy clay type of soil. Colluvium and alluvium soil deposits such as gravels, silts and sands intercalated with clay materials were accumulated in the side slopes of the bottom of the stream river valley.

The proportion of soil includes more than 50 % of coarse grained soils such as large sized boulder gravel and sand particles intercalated with appreciable amount of clay and fine silt soils. There are tension cracks with a width of more than 50 cm which acts as a surface water conduit for the infiltration of surface water into the ground and thereby activate sliding process of earth materials in the slope terrain of the Wacha Mizan road segment.

Due to this reason, open geological fractures play a great role in the activation of the old landslide material by storing water as temporary perched layer or aquifer in terms of ground water storage. The slightly to moderately weathered volcanic basalt and Trachyte rocks have more strength than the highly weathered and decomposed rock unit and therefore they are more resistant to mass wasting and slope instability problem.

Therefore, assessment of rock mass strength is also one of the lithological factor considered during landslide causative factor study. The Colluvium materials embedded in a reddish clay soil matrix units have low frictional forces and lose cohesion during high rainfall seasons.

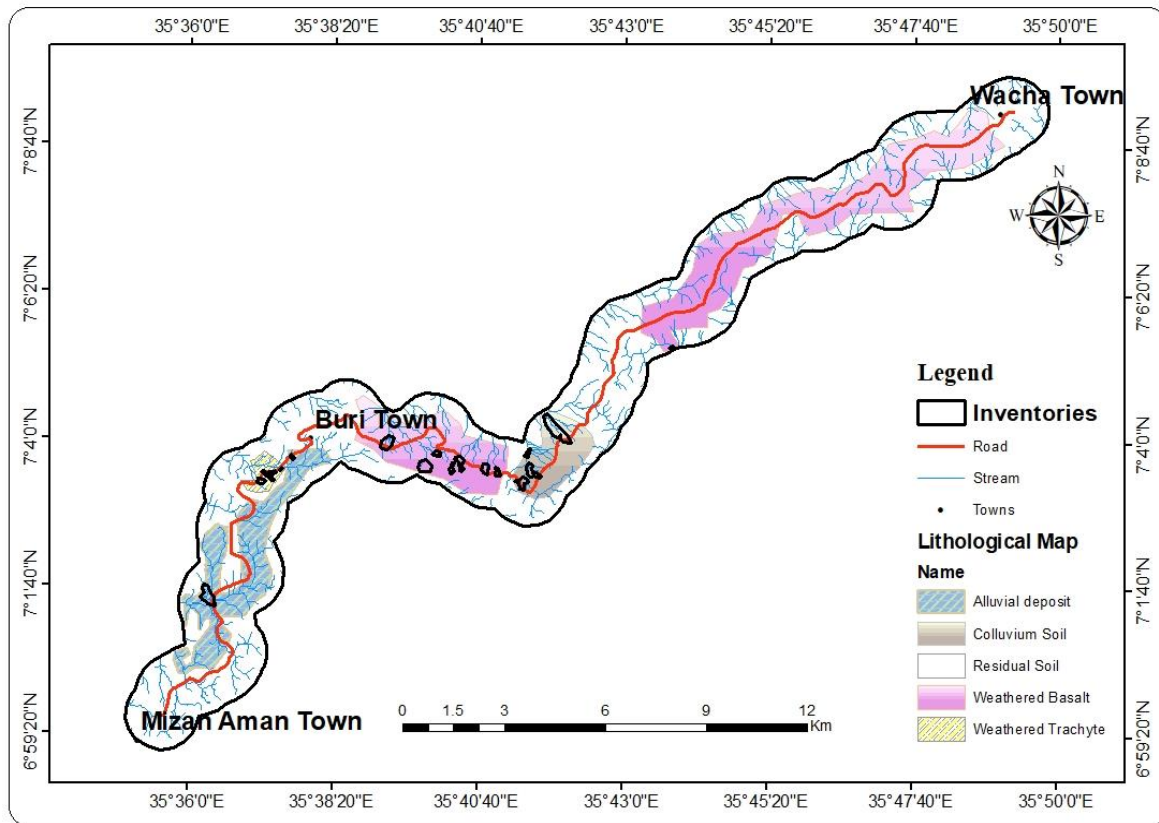


Figure 20 : Lithology map of the study Area

5.2.7. Land use and Land cover

The land cover and land use were considered as one of the most important landslide causative factors that affect the formation of landslide activity. The land cover types in the south west region includes eucalyptus, natural indigenous forests such as large oak olive trees, shrubs, girar etc. whereas the main cultivated agricultural products in the area include banana, coffee, maize or gidole, goner.

At the time of field observation the area is covered with agricultural crops, grazing lands and natural forest vegetation where as some of the area is bare land and the other land use is a settlement area. land use changes caused by human factors considered as one of the causative factors that may influence the slope mass movements and erosional susceptibility of the land catchment area. Improper slope land cultivation or grazing on the slope, removal of vegetative cover through deforestation for the search of new agricultural lands, road construction as well as the development of old outcrop quarry sites for the purpose of road construction aggregate material can contribute to the occurrence of landslides and debris flow in the study area.

The hilly and mountainous ridges of the slope terrain were covered with dense forest mainly of indigenous mixed with eucalyptus tree. The land surface which has a thick forest vegetation cover is relatively stable that can withstand the effect of slope movement through the action of binding force within the tree roots.

However, slopes with poor vegetation cover were more prone to slope movement during the time of high rainfall through the action of surface water. The agricultural bare lands have sparse vegetation cover that was occupied mostly with some eucalyptus and other indigenous forests susceptible to mass movement due to the erosion of the upper residual soil by flooding of surface water. Because the agricultural lands were responsible for erosion of the ridge slopes of the area through flood activity.

Thus, vegetation cover has a role in binding the Colluvium sliding loose soil materials through the action of their root and control Evapotranspiration through regulating micro climate of the ecosystem nature of the study area. Human made factor that cause landslide problem includes the construction of the settlement houses for residential purpose on the up slope areas that can have an impact for changing the direction of Stream flows through eroding soils of Colluvium slopes.

Agricultural practices without proper terracing and surface water management have an impact for decreasing shear strength of the slope mass. Therefore, settlement activities and agricultural practices on the slope were considered to be one of the possible human made landslide triggering factors that can induce instability problem to the slope.

Another man-made factors that cause landslides in this area were spoil of dumped material to the road side slope during the time of construction of road due to the surcharge weight of overlying slope material induces mass movement by decreasing the shear strength of the soil. Weathered rock materials and Colluvium spread midway down to the base of the gentle slope. Shear strength of slopes is reduced during road construction due to excavations and the unloading of the slope mass, which modifies the slope geometry.

Construction activities such as rock excavation for use as road aggregate and quarry sites also have a potential to exert a surcharge load on the slope surface. from the land-use and land cover map it is possible to indicate agricultural lands and settlements were more prone to landslides due to settlement activities in mountainous area makes the slopes more prone to failure. Poor farming practice of agricultural lands, management of activities and practices were also responsible for the failure of slope mass by flooding and erosion.

The land cover classes of forest and vegetation have less prone to landslide activities due to the very nature of the trees have the capacity of regulating Evapotranspiration of the area in addition to preventing erosion through spreading of their roots into Colluvium residual soil formation.

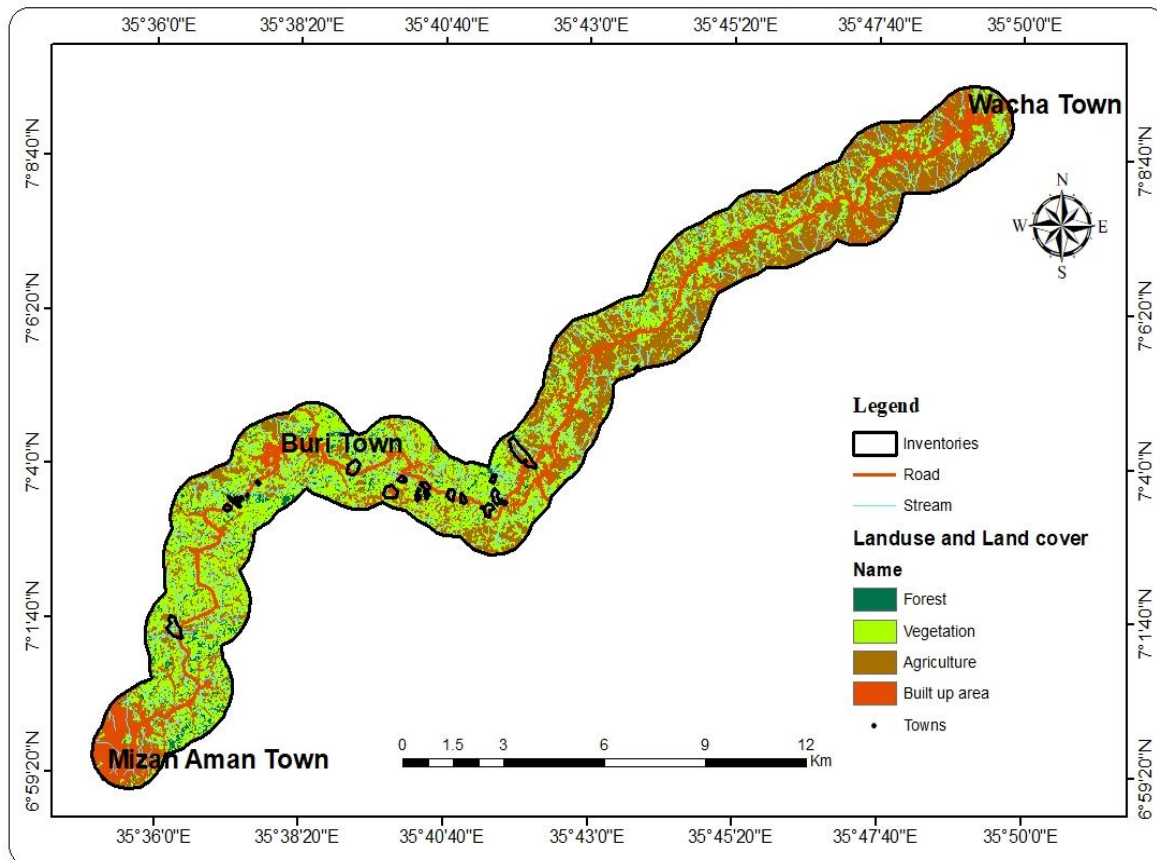


Figure 21: Land use and Land cover map of the study area

Table 5 Land use land cover classes and their areal coverage

No	Land use and Land cover Classes	Areal coverage (Km ²)	Percentage (%)
1	Forest	2.795544	3.36%
2	Vegetation	37.904174	45.57%
3	Agriculture	29.140741	35.03%
4	Built up area	13.338141	16.04%
5	Total	83.18	100

CHAPTER SIX

6. RESULTS AND DISCUSSIONS

6.1. Causative Factors Influence on Landslides

This study has analyzed the relationships between seven causative factors and landslide occurrence using the statistical information value model. For the present study, the seven causative factors were selected based on the nature of the study area, a literature review of previous works, field evaluation, and local people's interviews, since there are no universal guidelines or principles to select the main landslide causative factors in landslide susceptibility mapping (Shahabi and Hashim, 2015).

The selected causative factors, such as slope, aspect, curvature, groundwater, proximity to a stream, slope material, and land use and land cover, are considered primary causative factors for landslide occurrence. The causative factors were classified into thirty-four different parameter zones. The weights assigned for each causative factor class of statistical IV models are presented in Table 6.1.

The weight values derived from statistical IV model shows the spatial relation of the causative factor class contribution for the landslide occurrence. According to Yin and Yan (1988), When the statistical IV value is negative the causative factor has no contribution for a landslide occurrence whereas if the statistical IV value of the causative factor is positive the causative factor has contribution for the landslide occurrence.

The statistical IV method values are calculated, and their results are presented in Table 6. This study applied the statistical information value method to examine the relationships between seven causal factors and the occurrence of landslides. A total of 34 classifications were created in the GIS environment to categorize the causal factor elements.

Note: N_{cpix} = Factor class pixel count, N_{slpix} = Landslides pixel within factor, Con_prob = Conditional probability, $Prior_prob$ = Prior probability, $Con_prob / Prior_prob$ = Weight of factor classes, IV = Information value.

Table 6 Data used for the analysis and results obtained by the statistical IV method

Factor	Class	Nepix	Nepix %	Nslpix	Nslpix %	Con_pro	Prior_pro	Cp/Pp	IV
Slope	0-15	790	66.67	64195	69.23	0.012	0.013	0.95	-0.02
	15-25	323	27.26	23852	25.72	0.014	0.013	1.04	0.02
	25-35	66	5.57	4035	4.35	0.016	0.013	1.26	0.10
	35-45	6	0.51	638	0.69	0.009	0.013	0.72	-0.14
	>45	0	0.00	3	0.00	0.000	0.013	0	0
Aspect	Flat	26	2.19	1898	2.05	0.014	0.013	1.05	0.02
	North	121	10.21	5574	6.01	0.022	0.013	1.67	0.22
	North East	178	15.02	9133	9.85	0.019	0.013	1.50	0.18
	East	58	4.89	7432	8.02	0.008	0.013	0.60	-0.22
	South East	39	3.29	9471	10.21	0.004	0.013	0.32	-0.50
	South	46	3.88	11125	12.00	0.004	0.013	0.32	-0.50
	South West	55	4.64	11113	11.99	0.005	0.013	0.38	-0.42
	West	135	11.39	12278	13.24	0.011	0.013	0.85	-0.07
	North West	368	31.05	17489	18.86	0.021	0.013	1.62	0.21
Curvature	concave	483	40.75	35241	38.00	0.013	0.013	0.87	0.03
	Flat	450	37.97	35697	38.50	0.013	0.013	1.02	0.01
	Convex	252	21.27	21785	23.5	0.011	0.013	1.17	-0.05
Ground Water	Dry	218	18.40	61110	65.91	0.004	0.013	0.07	-1.15
	Wet	465	39.24	20710	22.34	0.022	0.013	1.54	0.19
	flow	502	42.36	10903	11.76	0.05	0.013	3.08	0.49
Proximity to Stream	0-100m	485	40.93	22412	24.17	0.02	0.013	1.66	0.22
	100-200m	373	31.48	29059	31.34	0.01	0.013	0.99	-0.01
	200-300m	254	21.43	32083	34.60	0.01	0.013	0.61	-0.22
	300-500m	73	6.16	9169	9.89	0.01	0.013	0.61	-0.21
Lithology	Residual Soil	2	0.17	56475	60.91	0	0.013	0.04	-2.56
	Colluvium	483	40.76	3685	3.97	0.131	0.013	10.08	1.01
	Alluvial Deposit	182	15.35	8129	8.77	0.022	0.013	1.72	0.24
	Weathered Trachyte	91	7.68	937	1.01	0.097	0.013	7.47	0.87
	Weathered Basalt	427	36.04	23497	25.34	0.018	0.013	1.4	0.15
LULC	Forest	20	2	3557	3.84	0.01	0.013	0.43	-0.36
	Vegetation	421	36	41323	44.57	0.01	0.013	0.80	-0.10
	Agriculture	439	37	32545	35.10	0.01	0.013	1.06	0.02
	Built up area	305	25	15298	16.50	0.02	0.013	1.56	0.19

6.1.1. Slope

Slope is considered the main topographic parameter necessary for landslide occurrence (Anbalagan, 1992; Raghuvanshi et al., 2014). According to Table 6.1, 66.7%, 27.26%, 5.57%, and 0.51% of landslides occurred in $0-15^{\circ}$, $15-25^{\circ}$, $25-35^{\circ}$, and $30-45^{\circ}$ respectively (Figure 21). The slope classes $0-15^{\circ}$ have a negative IV value because the ratio of the landslide pixel within this class to the causative factor class pixel is too small, therefore its weight class log becomes negative.

The slope classes $35-45^{\circ}$ have negative information value (IV) indicates that these classes have low contribution for the probability of landslide occurrence. However, there is no landslide activity occurred for the slope class $>45^{\circ}$ which have no recorded IV value.

The slope classes $15-25^{\circ}$ & $25-35^{\circ}$ have positive information values (IV) of 0.02 and 0.01, respectively, which shows those classes have a higher contribution to the probability of landslide occurrence. From the slope analysis result, it is possible to deduce that more landslides have the potential to occur in gentle to moderate slope terrain rather than on steep slopes, where the IV value is higher for the slope classes $15-25^{\circ}$ followed by $25-35^{\circ}$ degrees, respectively.

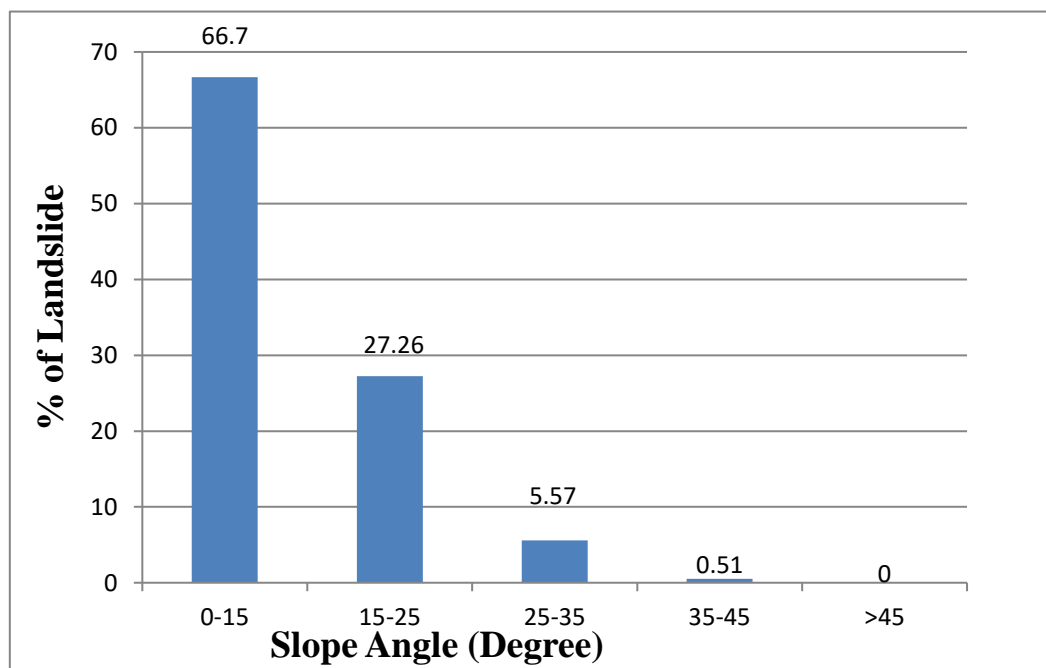


Figure 22: Relations b/n percentage of landslide distribution with Slope classes

6.1.2. Aspect

According to Clerici et al. (2006), as referenced in Matebie Meten (2015), slope direction (aspect) influences exposure to sunshine and winds, which in turn influences other elements that cause landslides, such as precipitation, soil moisture, vegetation cover, and soil thickness. In the present study area, aspect is an important causative factor for the landslide occurrence activity. The aspect classes facing north, north-west, north-east, west, and flat, with statistical information values of 0.23, 0.21, 0.18, and 0.02, have shown the highest probability contribution of the landslide occurrence.

This may be due to the fact that the north-facing slopes can receive a high amount of solar radiation and rainfall. This favors land sliding due to the increased rate of saturation and weathering, particularly in loose disintegrated rock masses and colluvium soil materials. Further, the overlay analysis showed that 31.1% landslides occurred in slopes that are oriented towards North west, 15% occurred in slopes that are oriented towards northeast, 13.4% occurred in slopes that are oriented towards north, 11.4% occurred in slopes that are oriented towards west, 10.2% occurred in slopes that are oriented towards North direction and the remaining 9%, 4.9%, 4.6%, 3.9%, 3.3% and 2.2% landslides occur in slopes oriented towards East, south west, south, southeast and flat respectively (Table 6 and Fig 22).

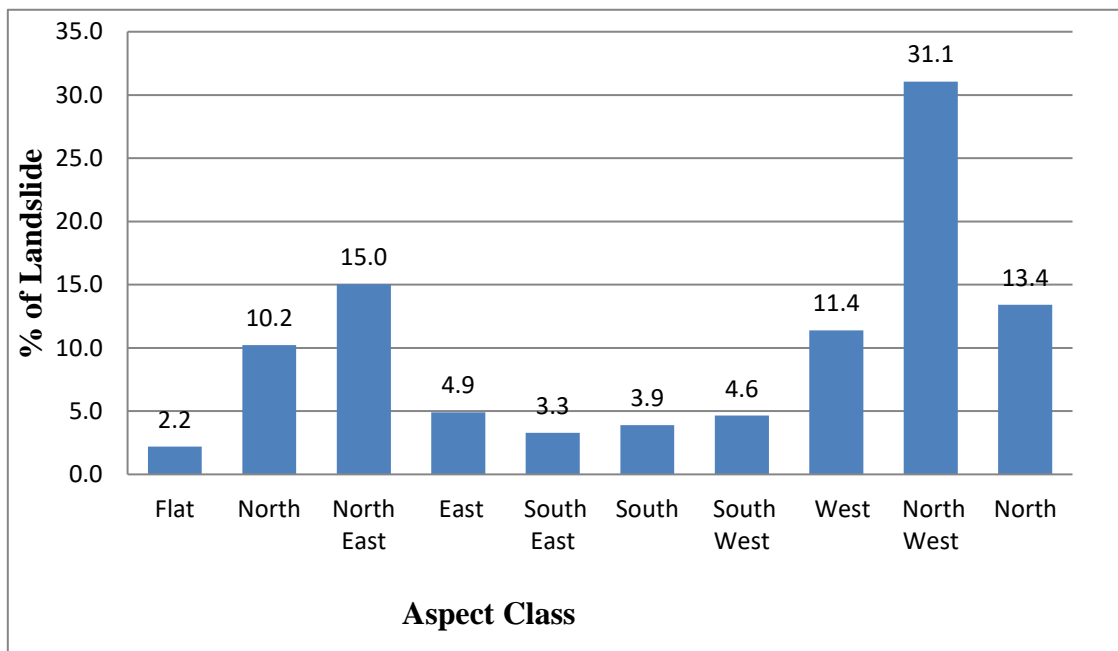


Figure 23: Relations b/n percentage of landslide distribution with Aspect classes

6.1.3. Curvature

Curvatures are morphological causative factors reflecting terrain surface shapes which affect the water flow on earth surface, thus they are considered as conditioning factors to landslide occurrences. Curvature is classified into different categories such as convex, flat, and concave (Lee et al. 2004). Plan curvature is a representation of the terrain's bending in a direction perpendicular to the slope.

According to Ayalew and Yamagishi, it affects the frequency of landslides by altering the earth's surface water flow, which controls the amount of moisture in the soil. The concave curvature classes have an IV value of 0.03. Convex classes have the lowest Iv value due to the drainage of the area, which is away from the slope towards the lowland flat areas. an IV value of -0.05, followed by flat classes with an Iv value of 0.01. Convex classes have the lowest IV value due to water is not being stored on the slope surface.

The reason the IV value is higher in the concave curvature class is due to surface runoff, which is responsible for the landslide activity. However, flat classes have a higher IV value, due to the gentle slope classes dominate in the study area indicating a higher probability of land slide occurrence next to the concave curvature class.

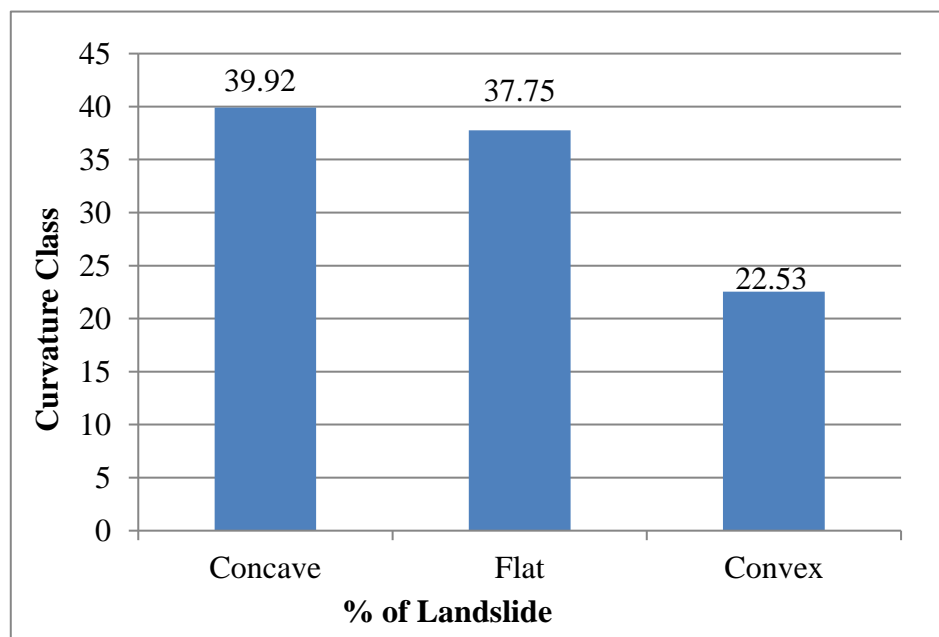


Figure 24: Relations b/n percentage of landslide distribution with Curvature classes

6.1.4. Lithology

Lithology is considered as one of the main causative factor for landslide susceptibility assessment. In the present study area with the distribution of upper Jimma volcanics rock such as basalt and trachytic volcanic rock yielded Colluvium deposits upon weathering and disintegration of the main parent rock material. The lithological causative parametres for the study area were classified into five thematic classes; these are Residual soil, Colluvium soil, Weathered Basalt, Weathered Trachyte, Alluvial deposit. The landslide occurrence and the causative factors lithological relation are shown in Figure 24. According to table the Colluvium soil, Weathered trachyte, Alluvium deposit and weathered Basalt have the statistical information values of 1.01, 0.87, 0.24 and 0.15 respectively. while residual soil has the statistical IV value of -2.56 respectively. lithological units which have positive statistical IV values have a strong correlation for landslide occurrences while the lithological unit with the statistical IV value negative does not have a strong correlation for a landslide occurrence. Residual soil has an IV value of -2.56. This indicates that this lithological unit has weak correlation with landslide activity and hence low probability of landslide occurrence. Therefore, it is possible to deduce that the lithological class with higher statistical IV values have higher contribution for the landslide occurrence, whereas the lithological class with lower statistical IV values have lower contribution for the landslide occurrence.

Colluvium soil has a maximum landslide occurrence 40.76% among the five classes and its statistical IV is 1.16. Weathered volcanic rocks such as basalts and trachytic rock exposed on the cut slope ridge surfaces prone to landslide activity. Thus, rocks lose their strength when intercalated with Colluvium material that results in high probability of landslide occurrence.

Weathered basalt causative factor have a 36.04% landslide occurrence next to Colluvium parameter class and the IV value is also higher for this class. weathered basalt is exposed to higher degree of weathering and fracturing indicating that the probability of landslide is higher for this lithological unit. The highest statistical IV value is recorded in Colluvium deposit, so the probability of landslide occurrence is high. This lithological unit contains unconsolidated geological slope materials and the probability of susceptibility for the landslide is higher. In residual soil there is no recorded landslide occurrence. It rests on the flat to gentle part of the study area. The overlay analysis shows that Weathered trachyte have a probability of 15.35 % landslide occurrence next to basalt.

Alluvium deposits have a probability of occurrence of 7.68% due to the fact that this unit is found at the base of the stream which is affected by erosion hence the probability of landslide is also higher for this class.

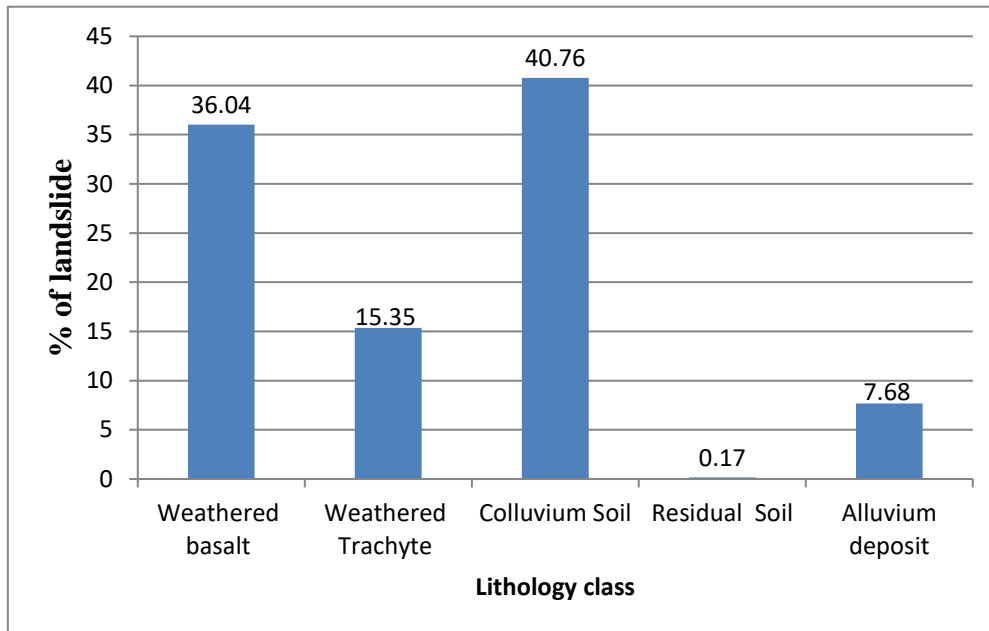


Figure 25: Relations b/n percentage of landslide distribution with Lithology classes

6.1.5. Ground water

Ground water seepage has an effect on the stability of slopes through increasing water level upon saturation of lithological units through infiltration of surface water runoff. Ground water study over large area is difficult. However, in order to make a quick appraisal, the nature of surface indications of the behavior of groundwater will provide valuable information on the stability of hill slopes for landslide susceptibility mapping purposes.

Surface indications of water such as dry, wet and flowing are used for rating purposes in the landslide hazard rating system. Ground water recharge is limited by the topography, the geological nature of the rock unit such as degree of fracturing and weathering.

The IV value for dry class has a value of -1.15 indicates it have a low probability for landslide activity. The IV value for wet class has a value of 0.19 and for the flow class has a value of 0.49 indicates it has high probability for landslide occurrence. Further, the overlay analysis for the ground water classes shows that 42.4% of landslides occurred on flow, 39.2% fall into wet and 18.4% occur on dry classes.

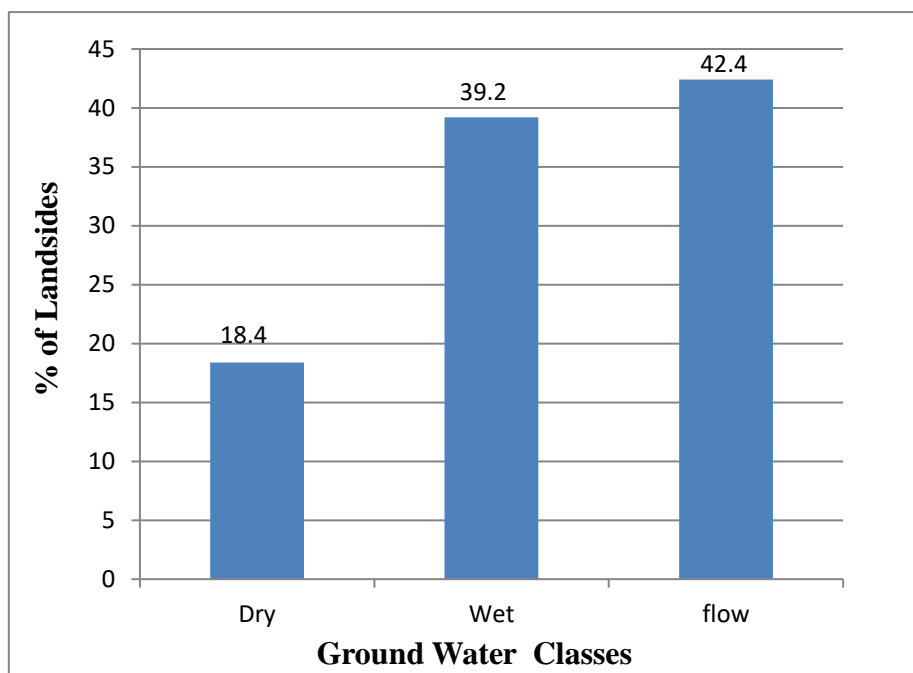


Figure 26: Relations b/n percentages of landslide distribution with Ground water classes

6.1.6. Proximity to Stream

The probability of landslide increases when the streams are eroding the surface of the slope terrain that makes the foot of the mountain slopes to become unstable. Proximity to stream was classified into four subclasses: 0 – 100m, 100m – 200m, 200m – 300m and 300-500m meter. In case of proximity to streams, the classes 0 – 100 and 100 – 200m were more prone to the landslide occurrence, while the class 200-300m, 300-500m has less prone to the landslide occurrence as the statistical information value confirms (Figure 26).

The present study area is dissected by various perennial and intermittent seasonal streams. Thus, as the network density of the stream increases the slope is prone to erosion by surface water and the probability of landslide is much higher than the lower drainage density of the stream network area. The toe of the slope is eroded by streams the slope is devoid of support and prone to landslide failure. The percentage of landslides with the proximity to stream class of causative factor is presented in Figure 26.

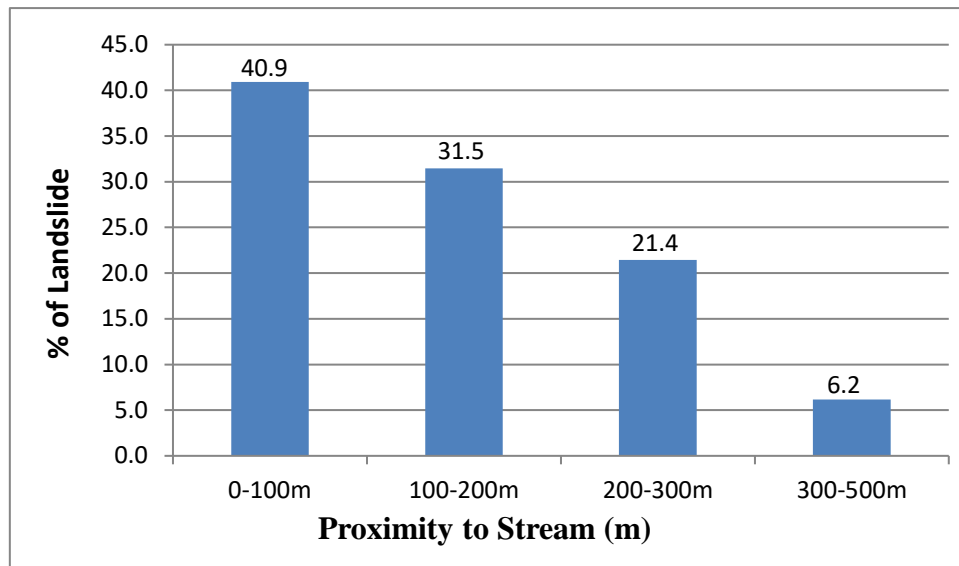


Figure 27: Relations b/n percentages of landslide distribution with Proximity to stream

6.1.7. Land use and Land cover (LULC)

The land-use/land-cover type of the study area was classified into four. These are; Forest, Vegetation, Agricultural Land and Built up area. The statistical information value is positive in Agricultural Land and built up area (Table 6). Thus, Agricultural land and built up area shows highest probability contribution for landslide occurrence.

Agricultural lands include ridge colluvium slopes, cultivated flat lands; Stream River bank slope surfaces have highest probability contribution for landslide occurrence. The statistical information value is negative in Forest and Vegetation indicates that they have lowest probability contribution for landslide occurrence (Table 6). Those four land-use land-cover classes and the percentage of landslide occurrence is presented as shown below (Figure 27).

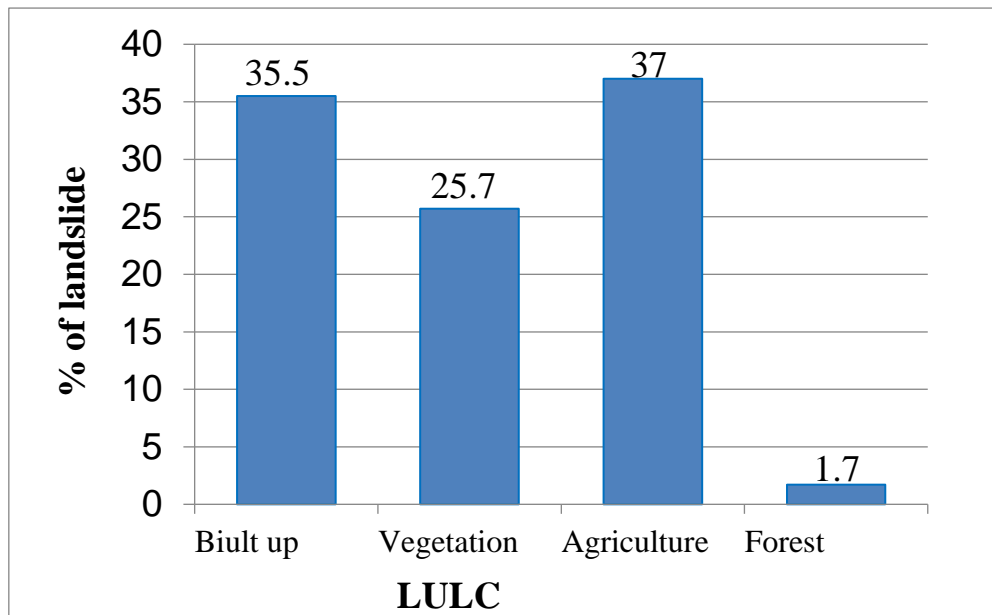


Figure 28: Relations b/n percentages of landslide distribution with LULC classes

6.2. Prominent Classes among Various Causative Factor Class

Landslide is a complex process in which various causative factors are contributed to its occurrence. In the present study seven causative factors were considered namely slope, aspect, curvature, ground water, proximity to stream, lithology, land use and land cover. From the past landslide data relational statistical correlation with various causative factors was established and prominence of various causative factor classes was worked out with the help of statistical information value.

Table 7 presents the highest statistical information value in respective factor class. The table clearly shows that the slope angle $25-35^{\circ}$ and the slopes which are trending towards north are more prone for landslide susceptibility. Similarly, slope profiles with Concave curvature classes, groundwater in flow and wet class, proximity to stream 0-100 m class are more susceptible for slope instability.

Landslide probability is higher in Colluvium deposits and built up or settlement areas. Because the Colluvium materials are more susceptible to mass movement and the settlement or built up areas are responsible for construction on the road slope that triggers landslide and sliding of failure of the slope surface.

Table 7 The highest information value classes		
Causative factor	class	Information value
Slope ($^{\circ}$)	25-35 $^{\circ}$	0.1
Aspect	North (337.5 -360)	0.23
Curvature	Concave	0.03
Lithology	Colluvium	1.01
Ground water	Flow	0.49
Proximity to stream (m)	0-100	0.22
LULC	Built up Area	0.19

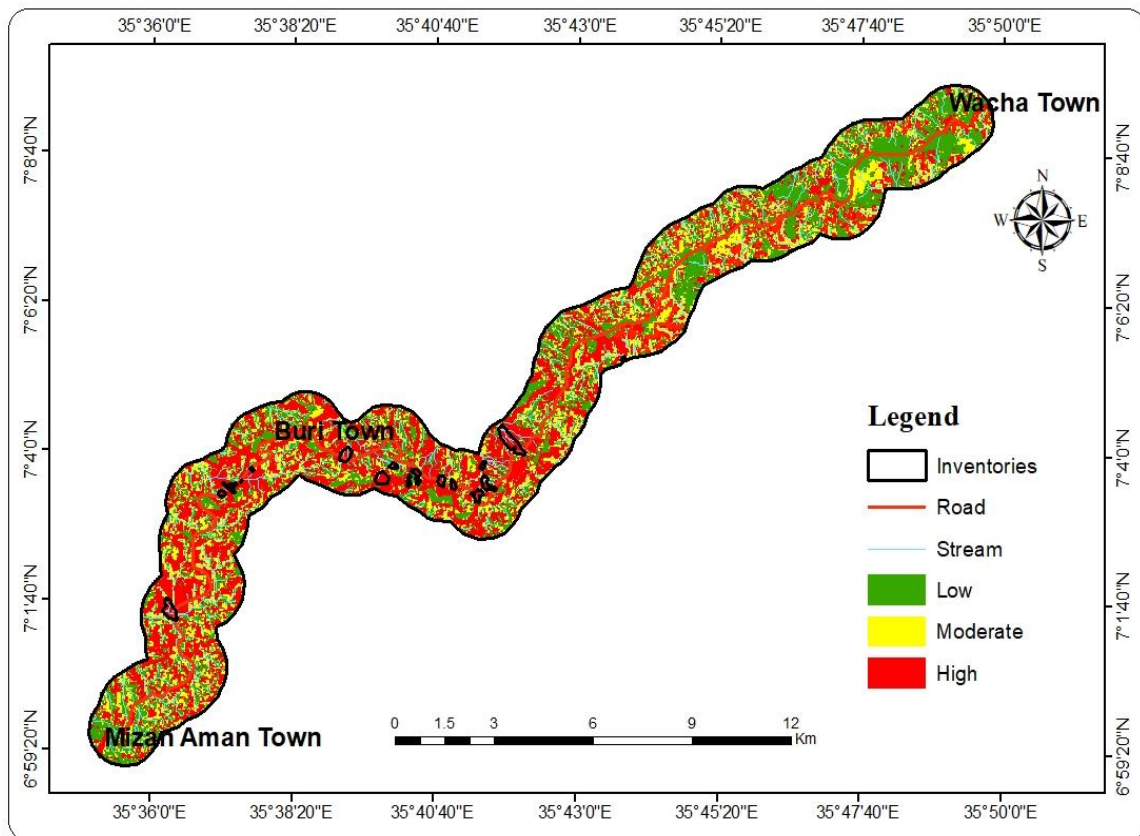


Figure 29: Landslide Susceptibility Map of the Study Area

6.3. Validation of Landslide Susceptibility Class Map

Thus, it was reasonable to conclude that the methods used to validate the LHZ map yielded satisfactory findings, and the delineated hazard zones could be used effectively for the area's infrastructure development and regional planning. Validation of the produced LSM is through an overlay analysis is necessary to understand the applicability of the model for use in practical purposes (Chung and Fabbri, 2003).

For thematic causative factor maps preparation and for statistical IV pixel calculation ArcGIS v 10.8 was used. A statistical method was used to assign weights to each class of landslide causal factors. Next, using a lookup tool in spatial analysis, the weighted causative factor maps were rasterized. After rasterizing the factor maps, the landslide susceptibility index (LSI) map was generated by the sum-up in ArcGIS v 10.8 of all raster maps using a raster calculator in Map Algebra, then the final landslide susceptibility map was prepared. For the calculated values of statistical IV for each pixel in the LSI indicates the relative susceptibility to landslide occurrence. According to Yin and Yalcin (1988) when the information value is positive the causative factor class has a higher contribution for the landslide occurrence while the information value is negative it has low contribution for the landslide occurrence.

The landslide susceptibility index value for each pixel was obtained by summing up all causative factor maps using raster calculator in map algebra in the study area.

The LSI map was reclassified by the natural break classification method in GIS Environment to develop the landslide susceptibility map of the study area. The relation analysis compares the statistical information value of the area where landslides occurred to the whole area. A greater value in relation to other classes implies a better correlation, while a lower value suggests a weaker correlation. Based on the LSI distribution the landslide susceptibility level in the present study area was divided in to three class levels: these are; low, moderate and high susceptible classes. Further, on trial basis LSI values were distributed into different susceptible classes and landslide susceptibility map (LSM) was produced. For each of such attempt the prepared landslide susceptibility map was validated with the past landslide data. Thus, the landslide susceptible map prepared is presented in Figure 29. For the present study bivariate statistical method especially information value model which is raster based method was used to prepare landslide hazard Susceptibility map of the study area.

The present study employed bivariate statistical methods, particularly the information value model, a raster-based technique, to generate a susceptibility map of the study area to landslides.

The overlay analysis (Figure 29) clearly shows that out of 23 past landslide inventory data 20 (87%) falls in high susceptible (HS) class, 2 (8.7%) falls in moderate susceptible (MS) class and 1(4.3%) falls in low susceptible (LS) class.

In addition, validation of the LSM showed that more than 85% of the past landslides fall in high susceptibility (HS) class. Thus from the result, it is possible to deduce that the landslide susceptible class demarcated in the present study validated with the past landslide data and the potential class described can reasonably be applied for safe planning of the area.

During field observation and verification, the high susceptible areas are characterized with landslides, slope toe erosion, as well as road crack and settlements.

- The pixels of the landslide susceptibility values have been divided into three classes: low susceptible (LS), moderate susceptible (MS), high susceptible (HS) using the classification system's natural break approach. The landslide susceptibility map's results clearly demonstrate that 20.7 km² (24.92%) of the study area falls in low susceptible class, 28.7km² (34.49%) of the area falls in moderate susceptible (MS) class and 33.7km² (40.59%) of the study area falls in high susceptible (HS) class.
- Therefore, it can be safely concluded that the susceptible classes in the current study validates with the past landslide data. Finally, based on the causative factors considered and the results obtained from the model shows that it is applied for the safe infrastructure planning of the study area.

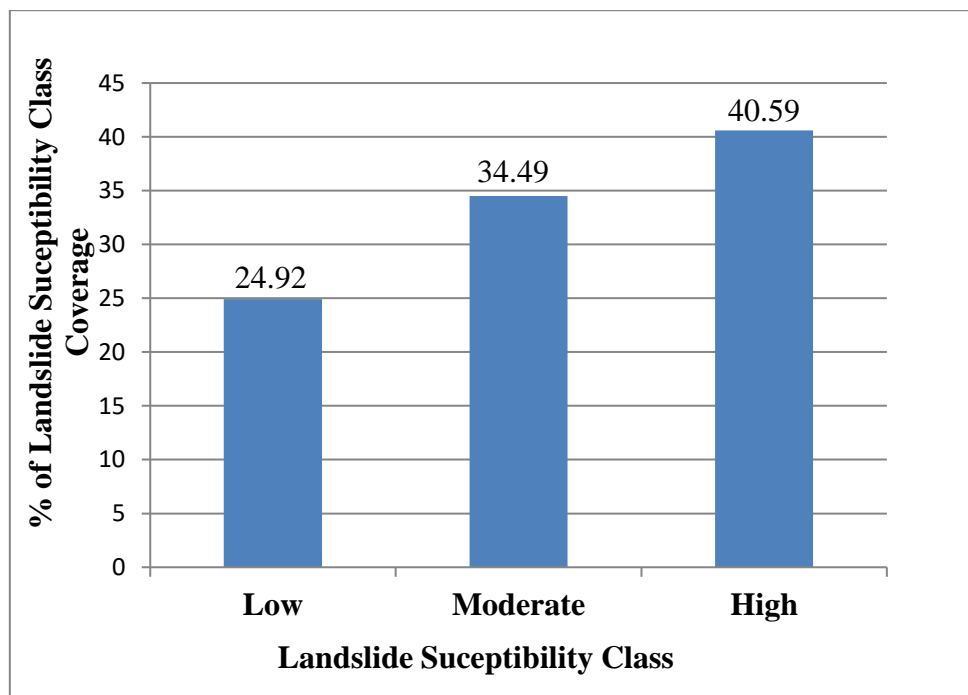


Figure 30: Distribution of landslide susceptibility classes

CHAPTER SEVEN

7. CONCLUSIONS AND RECCOMENDATIONS

7.1. Conclusions

Situated in the Bench Maji zone of South western Ethiopia, the Wacha-Mizan Teferi area, approximately 562 km from Addis Ababa, presents a varied terrain characterized by undulating landscapes and hilly ridges, with elevations ranging from 1,320 to 2,200 meters above sea level. The region's topography, marked by small mountainous ridges and river-incised valleys, is inherently susceptible to denudation erosion and landslide activity. This vulnerability is further exacerbated by the geological composition of the area, which includes tertiary volcanic formations and quaternary deposits.

The primary aim of this study was to conduct a comprehensive evaluation of landslide hazards along the Wacha-Mizan Teferi roadway and its adjacent regions. The study area were classified into low, moderate and high degree of landslide susceptibility based on the analysis obtained from the Information modeling value result.

To achieve the research objectives, we employed Information Value Modelling, a Bivariate statistical approach, considering seven causative factors: slope, curvature, proximity to streams, aspect, Lithology, land use and land cover, and groundwater conditions. Data representing these factors were meticulously gathered from both secondary and primary sources. To facilitate the creation of a landslide hazard susceptibility map, we meticulously documented past landslide events within the study area.

A total of 23 historical landslides were identified through a combination of Goggle Earth image analysis and on-site field investigations. The overlay analysis revealed that over 85% of the study area is at risk of landslides, necessitating immediate attention for the secure design and construction of local infrastructure. The resulting landslide susceptibility map serves as a prerequisite for landslide hazard assessment, enabling ongoing monitoring and the development of effective mitigation strategies.

Through diligent field observations and the analytical interpretation of Goggle Earth imagery, we established a statistical correlation between the various causative factors and the past landslide occurrences, thereby providing a robust framework for future hazard prevention and management in the area.

7.2. Recommendations

The study findings lead to several actionable recommendations to mitigate landslide risks:

- The developed susceptibility map clearly demarcates that more than 75% of the study area is susceptible to landslide hazard zones. Therefore, in the future, when it becomes necessary to establish infrastructure projects like roads, buildings based on the landslide susceptibility map developed.
- In line with this, Realignment of sections prone to landslide failure is considered based on the susceptibility degree of landslide zones of Wacha-Mizan area. Settlements, agricultural farm land, and development infrastructure have all suffered risks as a result of landslides in the current research area.
- Avoiding development in areas such as mountain ridges and river valleys, which are susceptible to landslides and flooding, is crucial. due to carried out on the mountain sides and stream valleys of the ridge, the slopes have become susceptible to erosion. Settlement and agricultural activities should be planned with caution in the high-risk susceptibility zones.
- Comprehensive landslide investigations employing geophysical methods and advanced monitoring techniques are essential for critical slope sections. Such detailed studies will elucidate the mechanisms and dynamics of complex landslide activities.
- Enhanced drainage systems and Properly designed drainage infrastructure will prevent water infiltration into landslide-prone areas, thus reducing the risk of slope failure.
- Slope management through vegetation plays a vital role in stabilizing slopes by reducing surface runoff and erosion. The integration of tree planting with slope terracing, particularly alongside road slopes, offers a natural solution to reinforce fragile areas.
- Restraint mitigation works involving the use of artificial structures can stabilize landslide-prone slopes by counteracting the forces within the soil mass. Implementation of landslide remedial works in the future is recommended as part of a comprehensive slope stabilization strategy based on the developed susceptibility map.

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Appendix

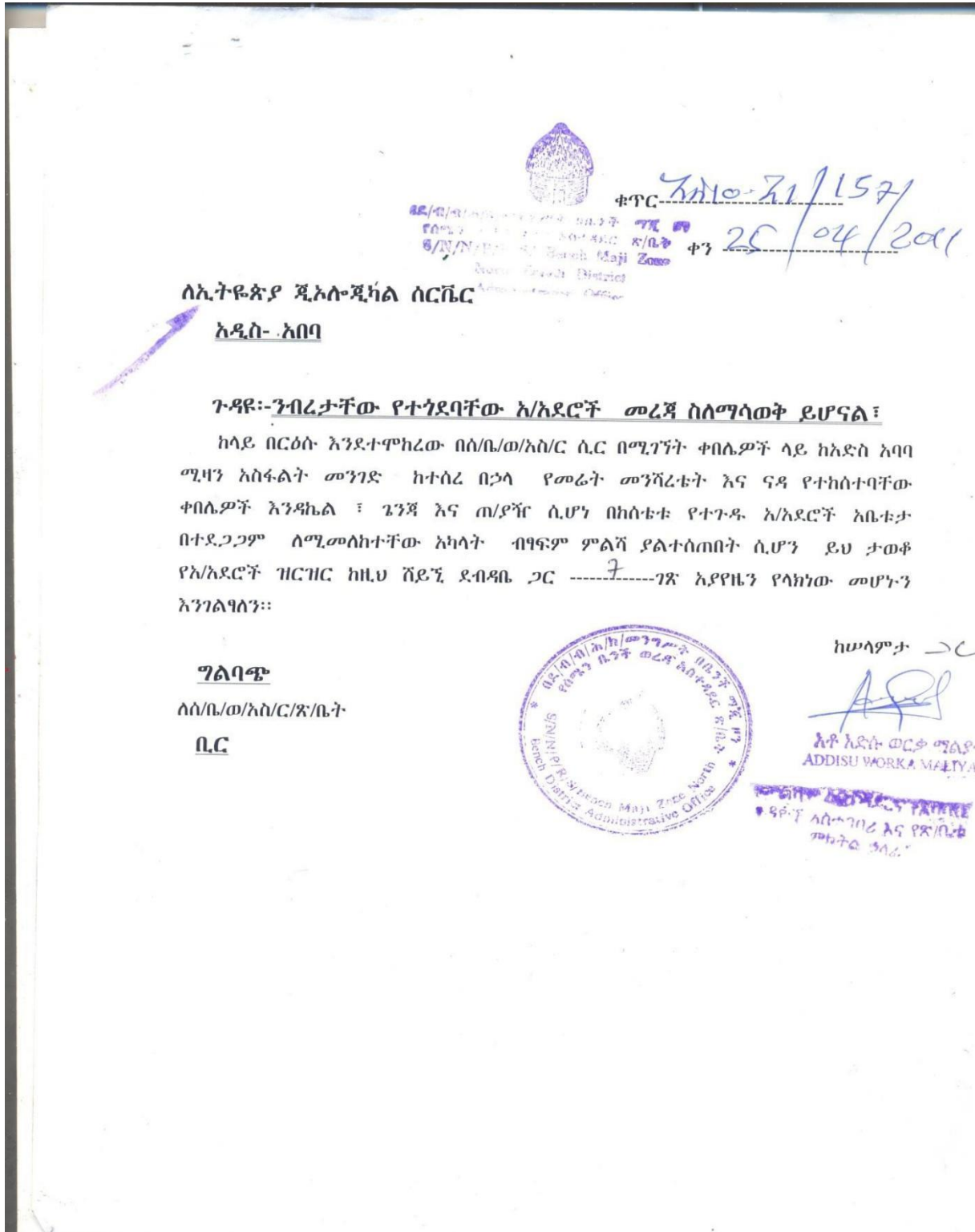
Annex 1 Average Monthly precipitation for the years 1990 to 2019 of Mizan Teferi station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	46.1	119.9	130.3	188	151.6	349.8	320.5	323.1	225.3	86.6	83.8	67
1993	148.7	78.3	148.7	102.4	208.7	-	267.2	228.5	228.5	142.2	79.2	16.3
1994	11.9	8.6	115.3	248.6	212.1	247.9	344.2	298	119.1	147.1	375.3	50.7
1995	0.2	38.4	77.8	141.9	218.5	210.4	190.6	306.1	291.7	198.4	129.4	235.8
1996	79.4	33.2	135.7	172.2	259.6	487.1	227.4	283.2	484	171.5	74.3	56.3
1997	46.5	6.7	163.2	325.5	218.8	199	232.1	203	262.9	249.9	267.7	167
1998	180.8	45.3	170.1	245.5	178.6	221.2	263	278.9	215.2	246.1	88.8	34.9
1999	62.6	21.1	112.2	280.8	267.9	187	243.5	310.2	230	276	70.2	84.2
2000	22.2	16	79.5	161.3	246.7	221	400.4	271.3	132.6	253.4	86.3	24.4
2002	83.3	8.7	134.1	137.2	126.1	225.1	149.5	197.5	126.4	201.3	68.9	111.1
2003	32.7	48.7	116.4	222.8	111.8	320.7	178.5	310.8	275.2	138.5	115.7	104.3
2006	35.4	43.8	150	130.8	320.6	-	233.3	452.9	226.8	164.8	200.1	142.9
2010	161	91	81	66	272	95	-	156	219	228	11	14
2016	15	65	92	121	362.6	260	407	280	258	180	197.5	229.6
2019	-	0	61.1	222.7	249	212.2	285.1	260	-	67.5	23.9	20.5
Sum Monthly	925.8	624.7	1767. 4	2766.7	3404.6	3236. 4	3742.3	4159.5	3294.7	2751.3	1872.1	1359
Mean Monthly	66.13	41.65	117.8 3	184.45	226.97	248.9 5	267.31	277.3	235.34	183.42	124.81	90.6

Annex 2 Annual Rainfall from 1990 to 2019 for Mizan teferi station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1990	46.1	119.9	130.3	188	151.6	349.8	320.5	323.1	225.3	86.6	83.8	67	2092
1993	148.7	78.3	148.7	102.4	208.7	-	267.2	228.5	228.5	142.2	79.2	16.3	1648.7
1994	11.9	8.6	115.3	248.6	212.1	247.9	344.2	298	119.1	147.1	375.3	50.7	2178.8
1995	0.2	38.4	77.8	141.9	218.5	210.4	190.6	306.1	291.7	198.4	129.4	235.8	2039.2
1996	79.4	33.2	135.7	172.2	259.6	487.1	227.4	283.2	484	171.5	74.3	56.3	2463.9
1997	46.5	6.7	163.2	325.5	218.8	199	232.1	203	262.9	249.9	267.7	167	2342.3
1998	180.8	45.3	170.1	245.5	178.6	221.2	263	278.9	215.2	246.1	88.8	34.9	2168.4
1999	62.6	21.1	112.2	280.8	267.9	187	243.5	310.2	230	276	70.2	84.2	2145.7
2000	22.2	16	79.5	161.3	246.7	221	400.4	271.3	132.6	253.4	86.3	24.4	1915.1
2002	83.3	8.7	134.1	137.2	126.1	225.1	149.5	197.5	126.4	201.3	68.9	111.1	1569.2
2003	32.7	48.7	116.4	222.8	111.8	320.7	178.5	310.8	275.2	138.5	115.7	104.3	1976.1
2006	35.4	43.8	150	130.8	320.6	-	233.3	452.9	226.8	164.8	200.1	142.9	2101.4
2010	161	91	81	66	272	95	-	156	219	228	11	14	1394
2016	-	0	61.1	222.7	249	212.2	285.1	260	-	67.5	23.9	20.5	1402
2019	15	65	92	121	362.6	260	407	280	258	180	197.5	229.6	2467.7

Annex 3 Letter From The woreda



በአንደኛው ቀበሌ በዳማ መንደር/ቤተ-ክርስቲያን ዙሪያ ውስጥ ያሉ በመንገድ ሥራና በመሬት መንሸራተት ጎብረታቸው የተጎዳባቸው አርሶ አደሮች ዝርዝር

ተ.ቁ	የአርሶ አደሩ ስም	ዕድሜ	ፆታ
1	ቄስ ታሩክ ቤስኪ	38	ወ
2	አቶ አበበ ቤስኪ	30	ወ
3	አቶ ከተማ ዶዱአብ	35	ወ
4	አቶ ኤፍሬም ቤስኪ	32	ወ
5	ወ/ሮ ጌና ዳድንባብ	40	ሴ
6	አቶ መንደር ኪዳኔ	30	ወ
7	አቶ አሰፋ አርዳ	35	ወ
8	አቶ ሉቃስ ቱሪያት	25	ወ
9	አቶ ጎጃም ማራ	27	ወ
10	አቶ ብረሃኑ ሸማብ	25	ወ
11	አቶ ፍቃዱ ሰምቴት	45	ወ
12	አቶ ማቲዎስ ሰምቴት	35	ወ
13	አቶ ኢራስ ሰምቴት	40	ወ
14	አቶ ጣጣ ኢራስ	34	ወ
15	አቶ አሰፋ ጎርሲያብ	35	ወ
16	አቶ አሰፋ ጊላል	35	ወ
17	አቶ አዲሱ ከተመራሽ	20	ወ
18	አቶ እዮብ ጽጥሮስ	20	ወ
19	አቶ ከድር ኤርጋ	30	ወ
20	አቶ ኪዳኔ ሸማብ	25	ወ
21	እገቅኤስ ዳዶአብ	25	ወ
22	ዳኛቸው ኤርጋ	21	ወ
23	አቶ ሸማብ አኒሲያብ	38	ወ
24	ወ/ሮ ጊሳ ቃሪቅያብ	50	ሴ
25	አቶ ኤርጋ አንሲያብ	60	ወ
26	ወ/ሮ ከርባ ዘለቀ	40	ሴ
27	አቶ አሰማየሁ ወልደየስ	25	ወ
28	አቶ ወንድሙ ወልደየስ	22	ወ
29	አቶ ደረጃ ታድ	30	ወ
30	አቶ ኤሲያስ አሰፋ	19	ወ
31	አቶ አሸቱ አረስ	25	ወ
32	አቶ ታምሩ ኪያንጎ	30	ወ



Handwritten signatures and initials in blue ink, including what appears to be 'ወ 24' and other illegible marks.

33	አቶ መሉቀን ዲጊት	22	ወ
34	አቶ አሰፋ ኪያንጉ	32	ወ
35	ወ/ሮ ቶስ ባርጨዲ	40	ሴ
36	አቶ ዘለቀ ኩንዲሳ	36	ወ
37	አቶ መላክ ገረመው	20	ወ
38	አቶ እያሱ ዘለቀ	19	ወ
39	አቶ መኮንን ወርቁ	30	ወ
40	አቶ የርማሮ ጌዳ	50	ወ
41	አቶ ዳላ መንገሻ	35	ወ
42	አቶ አላዛር ከተመራሻ	30	ወ
43	አቶ አሊ ዲሚቴት	30	ወ

ወ 39

ከ 4

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እንደኤል ቀበሌ በመሀል ዳማና በ108 ላይ በጎርፍ ምክንያት ንብረታቸው የተጎዳባቸው አርሶ አደሮች ዝርዝር

ተ.ቁ	የአርሶ ደሩ ስም	ዕድሜ	ፆታ
1	አቶ የማነ ባንካ	50	ወ
2	አቶ አብረሃም ባንካ	32	ወ
3	አቶ ጢሞቴዎስ ባንካ	30	ወ
4	አቶ ግርማ የማነ	35	ወ
5	አቶ ቲቲዮስ ባርሻብ	34	ወ
6	አቶ ማርቆስ ባርሻብ	30	ወ
7	ወ/ሮ ማይታ ሳግን	45	ሴ
8	አቶ ወሰነ ሶስቲያብ	28	ወ
9	አቶ ጌታቸው ሶስቲያብ	30	ወ
10	አቶ ዘሩ ሶስቲያብ	28	ወ
11	አቶ ድርሻን ሶስቲያብ	27	ወ
12	ወ/ሮ ጋዘ ሶደራሻ	50	ሴ
13	ወ/ሮ ማሚት ኃይሌ	45	ሴ
14	አቶ ፍቃደ የማነ	30	ወ
15	አቶ ታምሩ ጎደመራሻ	30	ወ
16	አቶ ብረሃኑ ወርቁ	27	ወ
17	አቶ ደርጅ ወርቁ	38	ወ
18	አቶ ጽጥርስ የማነ	35	ወ
19	አቶ አደመ ገላል	34	ወ
20	አቶ ተገኝ ጋይዳ	32	ወ
21	አቶ ዳንኤል ገላል	30	ወ
22	አቶ ተሸመ ግርባይ	31	ወ
23	አቶ ግዛት ወርቁ	35	ወ
24	አቶ ሳምፒ ቤስኪ	45	ወ
25	አቶ ጨነቁ ወርቁ	32	ወ
26	አቶ ስንታየሁ ሳምፒ	29	ወ
27	አቶ ዘማች ጎርሲያብ	30	ወ
28	አቶ ዩሴፍ ጋይዳ	30	ወ

ወ 25

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አቶዎች ጠቅላይ

A = 86
 ከ = 4
 ቆይ = 100



75 1

በአንደኛው ቀበሌ በካሪ/በክራቸር/ ውስጥ ያሉ አርሶ አደሮች ዝርዝር

ተ.ቁ	የአርሶ አደሩ ስም	ፆታ	ዕድሜ
1	አቶ አቤል መንባብ	ወ	30
2	አቶ አብረሃም ሻቴት	ወ	27
3	አቶ ጌና ሰርቴት	ወ	35
4	ወ/ሮ ወንጋ ማድንስ	ሴ	28
5	አቶ ሻል ዳቺ	ወ	50
6	አቶ ስንታየሁ አበራ	ወ	32
7	ወ/ሮ አስናቀች ዘለቀ	ሴ	32
8	አቶ ዩሴፍ ጣራ	ወ	35
9	አቶ ዚያታ ካሽት	ወ	50
10	አቶ ቱንቻ አምቱአብ	ወ	40
11	ወ/ሮ ወርቁ ጃኩ	ሴ	50
12	አቶ ታደሰ መንባብ	ወ	37
13	አቶ ባኩስ ዘምስ	ወ	40
14	አቶ ጌታቸው ሻቴት	ወ	50
15	አቶ ሻና ፋይኒያብ	ወ	47
16	አቶ አዲ ባይንባብ	ወ	45
17	ወ/ሮ አስከለ ባሩባብ	ሴ	45
18	አቶ አለማየሁ ወና	ወ	24
19	ወ/ሮ ካሰች ሱርም	ሴ	25
20	አቶ ከድር ዜምስ	ወ	45
21	አቶ ዩሴፍ ዳሬዝ	ወ	37
22	አቶ ወርቁ ሻቴት	ወ	40
23	አቶ ታደሰ አግሳር	ወ	28
24	ወ/ሮ ኩሽ ጋምስ	ሴ	50
25	ወ/ሮ አይነት ቦሊጥ	ሴ	42
26	አቶ ኤሊያስ ዚያታ	ወ	24
27	አቶ መዓል ኪያስኩ	ወ	25
28	አቶ ዘካርያስ ያንቁአብ	ወ	75
29	አቶ ወዳጆ ሻና	ወ	22

ጠ 22
ከ 7
9 29





የሰነድ ቁጥር: S/N/N/P/...
ቀን: ...

ለኢትዮ/መንገድ ባለስልጣን ምዕራፍ ሩጅን ዳይሬክቶሬት ዳይሬክተር

አዲስ አበባ

ጉዳይ:- በጎርፍና በውሃ ቤታቸውና ንብረታቸው የተጎዱ ግለሰቦች ጉዳይ በአስቸኳይ መፍትሔ እንዲሰጣቸው ስለማሳሰብ ይሆናል፤

ከላይ በርዕሱ ለመግለጽ እንደተሞከረው መንግስት ለመንገድ ስራ ልዩ ትኩረት ሰጥቶ ወደ ክልልና ዞኖች የአስፓልት ለመስራት የኪንግናም መንገድ ስራ ድርጅት ስራውን በሚሰራበት ወቅት ቤቶች የወደሙና በመንገዱ ስራ ምክንያት ከቤታቸው የተፈነቀሉ ግለሰቦች ጉዳይ በቁጥር አስ3-00/1231/08 በቀን 26/2/200 ዓ/ም በደብዳቤ አሳውቀን ምንም ዓይነት ምላሽ ያልተሰጣቸው ግለሰቦች

1. አቶ ይማም አባሞርኬ
2. ወ/ሮ አለሚቱ ተገኝ
3. አቶ ዋስታን ታደሰ
4. አቶ አማራ ጦዚያብ
5. ወ/ሮ ወሰኔ አወቀ
6. ወ/ሪት አበበች ደስታ

ከዚህ በላይ የተጠቀሱት ግለሰቦች በጎርፍና በውሃ ምክንያት ቤታቸው ወደ ውስጥ የተቀበሩ ቁጥር 1-6 የተፈነቀሉ ግለሰቦች ጉዳይ ቀደም ሲል በላክንላችሁ ከእንደኬል ቀበሌ አ/አደሮች በናዳ ምክንያት ንብረታቸው ከወደመጣቸው ግለሰቦች ዝርዝር ጋር አንድ ላይ ተያይዞ እንዲታይላቸው እንዲደረግ ከወዲሁ እንጠይቃለን።

ግልባጭ

ለኪንግናም መንገዶች ስራ ድርጅት አጭካሪ (ICT)
ለቤ/ማ/ዘ/ዋ/አስ/ሪ
ሚዛን ተፈሪ
ለቅሬታ አቅራቢ ግለሰቦች
ባሉበት



ከሠላምታ ጋር

Beyene Berhane
የሰነድ ሠሪያ ዋና አስተዳዳሪ
North Bench Woreda Chief
Administrator

Annex 4 Inventoried Landslide Types and Locations in The Study area

ID	Easting	Northing	Elevation	Mode of Failure
LS_1	807886	789842	2190	Translational/Earth flow
LS_2	806202	788117	2119	Translational/Earth flow
LS_3	801502	784748	1928	Earth flow
LS_4	798327	782088	2045	Complex
LS_5	797259	781629	1882	Translational/Debris flow
LS_6	797553	780955	1881	Rotational
LS_7	797559	780965	2009	Rotational
LS_8	797326	780469	2041	Translational
LS_9	797102	780733	2021	Translational
LS_10	796409	781017	2015	Translational/Earth Flow
LS_11	796011	781079	2010	Translational
LS_12	795325	781112	2042	Translational
LS_13	795277	781273	2002	Translational
LS_14	795039	781108	2030	Translational
LS_15	794600	781570	1913	Rotational
LS_16	794254	781156	1939	Translational
LS_17	793085	781761	1731	Rotational
LS_18	790254	781433	1547	Rotational Failure
LS_19	789958	781069	1527	Translational
LS_20	789658	780943	1543	Translational
LS_21	789561	780873	1563	Complex
LS_22	789389	780731	1542	Rotational
LS_23	787789	777435	1361	Debris Flow