LANDSLIDE HAZARD MAPPING USING GIS AND REMOTE SENSING TECHNIQUES: THE CASE OF ARBEGONA WOREDA, SIDAMA REGION, ETHIOPIA

Tekle Kayesso Kanbato

A Thesis Submitted to

The department of Applied Geology

School of Applied Natural Science

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Applied Geology

Office of Graduate Studies

Adama Science and Technology University

August, 2021

Adama, Ethiopia

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Declaration

I hereby declare that this Master Thesis entitled "Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Arbegona Woreda, Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Recommendation

We, the advisors of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Arbegona Woreda, Ethiopia" prepared under our guidance by Tekle Kayesso submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Applied Geology (Engineering Geology). Therefore, we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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Major Advisor	Signature	Date
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Co-advisor	Signature	Date

Approval Page of M.Sc. Thesis

We, the advisors of the thesis entitled "Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Arbegona Woreda, Ethiopia" and developed by Tekle Kayesso, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Tekle Kayesso have read and evaluated the thesis entitled "Landslide Hazard Mapping Using GIS and Remote sensing Techniques a Case of Arbegona Woreda, Ethiopia" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Applied Geology (Engineering Geology).

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AHP	Analytical Hierarchy Processes
Arc GIS	Aeronautical Reconnaissance Coverage Geographic Information System
ASTU	Adama Science and Technology University
DEM	Digital Elevation Model
ELH	Evaluated Landslide Hazard
ERDAS	Earth Resource Data Analysis system
ETM^+	Enhanced Thematic Mapper Plus
GPS	Global Positioning System
LHZ	Landslide Hazard Zone
LU/LC	Land use land cover
MCA	Multi-Criteria Analysis
MCE	Multi-Criteria Evaluation
NMA	National Metrological Agency
ROC	Receiver operating characteristics
SNNPR	South Nation Nationality People Region
SRTM	Shuttle Radar Topographic Mission
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

Abstract

Arbegona area is located in southern parts of the Ethiopian highlands around 349 km from Addis Ababa, the capital city of Ethiopia. The area is a part of southern Ethiopian highlands, it is characterized by rugged topography with deep-cut gorges, weathered volcanic rocks, heavy rainfall and active surface processes. Because of the aforementioned conditions, the area becomes prone to landslide hazards. The previously occurred landslides in the study area have caused widespread damage. The main objective of this study is to evaluate landslide hazard and prepare a landslide hazard zonation map of Arbegona Woreda. The evaluation is conducted by applying GIS-based multi-criteria analysis. Landslide inventory map was firstly developed from 209 active and passive landslide scarps using intensive fieldwork and Google Earth image interpretation. These landslide locations were randomly divided into 70% training and 30% validation datasets. In this case study, the following landslide conditioning factors were evaluated: slope, aspect, drainage density, lineament density, geology, land use land cover and soil type. The thematic data layers representing various factors were, generated using GIS and remote sensing techniques. Using Analytical Hierarchy Processes, the weight of each factor was calculated and assigned in GIS. By adding the aforementioned landslide conditioning factors, a landslide hazard map, was produced by weighted overlay method. The result showed that 8.06% of the study area falls in very high, 29.24% in high, 43.88% in moderate, 11.79% in low and 7.03% in the very low hazard zone. Finally, the resulted landslide hazard maps have been validated and verified using the area under the curve and landslide inventory data. The result showed that the landslide hazard map agreed well with areas that had recently experienced a landslide. The landslide hazard map showed that southeastern, northwestern and southern parts of the study area are more prone to landslides than other parts. The correlation between landslide occurrence and causative factors was carried out to examine their relationship. Based on the landslide hazard zone various mitigation measures were recommended for the stabilization of unstable areas. The landslide hazard zonation map can be used for preliminary land use planning and hazard mitigation purposes in the study area.

***Key word**: Landslide; Hazard zonation mapping; Arbegona Woreda; GIS and remote sensing, multi-criteria analysis.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Landslide is among the geohazard problems that cause damage to life and infrastructures. It occurs in the form of rotational, translational, and wedge forms of failure, causing a different impact on properties, lives, and blocking the traffic (Varnes, 1984; Courture, 2011). It is a frequent problem in Ethiopia, mainly in highland areas in most parts of the north, south and western region of the country and parts of the rift valley escarpment (Ayele et al., 2014). According to Ayalew (1999), the Ethiopian highland has established significant instability in both superficial materials and bedrocks.

The widespread distribution of landslides in Ethiopia is mainly related to the occurrence of several predisposing factors such as rugged morphology, high relief, and the nature of the outcropping rocks (Brabb, 1993). The triggering factors are essentially connected with the rainfall regime and, seismicity to a minor extent. The role of human impact within the context of the country's socio-economic development is of increasing importance in causing landslides (Chen et al., 2007).

Mapping and analysis of areas that are prone to landslide occurrence is of great importance, especially for disaster management and to minimize the impact of landslide hazards. According to Brabb (1993), at least 90% of landslide loss can be avoided if the problem is recognized before the landslide event. Moreover, landslide hazard analysis and mapping can offer, useful evidence for disastrous damage reduction, contributing to viable land-use planning (Chen et al., 2007; Raghuvanshi et al., 2014). Landslide hazard maps present a spatial division of the ground into areas of different levels of potential landslide hazard zones and it provides the essential framework for land use planning and development of proper engineering practices (Anbalagan, 2008).

Landslides can be triggered by different causative factors, including slope, aspect, lineament density, drainage density, land use land cover, geology and soil type (Raghuvanshi et al., 2014). All these causative factors need to be analyzed for landslide hazard evaluation and mapping.

Extraction of relevant spatial information related to landslide occurrence is an integral part of hazard assessment. Nevertheless, integrating remotely sensed (RS) data with Geographic Information System (GIS) is proved to be an effective tool for generating and processing spatial information (Anbalagan, 2008). Integration of remote sensing (RS) and Geographic Information system (GIS) play a vital role in natural disaster management, particularly in landslide studies by integrating various factors and selected as the best tool to locate landslide hazard zones with accurate precision, cost and time-effective (Chen et at., 2007). Keeping this uses in view, GIS and remote sensing techniques are used in the present study to prepare landslide hazard zonation map of Arbegona Woreda. The evaluation is conducted by applying GIS-based multi-criteria analysis.

1.2 Statement of problem

Landslide hazard is one of the major geo-environmental problems that cause considerable damages to infrastructures and the natural environment. It endangers the well-being of the society, particularly the local peoples living near the toe of steep slopes prone to active land. Many active landslides exist along the road section and surrounding with different levels and failure modes (Ayalew, 1999).

The main factors of land sliding in the Ethiopian highlands include the high relief (on average between 2000 and 3000 m), induced by the large-scale Pliocene-Quaternary uplift and the resulting rugged morphology, very deep valleys and gorges with high steep slopes (Ibrahim, 2014). Active river incision is widespread and causes further slope steepening and instability. Besides the natural vulnerability of Ethiopian highland areas to landslides, owing to their geological and hydrological conditions, human interference has played an important role in accelerating land degradation (Ibrahim, 2014).

Just like other areas in Ethiopian highlands, the Arbegona Woreda is also severely affected by landslide incidence. For instance, the landslides that occurred in Mikicho village/Kebele on 25/09/2020, due to heavy and prolonged rainfall resulted in the death:- 6 persons (1 male and 5 females), 38 animals (14 cows, 10 sheep, 7 goats and 7 hens), destruction of 1 home, farmland with crops, and the displacement of 186 people from their homes. Therefore, the area requires a due attention to minimize the impact by demarcating the areas potentially prone to landslides in the form of landslide hazard maps. Therefore, this work aimed to evaluate the causes, failure mechanisms of landslides, and generate a landslide hazard zonation map for identifying areas that are the most vulnerable to future landslides.

1.3 Objective of the research

1.3.1 General objective

The general objective of the study is to evaluate landslide hazards and prepare a landslide hazard zonation map of the study area using geographic information system and remote sensing.

1.3.2 Specific objectives

- ✓ To identify the type of landslide occurring in the study area;
- ✓ To prepare a landslide inventory map;
- ✓ To prepare maps of various causative factors.
- ✓ To prepare a landslide hazard zonation map of the study area; consider landslide causative factors;
- ✓ To check the validity of the prepared landslide hazard zonation map;
- ✓ To recommend suitable remedial measures based on the results of the present study.

1.4 Significance of the study

This study will be beneficial to the unclearity and further research in the area:

- ✓ It is applicable to understand the nature of unstable slopes and their potential to landslide.
- ✓ It is applicable in terms of providing future landslide hazard information so that people and property in the area can be protected and the adverse effects of landslides can be minimized.
- ✓ The study will serve as input for the purposes of disaster management, spatial planning and related decision-making processes.

1.5 Scope of the study

The scope of this study is limited to the evaluation of landslide hazard and landslide hazard zonation mapping of Arbegona Woreda. For landslide hazard zone mapping, seven causative factors such as; slope, aspect, drainage density, lineament density, geology, land use land cover and soil type were considered. Suitable data for the analysis was obtained from field investigation, satellite image interpretation and literature. The evaluation of the landslide hazard is conducted by applying GIS-based multi-criteria analysis. Two hundred nine past landslides in the study area were also identified and mapped through field survey and image interpretation.

1.6 Organization of the thesis

The present thesis study was, organized into five main chapters as follows;

The first chapter introduces the introduction, statement of the problem, objectives, scope, significance and limitation. In this chapter, the frequency and status of landslides throughout the world, in Ethiopia and the study area, were discussed based on different kinds of literature. In addition, the problem based on the issue that exists in literature, theory and practice that need for the study was, presented.

The second chapter discusses the literature review. This chapter introduces various literature related to the present study title that is used to give a brief review of the theoretical basis of landslide hazard zonation and different approaches for landslide hazard mapping. Although, the application of remote sensing, geographic information system (GIS) and integration of geographic information system and remote sensing for landslide hazard mapping was discussed.

The third chapter discusses the Methods and materials, data source, data collection, data preparation AHP approaches and general methodological steps.

The fourth chapter detailed description of study area, includes location, physiography, climate and geology.

The fifth chapter introduces the data analysis method performed in the present study, the result obtained from the analysis, and interpretation of the result in the perspective of a literature review or discussion section. In this chapter, the data analysis procedure and thematic data layer maps were, presented.

The sixth chapter discusses the work in the output of the work accomplished or conclusion and gives further research direction and suggestions or recommendations. In this chapter, the indication of the study and additional model and data needed for further analysis of landslide hazard in the area were, presented.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Landslide hazard and zonation

Landslide hazard is the probability of occurrence within a given period and within a specified area of potentially destructive phenomena (Guzzetti, 2002). Even though there are several approaches to defining landslide hazards. According to Varnes (1984), Guzzetti et al. (1999), landslide hazard refers to the probability of landslide occurrence within a specified period, area and magnitude. This definition can indicate that landslide hazards integrate three basic elements, magnitude (area, volume, and velocity), geographical or spatial location and time or period of the expected landslide.

Landslide hazard zonation is a basic and necessary step in landslide analysis and landslide risk management. The term zonation in landslide hazard analysis is, defined by different authors differently. According to Varnes (1984), zonation divides land surface into areas and ranks these areas according to the degree of hazard from landslides or other mass movements'. Moreover, Courture (2011) described landslide hazard zonation as a division or partition of a land into slightly homogeneous areas and ranking according to degrees of actual or potential landslide vulnerability, hazard or risk or applicability of certain landslide related regulations. However, there has been a significant increase in both landslide events and landslide studies in different parts of the world (Gutierrez et al., 2010). Furthermore, the statistical assessment of international landslide literature approved by Gokceoglu and Sezer (2009), illustrates that the publication of landslide-related articles in the international journals has experienced exponential growth. Subsequently, after the topical natural disasters worldwide, landslide monitoring and providing early warning have gained enormous interest (Nadim et al., 2006).

For a long period, landslide hazard zone, mapping has been, carried out in different parts of the world by various techniques and approaches. Several techniques and approaches have been, developed for, landslide hazard zone mapping. Generally, those approaches are; landslide inventory mapping, heuristic approach, probabilistic assessment, deterministic approach, statistical analysis and multi-criteria decision-making approach (Leroi, 1997; Fall et al., 2006). Nevertheless the effectiveness of one method over other depends on several factors like; the scale of the study area, the accuracy of the predictable outcomes, the availability of data, parameters measured, etc. (Fall et al., 2006).

Inventory analysis is one of the simplest qualitative approaches to landslide hazard mapping. Landslide inventory mapping collects information on the spatial and temporal pattern of landslide distribution and displays them on a map. According to Dai and Lee, 2001; Dai et al. 2002 and Fall et al. (2006), landslide inventory mapping is the identification and compilation of details of each landslide. Therefore, information collected during inventory analysis may include all about landslide pattern, location, magnitude, types of mass movement and so on. Thus, information collected through field surveys using GPS, Historical records or interviews of witnesses, satellite images, Google earth and aerial photograph interpretation. However, landslide inventory maps are used to show slope failure caused by single events or the cumulative effect of many events over a long period (Guzzetti et al., 2000).

Landslide hazard maps play a vital role in landslide studies and landslide risk management. Even though, the quality and extensiveness of landslide inventory map influence the reliability of landslide analysis. Galli et al. (2008) compared landslide inventory maps prepared for different parts of Italy, by establishing a relationship between geomorphological landslide maps and multi-temporal landslide inventories. The result shows that the complete landslide inventory map had highly useful for landslide analysis. Similarly, Guzzetti et al. (2003) compared three-landslide inventory using universal frequency-area statistics. The result indicates, the number of landslide events increased proportionally with increasing landslide area and decreased with decreased landslide area. They discussed the importance of completeness and resolution of landslide inventory maps in the landslide studies. The incompleteness of the landslide inventory map is happened during the field-based collection of information due to loss of evidence of the existence of landslide removed by erosion, cultivation or another factor. Therefore, historical records and interviews of witnesses are more significant for complete landslide inventory mapping (Guzzetti et al., 2003).

To minimize subjectivity in weightage assignment procedure and produce more objective and reproducible results, techniques toward landslide hazard zonation has been, changed from heuristic to statistical approach (Kanungo et al., 2009). According to Dai and Lee (2001), stated statistical approach emphasis identifying the relationship between past landslide and causative factors. Even though, in statistical approach, various causative factors have been, analyzed by univariate or multivariate statistical methods (Fall et al., 2006; Dai and Lee, 2001).

Conversely, the limitation of the statistical approach is the collection of data on landslide distribution and causative factors over a large area for a considerably prolonged period and the result is dependent on the quality of data and details of landslide frequency data (Fall et al., (2006). There are two types of statistical approaches in landslide hazard zonation: bi-variate and multi-variate statistical analysis.

This analysis has been, applied for landslide hazard zonation to compare each data layer of causative factor to the existing landslide distribution (Kanungo et al., 2009). Its main objective is to identify the density of landslide occurrences within each causative factor data layer and parameter of data layer classes and derive data weights based on class distribution and landslide density. However, the weight of the landslide causative factor is assigned based on landslide density. The major bi-variate statistical model used in landslide hazard mapping is; Weights of Evidence Model, Weighted overlay model, Frequency Analysis approach, Information Value Model (IVM) and Fuzzy Logic method (Piacentini et al.; 2012; Parise 2002; Chung and Fabbri, 1998).

Multivariate statistics is a form of statistics containing more than one statistical variable of actual observation and analysis. In contrast multivariate statistical analysis for landslide hazard zonation reveals the relative influence of each thematic data layer on the total landslide susceptibility (Kanungo et al., 2009). Moreover, the analysis related to landslide susceptibility determines the weights of landslide causal factors based on the relative contribution in the occurrences of past landslide events within a defined land unit area (Suezen and Doyuran, 2004; Ayalew et al.*;* 2005).

The multivariate statistical method is, used to determine the percentage of landslide area for each pixel and to produce landslide absence or presence data layer for the given area. Moreover, it also concerns understanding the objective and background of various forms of multivariate statistical analysis and how they are, related to each other (Shahabi et al., 2012). Logistic regression model, Discriminant analysis, multiple regression models, conditional analysis, etc.

are commonly used methods of multi-variate statistical analysis for Landslide Hazard Zone mapping (Tolga et al., 2005; Guzzetti et al., 2005; Clerici et al., 2002; Chang and Liu, 2004).

A probabilistic approach is a method that can identify the location, time and magnitude of landslide events. Guzzetti et al., (2005) stated that, the probabilistic approach in landslide hazard analysis had been applied to determine the spatial, temporal and size probability of landslides. Moreover, this approach brings objectivity in assigning weight, but a certain degree of subjectivity exists in the weight assignment process (Kanungo et al., 2009). Guzzetti et al., (2005) carried out landslide hazard assessment at the Basin scale using a probabilistic model. They determined the probability of landslide size, temporal and spatial probability of landslides using, frequency area distribution function. Although, Jaiswal et al., (2011) approved, quantitative landslide hazard assessment along transport route in Nilgiri Hills, India. They performed Frequency-volume statistics to get the probability of landslide magnitude for the different return periods. Several studies have attempted to apply the probabilistic approach for quantitative landslide hazard zonation in recent times (Ghosh, 2011; Floris and Bozzano, 2008; Jaiswal and Van Westen, 2013; Guzzetti et al., 2006; Polemio and Sdao, 1999)

2.2 Classification of the landslide

It is important for those professionals carrying out landslide mapping to use consistent terminology to classify and describe landslides. The types of landslides are usually differentiated by the nature of their movement and earth material involved. There are many classifications of landslides that are attributed to the complexity of movements (Hansen, 1984). However, by far the most widely used classification system is designed by Cruden and Varnes (1996), which has become accepted as the standard means of describing the form of landslides. They classified landslides according to the types of movement undergone on the one hand and the types of materials involved on the other hand. In brief, material in a landslide mass is either rock or soil (or both); the latter is described as earth if mainly composed of sand-sized or finer particles and debris if composed of coarser fragments. The type of movement describes the actual internal mechanics of how the landslide mass is displaced, i.e. fall, topple, slide, spread, or flow. Thus, landslides are described using two terms that refer to material and movement: rockfall, debris flow, and so on. Detail description of the common types of the landslide that happened throughout the world is elaborated in the following section.

2.2.1 Falls

Falls are the abrupt movement of a mass of geologic materials; such as rocks, boulders or soils that become detached from steep slopes or cliffs when elevated masses are separated along joints, bedding or weaknesses. The detached masses go downward by free-falling, bouncing and rolling which can be seen in Figure 1. The triggering mechanism of falls is undercutting of slopes by streams and rivers or differential weathering, excavation during road construction, loosened by rain, plant-root wedging, expanding ice and earthquake shaking (Highland et al., 2008).

2.2.2 Topples

Topples are similar to falls except that the initial movement involves a forward rotation of the mass. Toppling failures occur as a result of the overturning of the blocks rather than sliding (Figure 1). Topples can consist of rock, debris (coarse materials), earth materials (fine-grained). The triggering mechanism of topples is gravity, water or ice occurring in cracks within the mass, vibration, undercutting, differential weathering, excavation or stream erosion. It occurs in columnar jointed volcanic terrain as well as along streams and river courses where the banks are steep. The rate of movement ranges from extremely slow to extremely rapid. It can be extremely destructive especially when failure is sudden or velocity is rapid (Cruden and Varnes, 1996).

2.2.3 Slides

Slides can be defined as a downslope movement of soil or rock masses occurring on the surfaces of rapture or thin zones of shear strain (Highland et al., 2008). Typically failure surface is either 1) curved in concave upward sense (rotational slides) or 2) nearly planar (translational slides).

2.2.3.1 Rotational Slides

Rotational slides move along a surface of rapture that is curved and concave (Figure 1). In the crown parts of the slide, the displaced masses move downward vertically and the top surface of displaced masses angles back toward the scarp. Movement is more or less rotational on-axis parallel to the slope (Cruden and Varnes, 1996).

2.2.3.2 Translational Slides

Translational slides are types of slides where the sliding can extend downward and outward along a broadly planar surface, and slide out over the original surface (Cruden and Varnes, 1996) as depicted in Figure 1. This type of movement typically occurs along structural features such as on a bedding plane or the interface between resistant bedrock and weaker overlying material (Abbot, 2004). They are found globally in all types of environments and conditions. Translational slides generally fail along geologic discontinuities such as faults, joints, bedding surfaces, or contact between rock and soil. These slides typically reflect a weak layer or existing structural discontinuity (Cruden and Varnes, 1996). If the overlying material moves as a single, less-deformed mass, it is called a block slide (Figure 1).

2.2.4 Debris Flow

A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilizes as a slurry that flows downslope. Debris flows include less than 50% fine-grained mass. Debris flows are commonly caused by intense surface-water flow, due to heavy rainfall or rapid snowmelt that erodes and mobilizes loose soil or rock on steep slopes. Debris flows occur around the world and are prevalent in steep gullies and canyons. They can be intensified when they appear on slopes or in gullies denuded vegetation due to wildfires or forest logging. They are common in volcanic areas with weak soils (Highland et al., 2008).

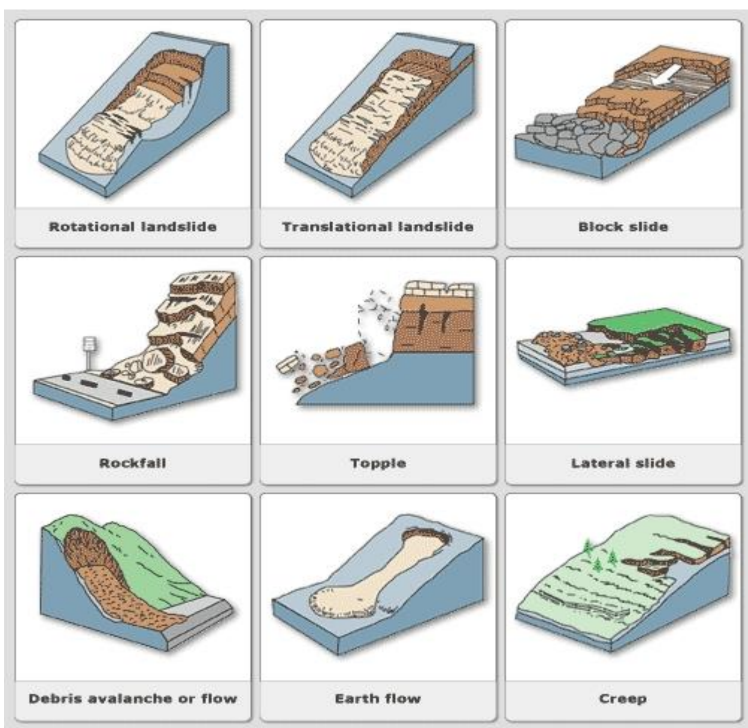


Figure 1: The most common types of landslides (Highland et al., 2008).

2.2.5 Earth Flow

Earth flows can occur on gentle to moderate slopes that contain fine-grained soils, commonly in clay and silt and very weathered clay-bearing bedrock. The mass in an earth flow moves as viscous flow with strong internal deformation. When disturbed, susceptible marine clay (quick clay), very vulnerable and may lose all shear strength with a change in its natural moisture content and suddenly liquefy, potentially destroying large areas and flowing for several kilometers. Earth flows occur worldwide in regions underlain by fine-grained soil or very weathered bedrock. Flows can range from small events of 100 square meters in size to large events encompassing several square kilometers in area. Earth flows in susceptible marine clays may run out for several kilometers. The depth of the failure ranges from shallow to many tens of meters (Cruden and Varnes, 1996). The common triggering mechanisms of Earth flows include saturation of soil due to prolonged or intense rainfall or snowmelt, sudden lowering of adjacent water surfaces causing rapid drawdown of the ground-water table, stream erosion at the bottom of a slope, excavation and construction activities, excessive loading on a slope, earthquakes, or human-induced vibration (Highland et al., 2008).

2.2.6 Creep

Creep is the slowest type of mass movement which travels a few millimeters up to several centimeters per year. It is characterized by an imperceptibly slow, steady downward movement of slope forming soil or rock. This movement is caused by internal shear stress sufficient to cause deformation but insufficient to cause failure. Creeps may produce tilting of objects such as fence posts, telephone poles, power lines and retaining walls (Figure 1). It also causes trunk in trees on creeping slopes (Cruden and Varnes, 1996). Landslides can be grouped into three types based on the state of phenomena including active, passive and reactivated. An active landslide is a landslide that is moving at present either for the first time or reactivated. Passive landslide occurred in the past such as prehistoric landslide but bears a potentiality to be reactivated. Reactivated landslide is a landslide that is active after being inactive (Fell et al., 2008).

2.3 Techniques and approaches for landslide hazard zone mapping.

2.3.1 Analytic Hierarchy Process approach

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision-maker towards a judicious choice (Chakhar and Mousseau, 2008). MCDA consists of a series of techniques (such as weighted summation or concordance analysis) that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by; experts, interest groups and stakeholders according to their degree of suitability or importance for locating/siting a particular facility/service (Malczewski, 2004).

AHP (Analytical Hierarchy Process) is; considered as relevant to derive the weights of multi-criteria by comparing the relative importance of criteria using pair-wise comparison. It depends on the principle of; decomposition, comparative judgment, and synthesis of priorities (Malczewski, 1999). Subsequently, this technique involves multi-criteria decision making and a multi-objective approach to allow the active participation of decision-makers in reaching an agreement (Sahnoun et al., 2012).

2.3.2 Application of Remote Sensing for landslide hazard Mapping

Remote sensing is the science, art and technology of acquiring data about any physical object or entity without physical contact**.** Remote sensing assists as a tool for environmental resource assessment, monitoring and management. The development of remote sensing technology to provide multi-spectral, multi-temporal and multi-spatial images is very helpful to increase the speed and frequency with which one can analyze a landscape. Moreover, remote sensing contributes to the development of impartial and complete assessments over larger geographic extents and remote areas than is possible with fieldwork alone (Steininger and Horning, 2007). Remotely sensed data is the main source of input data for analyzing; and interpreting any natural resource on the earth's surface. The recent developments in the application of satellite RS data in landslide studies in Europe have been studied. The study showed that over 70% of the total applications of RS data for landslide studies are; owned by landslide detection, mapping, and monitoring.

Good quality aerial photographs help in accurate landslide detection and mapping. However, aerial photographs may not be, used in continuous landslide monitoring since they do not prove repetitive coverage of the same area. Conversely, the availability of remotely sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions has made remote sensing one of the best sources of data for large-scale applications and study (Assefa et al., 2007). According to Dai et al. (2001), the most common inputs data to GIS are remotely sensed data from satellites or aircraft. Therefore, remote sensing serves as one of the main source data for GIS and prepares for further analysis in the GIS environment.

2.3.3 Application of Geographic Information System (GIS) for landslide hazard mapping

A geographic Information System is a computer system designed to store, retrieve, manipulate, analyze and display geographically referenced data. GIS in science view; defined as science used to analyze locational-based information. This makes it possible to take data stored in one form and combine it with data entered and stored in some other form (Church, 2002). It has become possible to efficiently collect, manipulate and integrate a variety of spatial data such as geological, structural, surface cover, and slope characteristics of an area, which can be used for hazard zonation using GIS techniques. The data layer can well integrate using GIS, and weighted analysis is helpful to find Landslide-prone areas. With the help of GIS, we can do a risk assessment and reduce the losses of life and property. It also helps to answer questions and solve problems by looking at your data quickly and easily.

Moreover, GIS integrates different data sources stored in a different format to display all forms of geographically referenced information. Geographical Information System is widely used in landslide hazard assessment, especially for generating of thematic data layers, computation of different indices, weight assignment, data integration and generation of LSZ maps. In hazard assessment, GIS is provided to model and rank hazard risk occurrence according to its distribution or intensity and output visualization in various formats. However, geographic information system supports as geo-database, geo-visualization and geo-processing views to support the decision-making process.

2.3.4 Integration of GIS and Remote Sensing for landslide hazard mapping

GIS and remote sensing techniques are applied in several scientific disciplines like Environmental Science (Akar, 2009). Integration of GIS, Remote sensing and GPS provide timely and useful information about the natural resource and the change that appears on earth.

Moreover, integrations of geospatial technology can process and evaluate locational-based data to locate and predict hazard risk. This technique plays a key role in monitoring and predicting disasters like landslides through evaluating, manipulating and analyzing geo-spatial data. The review of few studies on landslide hazard assessment using RS data indicates that aerial photographs are widely used in landslide detection and mapping (Galli et al., 2008).

Several landslide hazard zonations, methods such as Decision Tree model, Weighted Overlay, AHP, IVM and physically-based landslide hazard models are GIS and remote sensing-based models to predict landslide probability (Chang and Liu, 2004).

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1 Materials and Softwares

Materials are extremely important in researching solving certain problems, as they are a means for data collection in the field, recording of data, and others. Hence, the materials used for this study range from equipment used for obtaining and collecting data in the field to those used to carry out to insert in software used to carry out to insert in software that was used for processing the raw data obtained from the fieldwork. Classifications of materials used to carry out research (Figure 2).

The materials used in this research include the following:-

- ✓ Topographic maps with a scale of 1:50000 were obtained from the Ethiopian Geospatial Information Agency.
- ✓ Base map prepared from the topographic map for the delineation of active landslides, types and lithology contacts, location of springs, to locate the typical land use, aerial photographs and satellite images,
- ✓ Geographic Positioning System (GPS) to locate active landslides, lithological units, to capture spring location during fieldwork.
- ✓ Stationary materials to draw, write, and prepare a precise note before, during and after field investigation.

The different Software's were used in this work include: - ArcGIS 10.8, Global mapper, IDRISI selva17 and Microsoft excel 2013, ERDAS imagine.

- ✓ ArcGIS 10.8 was used for all the analysis and extraction of conditioning and triggering factors, inventory maps, and landslide hazard maps for both training and validation steps.
- ✓ Global Mapper was used to prepare the area's profile section, 3D view of the area from DEM data, and generate line data.
- ✓ Google earth was used for visual interpretation tools for LULC classification and inventory map preparation.
- ✓ By using pairwise comparison of 9-point continuous rating scale in IDRISI selva 17, after the standardization to a common scale (30*30m) of each causative factor, weight

is, given for each layer based on pairwise comparison of two data layers at the same time.

- ✓ Microsoft Excel 2013 was used to calculate the area percentage for each causative factor and final for the landslide hazard map.
- ✓ ERDAS 15 imagine was used to prepare a land use land cover map.

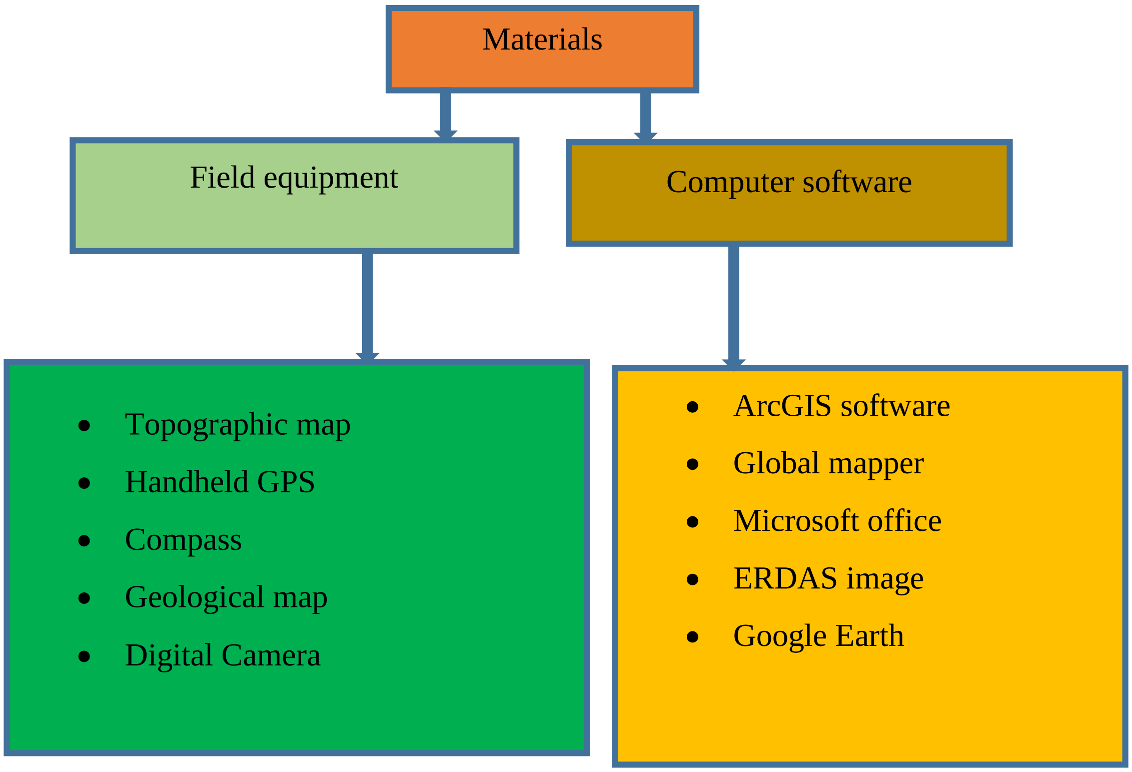


Figure 2: Classifications of materials used to carry out research.

3.2 Methods

The following steps have been carried out systematically as a general procedure to produce the landslide hazard zonation map. These are Data collection and organization, preparation of landslide inventory datasets, database construction of landslide causative factors, application of weighted overlay models to construct LHZM and validation of the output map. Generally, to accomplish the goal of this study effectively the following procedures were followed (Figure 3).

3.2.1 Data Sources

In this study, the necessary data for the study were, identified. Because of the nature of the study proposed number of data is, used for the present study. The availability of data was, recognized with relative sources. Most of the data source in the present study is internet, and some data sources are organization office. Thus, the data used in the present study were primary and secondary data. Table1 presents the main data source with their source and scale.

Table 1. List of data and sources

S. No.	Type	Description	Source
1	Maps	Geology map (1:50,000)	From field work
2	Raw data	SRTM (30*30m resolution)	USGS (United States Geological Survey) Earth Explorer
		ETM^+ images (year 2021, path, 169 row 54)	USGS (United States Geological Survey) Earth Explorer
		Soil data by Ethiopia shape file (vector format)	Hawassa city administration of agriculture office; it is taken from ministry of Agriculture

3.2.2 Data Collection

Collecting reliable and accurate data is the most predetermining factor for the final output of the proposed study. While collecting data, it is better; first to introduce the data requirement. In this study, before collecting data, the purposes of data were recognized. For the present study, data was; collected from the different government offices and downloaded from the internet. As part of data collection, different data formats, projections, and types were; collected. SRTM image (30*30 resolutions) from USGS to derive the digital elevation model of the study area. To extract slope, aspect, and drainage network, digital elevation models were; used as input source data. Soil data was; collected from the Ministry of Agriculture to extract soil type and soil texture. ETM^+ images from USGS to map land use land cover of the area.

3.2.2.1 Secondary data (pre-field or before field work)

During the pre-field investigation, secondary data and required materials were gathered from different organizations. Climate data and field equipment include GPS from the National Metrological Agency of Ethiopia and Arbrgona woreda Agricultural sector office. The pre-field study involved preparing various types of maps, such as slope angle, aspect, elevation (DEM), land-use and land-cover (Landsat image), and regional geology map. The already available satellite imageries were studied to understand the physiographical characteristics of the study area.

3.2.2.2 Field work (Primary Data)

During the field study, observations and measurements were made and relevant data was collected. These include data of slope material, LULC, geological structure, landslide inventory data, and identified existing and potential landslide areas. The detailed lithological and structural maps were prepared. Finally, other maps prepared during the pre-field study were verified in the field and modified wherever necessary.

3.2.2.3 Post-Field Investigation (After field work)

During post field investigation stage, the following activities were performed:-

- The thematic map of the triggering factors map and the landslide inventory map was prepared and verified.
- The triggering factors map and landslide inventory map were analyzed to get the relationship between the factors and landslide in the study area using the weighted value.
- LHZ map was prepared by overlay (combine) triggering factor maps.
- LHZ map was verified and check validation using Landslide inventory data and AUC graph respectively.

3.2.3 Data Analysis

The data analysis method employed in the present study depends on the qualitative data collection and analysis. The analysis of qualitative data collected was accomplished through the integrated use of ERDAS imagine and ArcGIS software packages along with excel and Microsoft office tools. The input data in the form of Regional geological maps, soil maps and satellite images were, used to extract the variables that may have a consequence on landslide occurrence. The present study selected slope, aspect, drainage density, lineament density, geology, land use land cover, and soil type as the conditioning factors for landslide hazard mapping in the study area. It was, assumed that these causative factors were probably responsible for landslides in the area. However, there are no standard guidelines for selecting these parameters (Ayalew et al., 2005). One parameter may be an important controlling factor for landslide occurrence in a certain area but not in another one. Therefore, the nature of the study area, the scale of the analysis, and data availability were; taken into account (Yalcin, 2008). Collectively, the seven factors used in the current study were, selected based on the above-mentioned criteria, while literature outputs and general guidelines for GIS-based studies were also considered (Magliulo et al., 2008). Generation and production of thematic data layers are the most important and time-consuming tasks in the present study. A various number of thematic maps stated were; generated.

3.2.4 Data Preparation

The selection of conditioning factors and the preparation of corresponding thematic data layers is crucial for any landslide hazard analysis. In this study, before the preparation of factor datasets from raw data, all datasets were converted into the same projection system and Universal Transverse Mercator (UTM) projection of Adindan datum was, used for all the data set. The datasets include geology map and soil map, which were represented by polygon feature. This discrete form of data was not suitable to be, used in landslide hazard mapping. For this reason, it was converted into continuous surfaces (Suzen and Doyuran, 2004). Then the raw data were, used for the production of input data with the same data type.

Preparation of Land use Land cover dataset: the downloaded ETM^+ images of 2021 were layer stacked using seven bands, and sub-setting the image was performed by the shape file of the study area. Radiometric enhancement techniques like haze reduction and atmospheric noise reduction were, applied to enhance image appearance. The dataset containing 7, 5, and 3 Red, Green, Blue bands, respectively, were prepared for land use land cover classification of the study area.

Preparation of Geology dataset: To prepare geology datasets of the study area, the geology map of Arbegona was, prepared at field work. The geology Map incorporates the geological units and the faults lines in the area (Figure 12). The geology map has a database concerning the geologic unit names. The map was prepared after field work; at the field, in addition to identifying lithological units and different structures, geographic coordinates and elevation were also recorded by using necessary materials with a topographic map. Finally, the geological map was prepared by using ArcGIS software.

Preparation of Soil dataset: Soil datasets were, acquired from the Sidama region agriculture office, which is taken from the ministry of agriculture of Ethiopia. The soil datasets were; obtained in vector data form by Ethiopia boundary shape file based on soil survey of 2008. The soil dataset of the study area was; clipped from the Ethiopia soil dataset. The most relevant attribute for deriving soil texture information was soil class, which captures the type of soil in terms of texture. As part of the preparation of these datasets vector datasets of the study, area soil was, converted to raster datasets and prepared for further analysis.

Preparation of DEM datasets: The downloaded SRTM (30*30-resolution) images of the study area and its surrounding from USGS (United States Geological Survey) were; imported into ArcGIS software. ArcGIS was, used to fill missing SRTM values. As part of the preparation of these datasets, the study area's digital elevation model (DEM) was extracted by the shape file of the study area. When extracted digital elevation model of the area prepared was; used to determine the elevation of the area and for extraction of the slope, aspect, stream network and drainage density datasets of the study area.

Preparation of Slope dataset: Digital elevation model of the area was, used to generate the slope datasets. To prepare slope datasets, digital elevation models were, processed under the arc toolbox of the GIS environment. The generated slope datasets were prepared for further reclassification of slope angle.

Preparation of Aspect dataset: Aspect datasets were prepared from a digital elevation model of the area. Digital elevation model was, processed under arc toolbox of GIS environment. The generated aspect datasets were, prepared for further analysis and reclassification.

Preparation of Stream/ Drainage network datasets: stream network datasets, were extracted from Digital elevation model data of the area by performing various processes. The preparation of stream network datasets was, performed under the spatial analysis toolbox of the hydrology tool. The stream network prepared datasets were used to generate the drainage density of the area.

Preparation of Drainage density datasets: Drainage density datasets were prepared from the stream network of the area; the stream network dataset is in figure 24. Frist, stream datasets were, converted to vector data format by using a conversation tool (raster to polyline). The polyline vector format of the stream network was, used to generate drainage density dataset by line density tool.

Landslide inventory: In landslide Hazard Zonation mapping, landslide inventory mapping is one of the key elements, which can be prepared using various techniques like the aerial photograph or Google Earth Imagery interpretation, field investigation, and evaluation of archived data coupled with GIS tools (Van Westen et al., 2008). Landslide inventory map used as the base for future landslide prediction by evaluating the relationship between the current landslide event and landslide driving factors (Mohammad et al., 2012; Yalcin et al., 2011; Corominas et al., 2014). Van Westen et al., (2008) prepared a landslide inventory map using GIS from field investigation, historical landslide events, and satellite image analysis. Landslide inventory maps can also be prepared using field surveys and Google Earth Imagery (Meten et al., 2015; Roy and Saha, 2019; Zine et al., 2019; Wubalem and Meten, 2020). For the present research work, I was going to prepare a case study around Arbegona, the map of landslides and risk areas, by using as the basic data sources. The landslide inventory map result was discussed in figure 28.

Preparation of Lineament density datasets: lineament density datasets were prepared from lineament datasets of line features. Calculating a magnitude-per-unit area from polyline features that fall within a radius around each cell (line density) lineament density datasets was generated. The general methodology adopted in the present study was, shown in the flowchart of landslide hazard mapping (Figure 3)

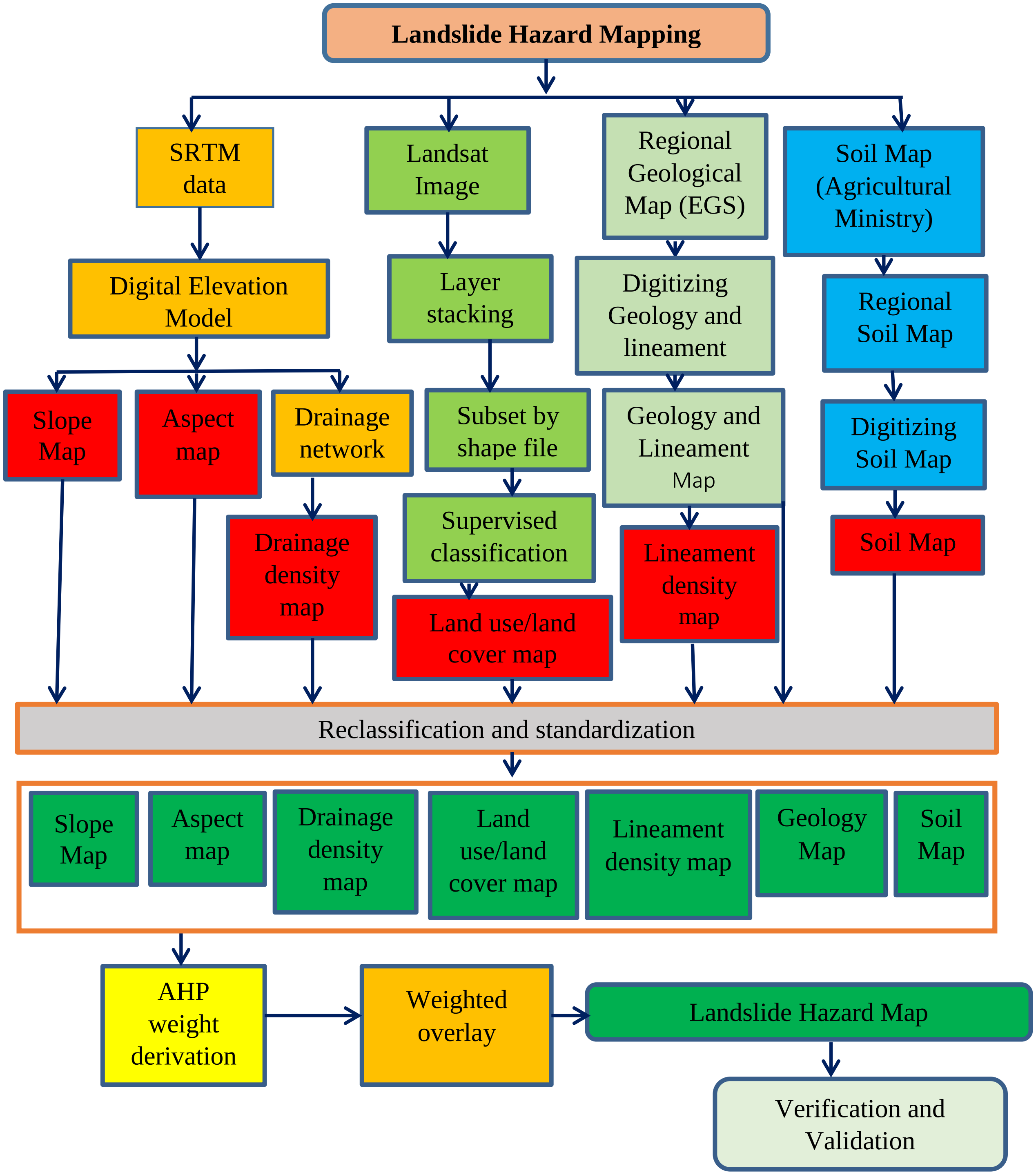


Figure 3: Flowchart of the methodology used for landslide hazard mapping

3.2.5 Analytical Hierarchy Process (AHP) method

AHP is a well-known multi-attribute weighting method for decision-making. The analytic hierarchy process is a theory of measurement for dealing with quantifiable and intangible criteria and has been applied to numerous areas, including decision theory and conflict resolution (Vargas, 1990). AHP is a multi-objective, multi-criteria decision-making approach that enables the user to arrive at a scale of preference drawn from a set of alternatives. AHP has gained wide application in site selection, suitability analysis, regional planning, and landslide hazard analysis (Ayalew et al., 2005). To apply this approach, it is necessary to break a complex unstructured problem down into its component factors, arrange these factors into an ordered hierarchy, assign numerical values to subjective judgments on the relative importance of each factor, and synthesize these judgments to determine the priorities to be assigned to these factors (Saaty, 1980). Pairwise comparisons are used in this decision-making process to form a reciprocal matrix by transforming qualitative data to crisp ratios. The reciprocal matrix is then solved by a weight finding method for determining the criteria' importance and alternative performance (Vahidnia et al., 2009). Once the pairwise comparison matrix is obtained:-, based on the problem elements, the aim is to summarize preferences so that each element can be assigned relative importance (Boroushaki et al., 2008). The Eigenvalue method is one way to access the ultimate weights of criteria. In the AHP, the measure of weighting to each informational unit is based on which role this unit plays in this layer and the most weight is for which layer maximum effect has in the determination of goal. In this method, the weight of each layer depends on the judgment of the expert, so that the more precise is the judgment, the more compatible is the produced map with reality (Moradi et al., 2012).

To weighting determinant parameter in a landslide, a questionnaire containing the table of paired comparisons in criteria and sub-criteria were presented to experts. In these comparisons, the decision-makers use oral judgment. Such judgments have become slightly between zeros to nine by Saaty (2000). In constructing a pair-wise comparison matrix, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell (Table 10). When the factor on the vertical axis is more important than the horizontal axis, this value varies between 1 and 9. Conversely, the value varies between the reciprocals 1/2 and 1/9 (Table 10). Generally, the Steps of Analytical Hierarchy Process (AHP) method are, listed in figure 4.

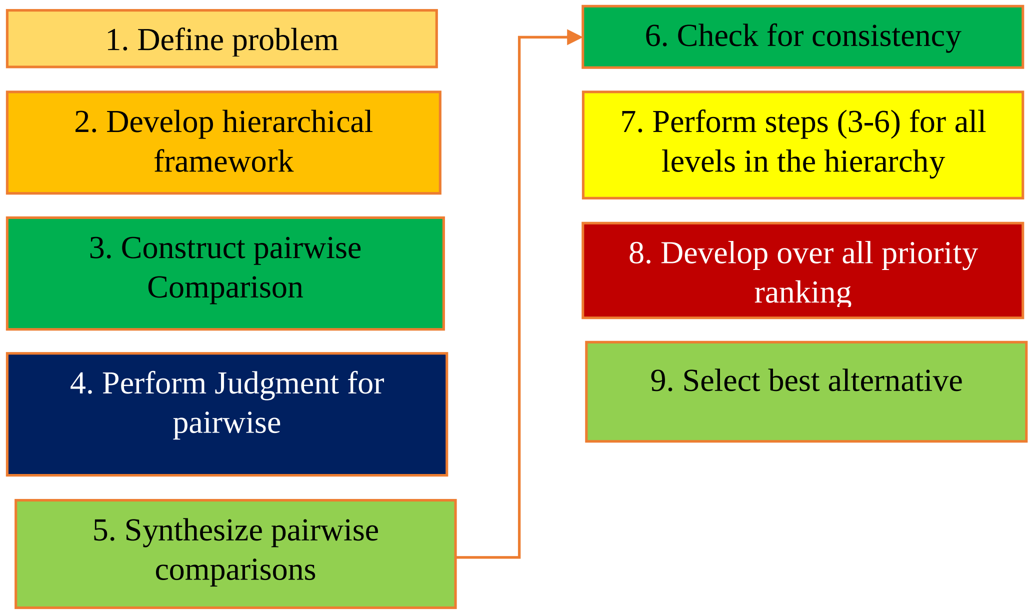


Figure 4: Steps of Analytical Hierarchy Process (AHP) method.

CHAPTER FOUR

4. DESCRIPTION OF STUDY AREA

4.1 Geographic location

Arbegona woreda is founded in the Sidama Region, Southern parts of the Ethiopian highlands. It is around 349 km from Addis Abeba, the capital city of Ethiopia, and 74 km from Hawassa, the capital city of Sidama Regional State and SNNPR in Southern Ethiopia. It geographically lies between 459158.09m to 482293.42m Latitude and 724623.11m to 752425.48m Longitude (Figure 5). It is demarcated by Gorche Woreda in North West, on the North by Oromia Region and the East Bensa Woreda. The Woreda has two agro-ecological zones: Dega (86%) and Woyna Dega (14%). Annual rainfall is between 1250-1300 mm per year. The altitude ranges between 2000-3336 m above sea level. The economic activity of the Woreda is mainly agriculture with rearing farm animals and cultivation of land. The dominant crops in the Woreda are maize, wheat, enset, barley, pea and bean.

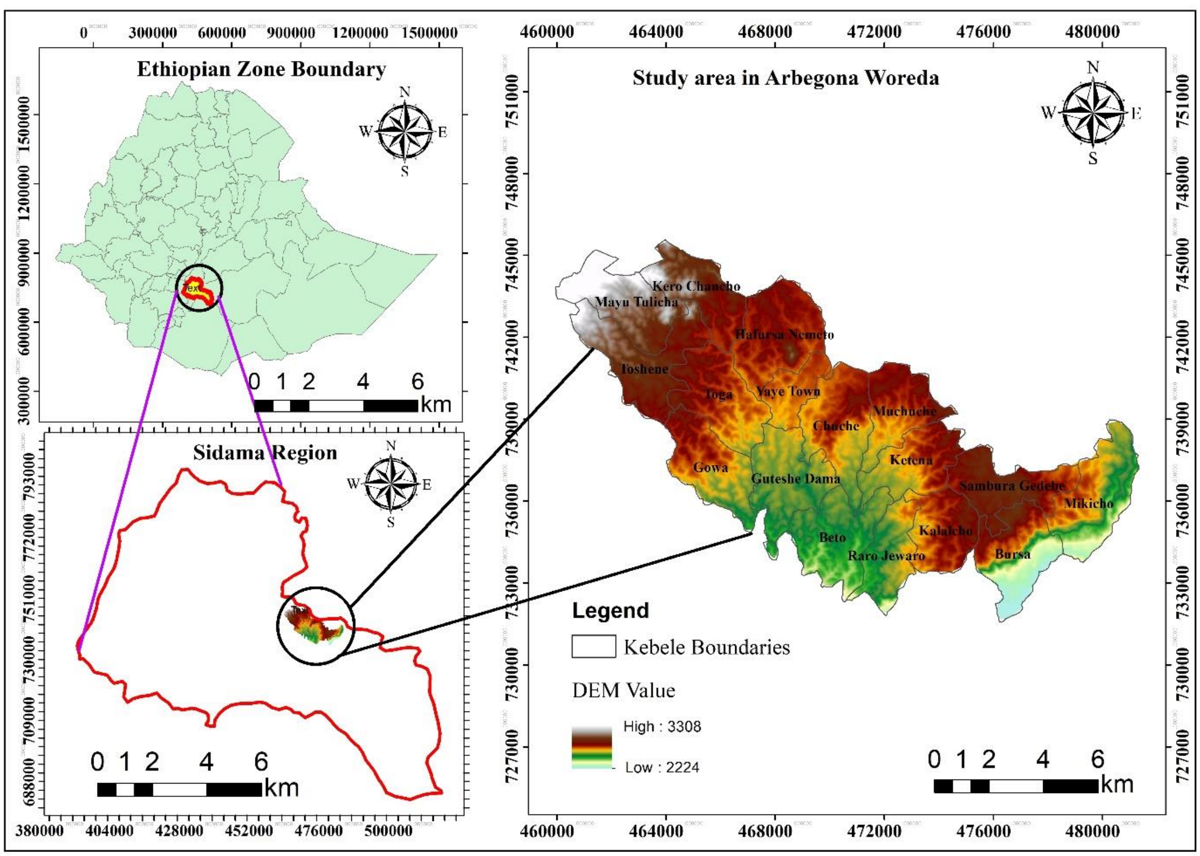


Figure 5: Location Map of the Study Area.

4.2 Physiography

The study area belongs to the southeastern Ethiopian highlands. The elevation ranges between 3187.6m and 2224m above mean sea level. The presence of steep scarps, cliffs, sharp ridges, rugged slope faces, deep gorges and valleys generally indicate that the area is prone to active surface processes and landslide activities. The area can be classified into two main physiographic regions. These are the plateau and rugged terrain. The plateau areas are characterized by volcanic landscapes and different soil deposits that represent the high flatlands of the Yaye Town and Bocessa Village areas. In this area, the slopes are horizontal on top to steeper at the plateau scarp. Even if this area is classified as a plateau their landscape is completely dissected plateau. The rugged terrains are rivers and streams dissected volcanic terrains, which represent the deep narrow valleys and gorges of the area. Slopes in these areas are steep to vertical and susceptible to erosional and landslide activities. For example, around Logita river at Mikicho and Bursa Kebele and around Garamba Mountain represent rugged terrain (Figure 6).

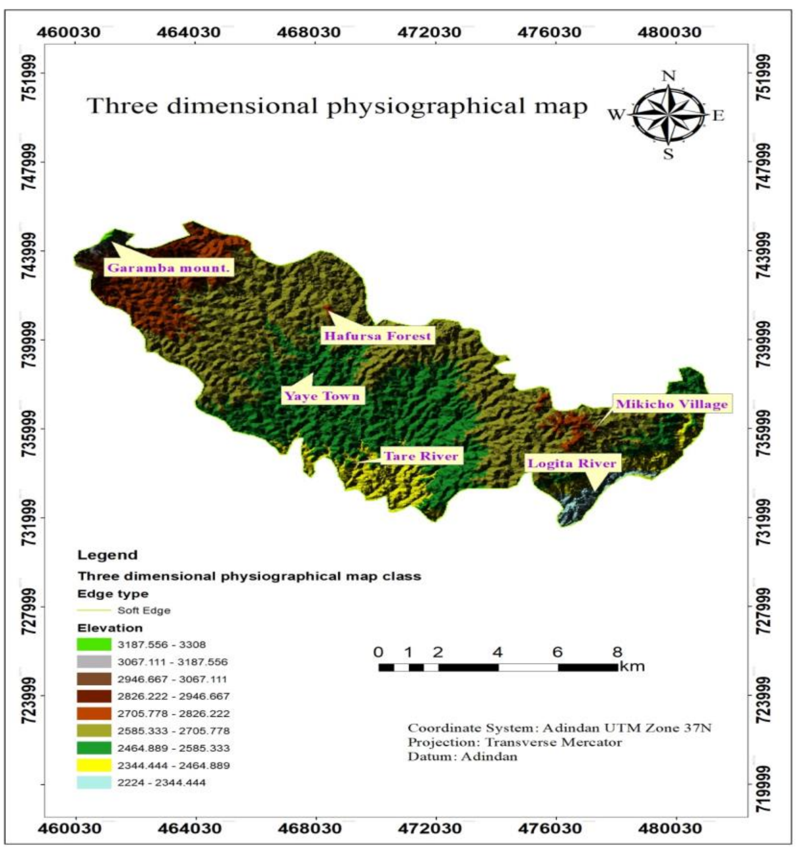


Figure 6: Three-dimensional physiographical map of the study area

4.3 Climate

The study area is characterized by extreme variation in topography. The mean annual minimum and maximum temperature of the district ranges between 7 c/^{0}C and 21c/^{0}C, respectively with an average of 14 c/^{0}C. The mean annual temperature of the area varies from 18 c/^{0}C in the lower elevation areas to 14 c/^{0}C in the highland area, where the temperature is reduced due to the effect of altitude and humidity.

The average yearly maximum temperature of the woreda was 19.3 c/^{0}C (Figure 8), while the average minimum temperature of 7.86 c/^{0}C (Figure 9). The rainfall pattern of the study area is characterized by bimodal distribution. Spring (short Rainy seasons from February to May) and summer (long rainy season occurs from June to September). The study area receives a mean annual rainfall varying from 800-1650 mm, and the amount of rainfall increases with increasing altitude.

The annual rainfall of the study area ranged from 997.853 – 2207.397 mm, indicating that there is inter-annual rainfall variability over the years. The results also revealed a declining rainfall amount over the last three decades. For instance, in 1983, the amount of rainfall received was 1486.254 mm and it was declined to 1105.599 mm in 2017. The rainfall shortage was observed in 2002, 2015, 2016 and 2017, which was 997.853, 1293.749, 1323.244 and 1105.599 mm per year, respectively when we compare the rest of the rainfall in the years (Figure 7).

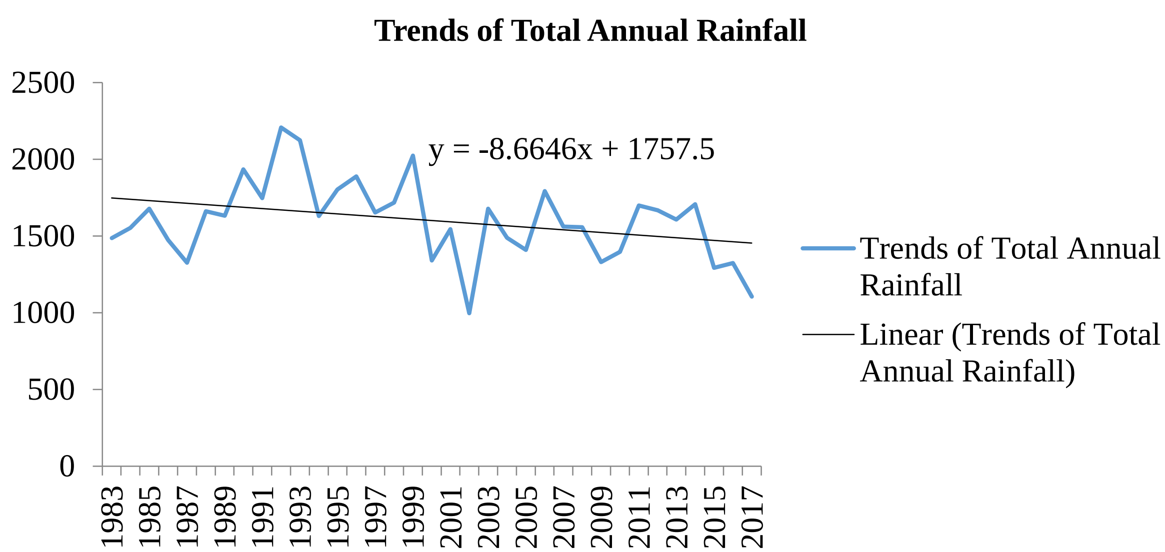


Figure 7: Annual rainfall trend and variability at Arbegona district (1983 – 2017)

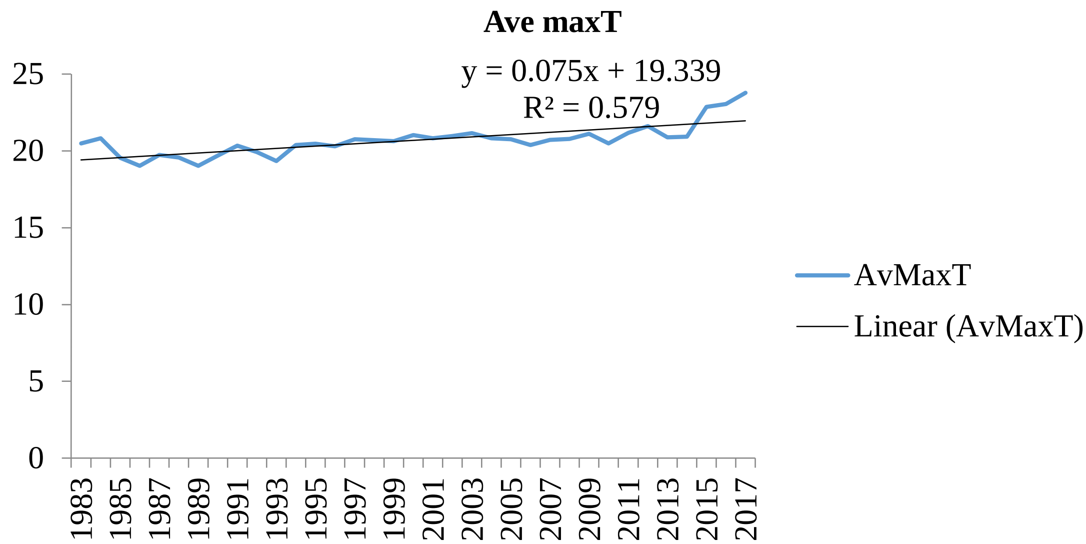


Figure 8: Trends of maximum temperatures of the study area (1983 – 2017)

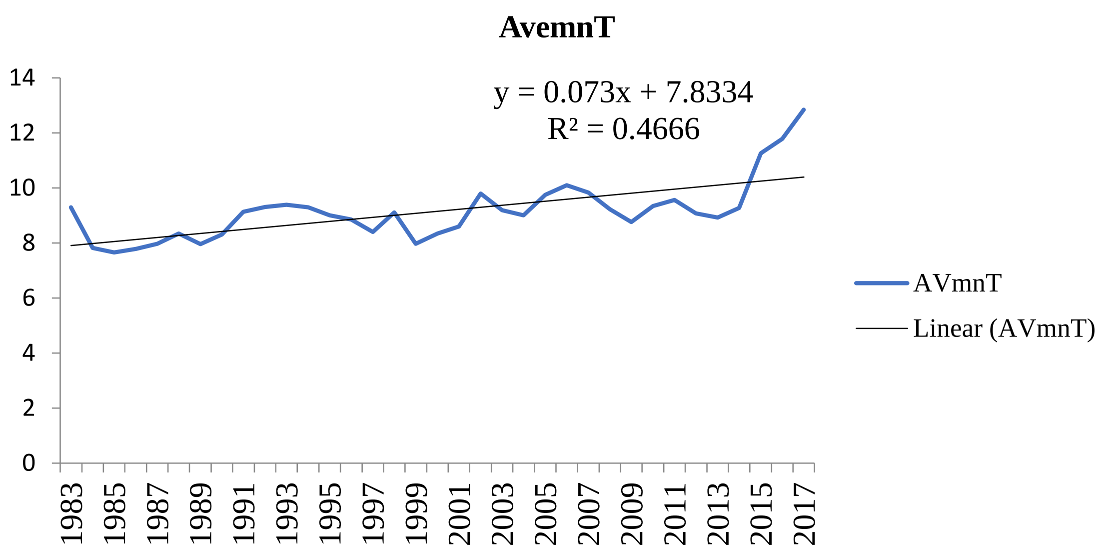


Figure 9: Trends of minimum temperatures of the study area (1983 – 2017)

4.4 Regional geology

The study area is regionally located within the border part of the Main Ethiopian Rift System and southern segments. The basement Precambrian metamorphic rocks, Paleozoic-Mesozoic sediments and Cenozoic volcanic rocks are the main rock units found in Ethiopia (Kazmin, 1972). The general framework of the mapped area can be divided into four groups. The Precambrian high-grade metamorphic rocks, low-grade metamorphic rocks, intrusive rocks and the Cenozoic volcanic. All the units are shown on the 1:250,000 scale map on the Dilla topo sheet map and described in the report (Figure 10).

4.4.1 Tertiary volcanic rocks

4.4.1.1 Transitional to mildly alkaline and sub alkaline basalts and rhyolites

This unit is exposed in the western and southeastern parts of the study area. It forms cliffs and shows fractures and jointing. It is composed of olivine, pyroxene and plagioclase; the rhyolites overlie the basalt. The rhyolite is composed of quartz and k-feldspar which is slightly weathered; cliff cutting exposure shows pink to light pink fresh color. Minor ignimbrites and trachyte which are not map-able also occur in this unit (Aman et al., 2015).

4.4.1.2 Aphyric and porphyritic basalt with lesser vesicular basalt, minor alkali trachyte flows and tuffs.

This unit is found in the southern part of the study area. It consists of Aphyric basalt which is black and slightly weathered exposed on the top of the small hills. It occurs in Bansa (Daye) areas to Kibremengist, towards the eastern part (Aman et al., 2015). The porphyritic basalt is olivine-pyroxene phyric which has a fresh dark gray color and shows slight to medium weathering. When weathered it shows light gray to light brown color. The lesser vesicular basalt is a brown-colored medium to highly weathered and it forms cliffs. It contains olivine pyroxene phyric basalt, pyroxene phyric basalt, olivine pyroxene plagioclase phyric basalt and aphyric basalt. There are scarcely exposed trachyte in some parts of the mapped area, but they are not map-able for the scale. Porphyritic basalt is intercalated with the aphyric basalt especially along the road from Bule to Hacha small towns (Aman et al., 2015).

4.4.1.3 Alkali trachyte flows, alkali trachytic tuffs and basalt

This unit is exposed on the east part of the map sheet, extend from Daye to Kibremengist. The basalt is highly weathered brown colored, and it is ridge forming. The tuffs are mostly composed of trachyte fragments and are not compacted as well as the ignimbrites. It shows light pink to dull white color intercalated with the basalt (Aman et al., 2015).

4.4.1.4 Alkaline basalts, trachytes, and peralkaline rhyolitic ignimbrites

This unit is exposed on the northeastern corner of the map area. It makes a small ridge with an elevation up to 3000m high. The basalt shows the dark gray fresh color and light gray weathered color. Even if the dominant exposure on the area is the basalt, some trachytes and rhyolitic ignimbrites are exposed over the area (Aman et al., 2015).

4.4.1.5 Nazreth Group and Dino Formation

It is exposed on the northwest part following the Galena and Wabe Rivers. It flows to Hagere Selam and on the northeast parts of the area along Bale River to dame and Kulu Rivers by surrounding mountain Damote. It has a sharp contact with Alkali trachyte flows with some plugs minor alkali trachyte tuffs and basalt on the east part, Middle basalt porphyritic basalt on the South. It contains different types of litho units such as Ignimbrites, rhyolites, Basalts, and tuffs. These different types of units are the upper Miocene exposure controlled by some primary structures that have a North East trend. This lithic fresh Ignimbrite shows light gray to gray color the weathered color is light brown. Most of it contains rhyolitic and trachytic rock fragments with fine and compacted ground mass. It makes columnar joints. The fresh rhyolite shows pink color, medium to coarse grains and slight to high weathering. Some of the basalts are slightly weathered porphyritic textured consisting of olivine, pyroxene, and plagioclase; the Aphyric one shows dark gray color, slightly weathering, and most of them the time, it makes small hills.

4.4.2 Quaternary Volcanic Rocks

4.4.2.1 Ignimbrites, tuffs, waterlain, pyroclastics

These rock units are found in the center and the northwest part of the map sheet. Such rocks are exposed around Aleta wendo, Koye, Chuko and Seke, and some other small towns. The unit contains light gray, coarse-grained lithic ignimbrites, unwelded tuffs with a light gray color exposed by making flat land, and pyroclasts. Petrographically, the ignimbrite comprises 7% alkali feldspar and 3% quartz phenocrysts with 79% ash matrix, 8% crystal fragments, 2% volcanic glass and 1% opaque minerals (Aman et al., 2015). The quartz phenocrysts and alkali feldspar are fine-grained to finer ash matrix. Minor biotite minerals also occur as accessories (Aman et al., 2015).

4.4.2.2 Per alkaline silicic

This unit has a fresh light yellow color. Per alkaline silicic include rhyolite and trachyte rock. Which are often coarse-grained and both are slightly weathered. Petro graphically, the trachyte is composed of 11% sanadine, 14% opaque, 75% alkali feldspar mineral constituents. The alkali feldspar is displayed as a ground mass in the study. The sanadine phenocrysts are euhedral to subhedral, and quartz crystals are accessories (Aman et al., 2015).

4.4.2.3 Pumice and unwelded tuff

This unit is exposed on the north western parts of the mapped area along with the northern Abaya. Both the pumice and the tuff have shown broken white color. The pumice is fine-grained, rounded and it has a light density. The tuff is friable unwelded and contains minor rock fragments and few minerals.

4.4.3 Stratified high-grade metamorphic rocks

4.4.3.1 Biotite-quartz-oligoclase gneiss, amphibolites, and minor oligoclase-quartz microcline gneiss

This unit is exposed in the southeast part of the area. It is distributed along Girja, Harsu, Buwanbwa wuha and Meleka towns. The north-south trending shear zone crosses this lithology. It is composed of well-banded amphiboles, quartz, and feldspar and has a sharp contact with mica schist and lesser chlorite schist. The dominant rock type is biotite-quartz-oligoclase gneiss, which is leucocratic and mostly fine-grained, with a subordinate coarse-grained variety. Some migmatization is indicated by moderately developed thin lenticular banding. This rock type displays a granoblastic texture. The major constituents are oligoclase, quartz and biotite. Muscovite and microcline may occur with minor apatite, opaque minerals and epidote. The second rock type in this unit is fine to medium-grained amphibolite, which occurs mainly as bands. It is a melanocratic and often schistose rock, exhibiting well-developed mineral lineation defined by hornblende crystals. This unit is exposed in the southeastern part of the area. It is homogeneous, with rare, thin intercalation of quartzite, amphibolite, and muscovite or biotite bearing schists and minor gneisses. Oligoclase-quartz-microcline gneiss is leucocratic, fine to medium-grained rock that is mostly friable. Foliation is more pronounced in the fine-grained type. The coarse-grained variety generally appears massive.

4.4.4 Stratified low-grade metamorphic rocks

4.4.4.1 Abale schist and lesser chlorite schist

It is exposed on the southeast of the study area making small hills. It is composed of muscovites and chlorites. The chlorite schist shows green color due to the chlorination, and in the mica-schist, they show light brown color. It is highly weathered and highly friable, and a representative sample is difficult to obtain. This unit is exposed to the eastern part of the area, extending from Chebe town to Mejo town. It is wide in area coverage, and it occurs intercalated with the biotite-quartz-feldspar gneiss. It shows gray color and schistosity, and also the grains are coarse to medium. It is composed of amphiboles, muscovites, quartz, and some feldspar. In this exposure, there are some talks, in some parts of it, chlorites are shown.

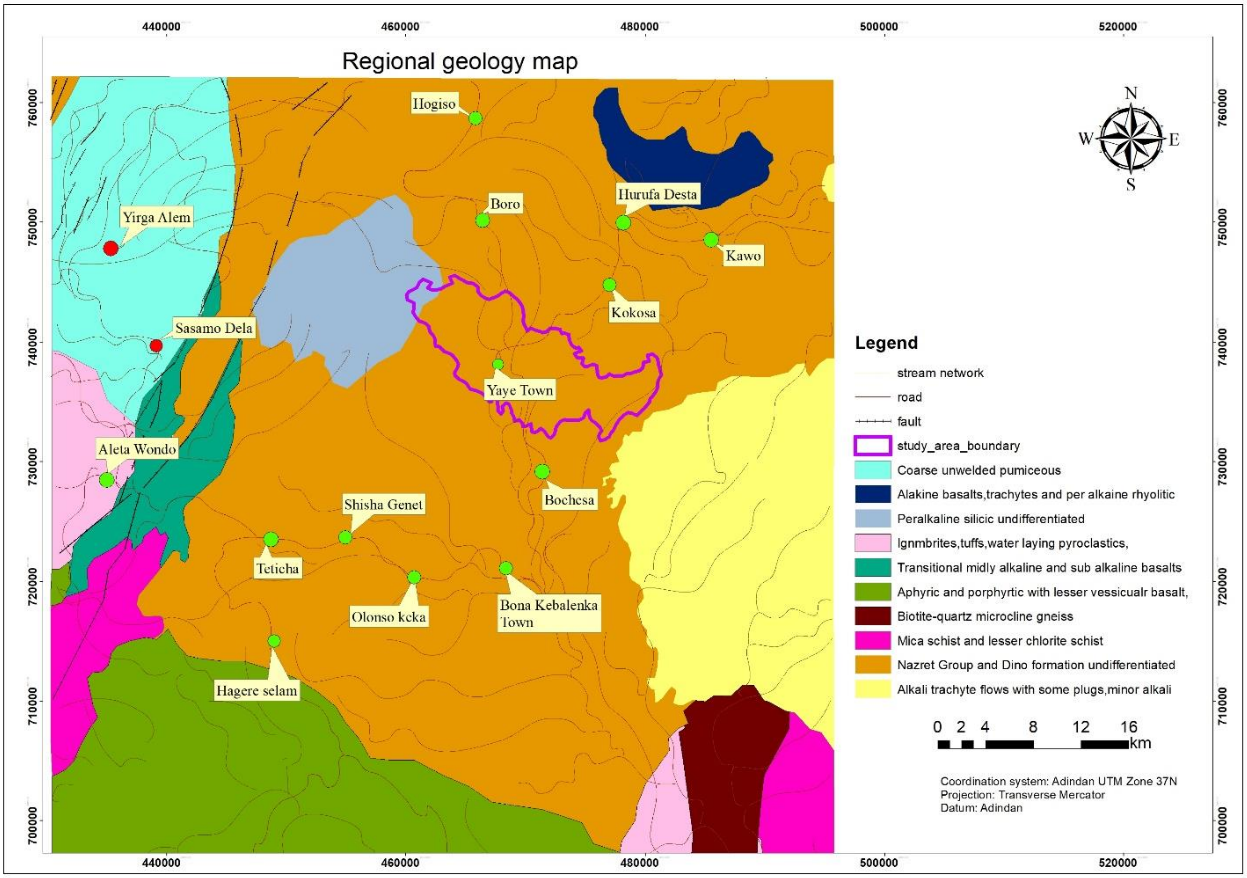


Figure 10: Regional geological map of the study area. (Digitized from Dilla topo sheet map 1:250,000)

CHAPTER FIVE

5. RESULTS AND DISCUSSIONS

5.1 The relation between preparatory factors and landside distribution

By applying the AHP method, the weight value of each factor has been determined, and the results illustrate their relative importance in causing regional landslides. Table11 lists each parameter used or calculated landslide proportion in each causative factor, which can be further applied by using the AHP method to determine the value of each weight. The obtained weight value reveals the spatial relationship between landslide distribution and each landslide factor class.

The Preparatory factors (mechanisms) are cumulative events, which are responsible for the landslide initiation. Preparatory factors include slope, slope aspect, geological, drainage density, lineament drainage density, soil, and land use land cover. Assessment of the event controlling parameters should be the basis of a systematic inventory assist in creating a database. This database established the correlation between landslide initiation and the characterization of event controlling parameters in the study area. The following event controlling parameters and landslides distribution are examined below:

5.1.1 Slope

The slope is the first derivative of elevation with each pixel denoting the angled slope at a particular location. The slope is an important factor, which influences the landslide process. If the slope is steeper, the increment in shear stress is high and the tangential component of the weight of the mass increases while the perpendicular weight will decrease. Therefore, when the shear stress is higher than the resisting force, the slope mass gets the tendency to slide down the slope. Slope angle is an essential component of the landslide influencing factor set, which indicates how steep the ground surface. Gentle slopes are expected to have a low frequency of landslides because they possess lower shear stresses associated with low gradients. Because of its relationship with landslides, slope angle is a crucial factor in landslide Hazard assessment; it is frequently used in creating landslide hazard maps (Clerici et al., 2002 and Lee et al., 2004). For the present study area, the slope was, divided into five categories classes: (0-10), (10-20), (20-30), (30-40) and greater than 40 (Figure 11).

Table 2: Slope class and area coverage

S.No.	Slope class (%)	Area(km^2)	Area (%)
1	0-10	29.94	23.02
2	10-20	39.47	30.35
3	20-30	34.82	26.77
4	30-40	20.04	15.41
5	>40	5.80	4.45
Total		130.07	100

As indicated in the table, most of the area was, dominated by gentle topography. Among the part of the study area, the eastern, northeastern, and central parts were characterized by gentle slope topography. In addition, the area was, characterized by northwest and southeastern facing steeper ranges, which are, divided by numerous river valleys. However, when the slope is steeper the thickness of the colluvial material decrease. Conversely, the very small topography of the area was, dominated by a steep slope. The village has moderate and high slope occurs in agricultural land.

As shown from the table 2, topography of the area were dominated by a slope with 10-20%, which covers 39.47 km^2 of the total area. This is mainly found in northern, central, and southern parts of the study area. The second dominant topography of the area is a slope with 20-30% found in the western and southeastern parts, covering 34.82 km^2 of the total area. This slope class includes a large portion of the cultivated lands. The third dominant topography of the area is a slope with a slope of 0-10%, covering 29.94 km^2 of the total area. In this slope class, agricultural and grassland were found as relatively gentler slopes favor agriculture practice. However, only 5.80km^2 of the area is a slope with >40, mostly found in the southeastern and northwestern part of the area. Much of the forest and agricultural land were found in this slope class.

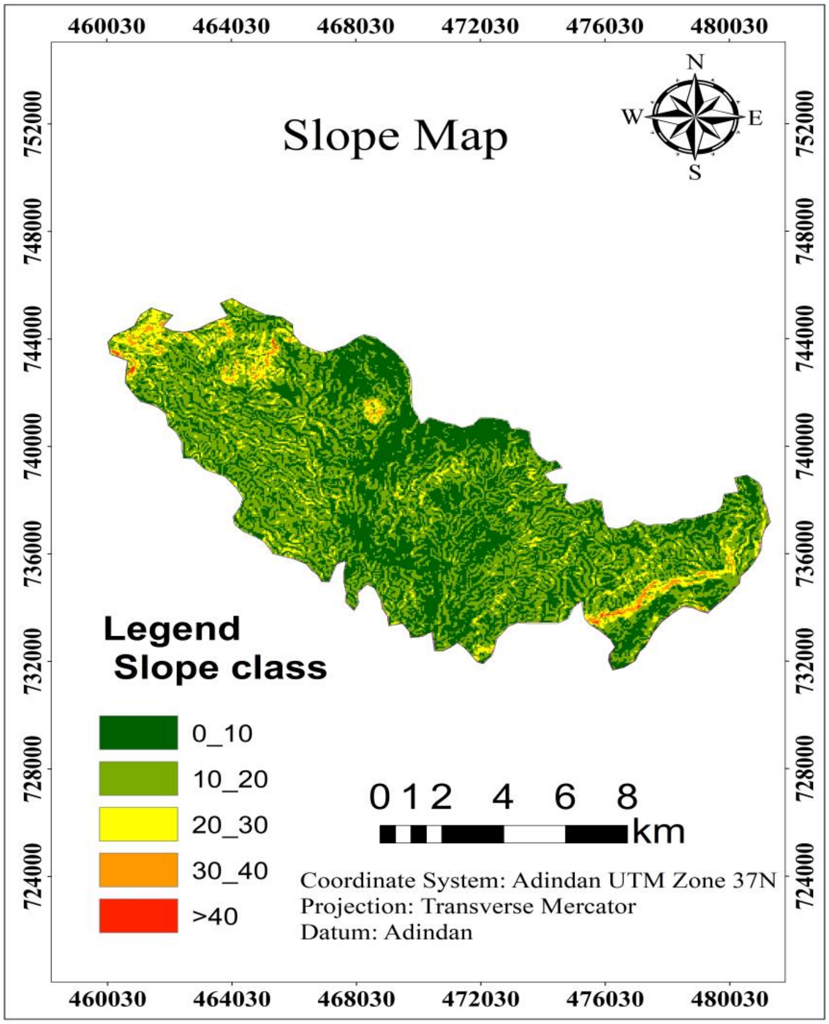


Figure 11: Slope map of the study area.

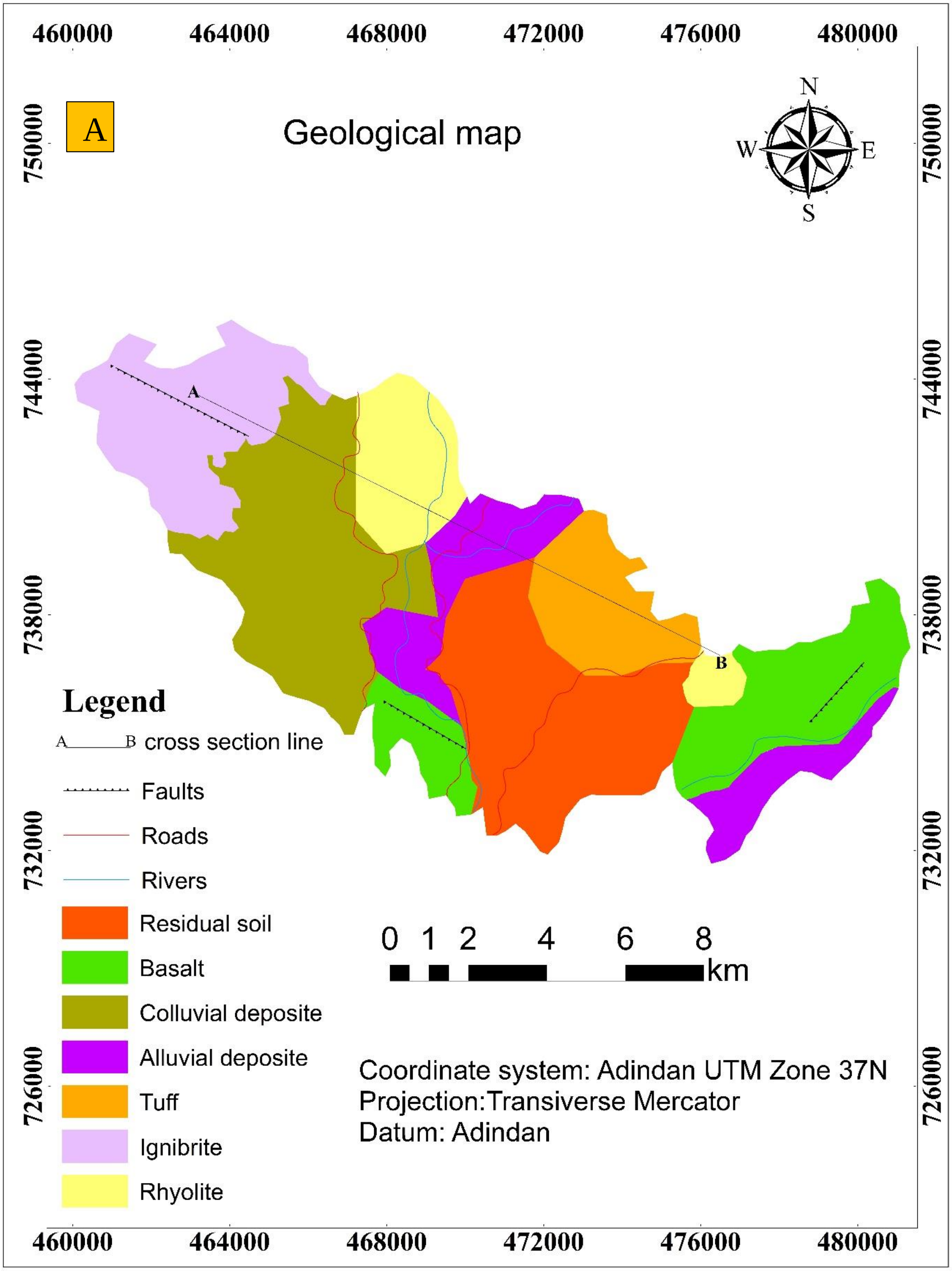
5.1.2 Local Geology

It is widely recognized that geology greatly influences the occurrence of landslides because lithological and structural variations often lead to a difference in strength and permeability of rocks and soils. Thus, landslide activity is highly influenced by the nature and type of regolith material (Thomson, 1971). Due to this, the stability of the slope is greatly influenced by the type and nature of underlying bedrocks. The various mechanical properties influencing the stability of the slope are entirely dependent on the rock formation and the type of soil that constitutes the slope. In the present study area located in the Eastern Highlands and thus on the eastern shoulder of the Great Rift Valley, the geology of the area is characterized by tertiary intrusive and extrusive rock and thus a trap series of lava deposits, which was (further) uplifted during the formation of the Rift Valley in the Tertiary. The chemical composition of these rocks corresponds to alkaline rhyolites and trachyte (Rapprich et al., 2014). The entire sequence belongs to the syn-rift stage, cropping out in the footwall of the Yubo basalt along the NNE–SSW trending fault scarp, being exposed mainly in a quarry SW of the Yirga Alem town. The thickness of the Miocene ignimbrite sequence reaches several hundreds of meters (WoldeGabriel et al., 1990). For the present study area Geology, almost all are Syn-rift (deposited during active rifting) volcanic deposits, Nazareth Formation (Miocene age) (WoldeGabriel et al., 1990). Geology is considered as a basic contributing factor in the present study area. Accordingly, seven different geologic units were, observed in the study area. The list of units and their respective total area was, summarized in Table3.

Table 3: Lithology class and area coverage

S.No.	Types of Lithology	Area coverage (km^2)	Area (%)
1	Residual soil	26.25	20.18
2	Basalt	19.71	15.16
3	Colluvial deposit	28.22	21.70
4	Alluvial deposit	15.06	11.58
5	Tuff	10.93	8.40
6	Ignimbrite	18.20	13.99
7	Rhyolite	11.70	8.99
	Total	130.07	100

According to the table 3, most of the study area is covered by Colluvial deposit, which covers 21.70% of the total area. This type of geology was, found from the western to the northwestern part of the study area. However, this type of soil has a high tendency to produce migratory flows of rock or soil; because it is unstable to resist the sliding of the earth. The second most dominant geologic type in the area is Residual soil, which covers 20.18% of the total area. It was, found extensively in the south and central parts of the study area. It is located in a grassland area. The third dominant geologic type in the study area is Basalt, which covers 15.16% of the total area. This rock is found in the southwestern and southeastern parts (Figure 12).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Coordinate system: Adindan UTM Zone 37N
Projection:Transiverse Mercator
Datum: Adindan

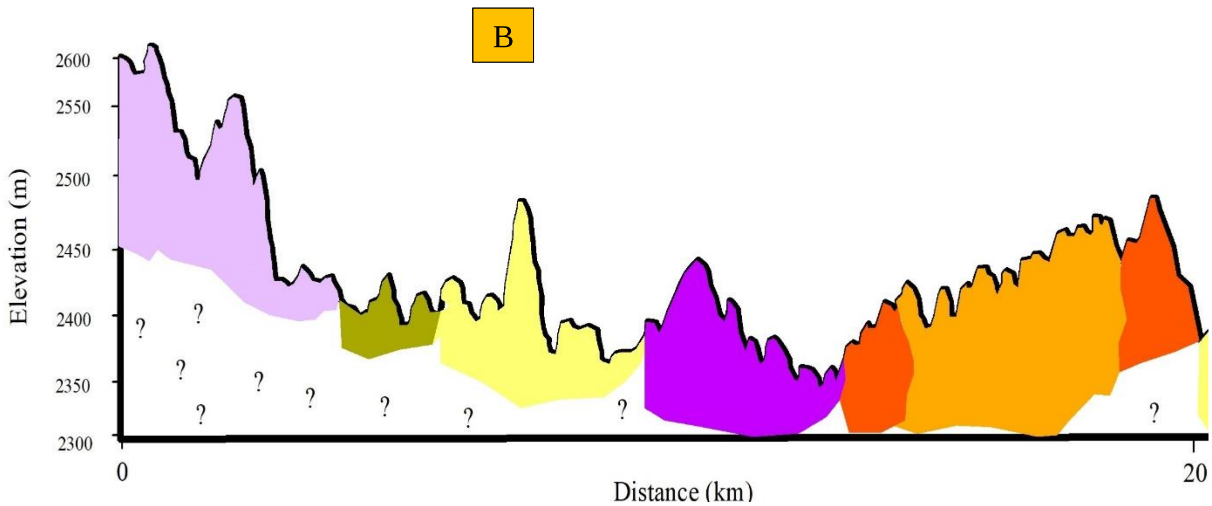


Figure 12: (A) Geology map of the study area. (B) Cross section (Source: Field work)

5.1.2.1 Residual soils

Residual soils result from weathering and decomposition of materials that have not been transported from their original place. Residual soils are mostly underlain by weathered volcanic ash, followed by volcanic pyroclastic materials such as rhyolite and basalt. The effect of weathering decreases soil resistance. These soils are susceptible to slope instability problems. Residual soils are commonly found in a flat area, which covers a second dominant portion of the study area next to the Colluvial deposit, dominantly observed in the Yaye town and southeastern side of Yaye town (Figure 13).

Figure 13: Residual soils

5.1.2.2 Alluvial deposit

Alluvial deposits are unconsolidated and weathered materials located in low-lying areas close to the stream and river courses and deeply cut gullies (Figure 14). They contain boulders, cobbles, and gravels; in general, it contains different intercalated materials. These deposits are observed along Logita, Goronte and Tare Rivers. It covers (11.58%) of the study area (Table3).

Figure 14: Alluvial deposits

5.1.2.3 Colluvial deposit

Colluvial deposits are also unconsolidated and weathered materials observed at the foot of hills and steep slopes or cliff areas along the road and river. It represents widespread deposits gravitationally driven by mass wasting processes (landslides, rockfall, debris flow) occurring at the foothills of the escarpments. The deposits represent heterogeneous admixtures of sediments with different granular sizes. These deposits comprise basalt blocks, rhyolites associated with soil that is detached from the cliffs and rugged terrain. These deposits in the study area are exposed around at Hafursa forest (Figure 15).

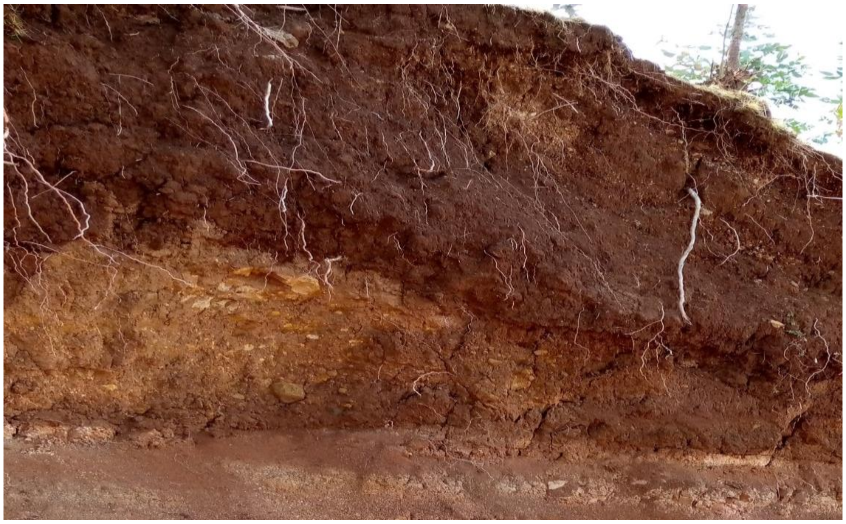


Figure 15: Colluvial deposit

5.1.2.4 Basalt

Basaltic rocks are well exposed in the southeastern and southern parts of the study area. Further, in Bochessa village, near the Logita River, an exposure of stream cut basalt flows has been observed (Figure 16). Generally, the basalt flows are black to dark grey in color and texturally composed of massive, fine-grained and porphyritic ones. Based on the topographical description, the weathered basalts are exposed in the lower elevation of the study area. This lithological unit is the third dominant rock next to the Colluvial deposit and Residual soil (Table 3).

Figure 16: Basalt rocks

5.1.2.5 Rhyolite

Rhyolite in the study area forms a hill and rugged terrain. The rhyolite rock units are generally formed horizontally layered flows, glassy and columnar jointed structure. Generally, the rocks can be texturally described as fine-grained and light grey colored. It is dominantly observed in the northern part of Yaye town and Bochessa village (Figure 17). It is extensively exposed in the northern and southeastern parts of the study area.

Figure 17: Rhyolite rocks

5.1.2.6 Tuff

Tuff is the product of explosive volcanic activity. These rocks are exposed by road cut and stream cut exposures in the study area. The texture of these rocks includes white-colored ashes and rock fragments of varying sizes and compositions and covers the smallest portion of the study area on the northern side (Figure 18).

Figure 18: Welded Tuff

5.1.2.7 Ignimbrite

Ignimbrite is a pumice-dominated pyroclastic flow deposit formed from the cooling of pyroclastic material ejected from an explosive volcanic eruption. As the pyroclastic material settles, it can build up thick layers. Near the volcanic source, ignimbrites commonly contain thick accumulations of lithic blocks, and distally, many show meter-thick accumulations of rounded cobbles of pumice. Ignimbrites may be white, grey, pink, beige, brown, or black, depending on their composition and density. It is found in the northwestern part of the study area (Figure 19).

Figure 19: Ignimbrite

5.1.3 Lineament Density

Lineament is a map-able simple or composite linear feature of the surface whose parts are, aligned in a straight or slightly curved and which differ distinctly from the pattern of adjacent feature and reflect a subsurface phenomenon. Such linearly oriented fracture-controlled zones can be; interpreted as lineament. Hence, lineament with open fracture allows more water to infiltrate, increase pore water pressure, and trigger slides along weaker zones.

Therefore, a landslide is more prone in the fractured, fault and jointed zone (Anbazhagan et al., 2014). Although, the probability of landslides occurring is greater in highly fractured areas than those with a lower fracture density. Conversely, lineament density is, used in landslide hazard assessment (Atkinson and Massari, 1998). However, it would seem that utilizing both lineament density and lineament buffer was, produce a more accurate landslide hazard assessment and introduce more uncertainty. The significance of either using one or both factors when undertaking hazard mapping would be a useful issue for further study. Several lineaments in the study area occur tendency of, almost parallel to each other, implying that the stresses, which produce these features, were not local but acted in a large region to produce several failed or weak zones parallel to a particular direction.

Several parallel lineaments were, observed in different parts of the study area, especially in the southern region (Figure 20). Based on the Lineament density the area was, divided into five category zone as very low density (less than 0.0027 km/km^2), Low Density (0.0027-0.0055 km/km^2), moderate density (0.0055-0.0082 km/km^2), high density (0.0082-0.011 km/km^2) and very high density (greater than 0.011 km/km^2).

Table 4: Lineament density class and area coverage

S.No.	**Lineament density Class (km/km^2)**	**Lineament density**	**Area coverage (km^2)**	**Area (%)**
1	<0.0027	Very low	58.44	44.93
2	0.0027_0.0055	Low	23.2	17.84
3	0.0055_0.0082	Moderate	28.55	21.95
4	0.0082_0.011	High	13.52	10.39
5	>0.011	Very high	6.36	4.89
Total			130.07	100

According to the table 4, the study area was, almost characterized by very low lineament density. Lineament density of the area was, distribute almost all parts of the area:-, but more dominate at northern and central parts of the area. The area, which has <0.0027 dominated by very low lineament density, which covers 44.93% of the total study area. This shows that a large part of the area falls under very low lineament density. The second dominated lineament density is moderate, accounting for 21.95% of the total area. It was, found mainly in the northwestern and southwestern part of the study area. The third dominant lineament density in the area is low, the area between 0.0027_0.0055km/km^2. It was, found mainly in the northern and central part of the study area. High lineament density also cover 10.39% of the total area. It was, mainly found in the northwestern and southern parts of the area. It is, found between the areas 0.0082_0.011/km^2. Very high lineament density covers a small area, which accounts for 4.89% of the study area. It was; mainly found in the northwestern and southwestern parts of the study area.

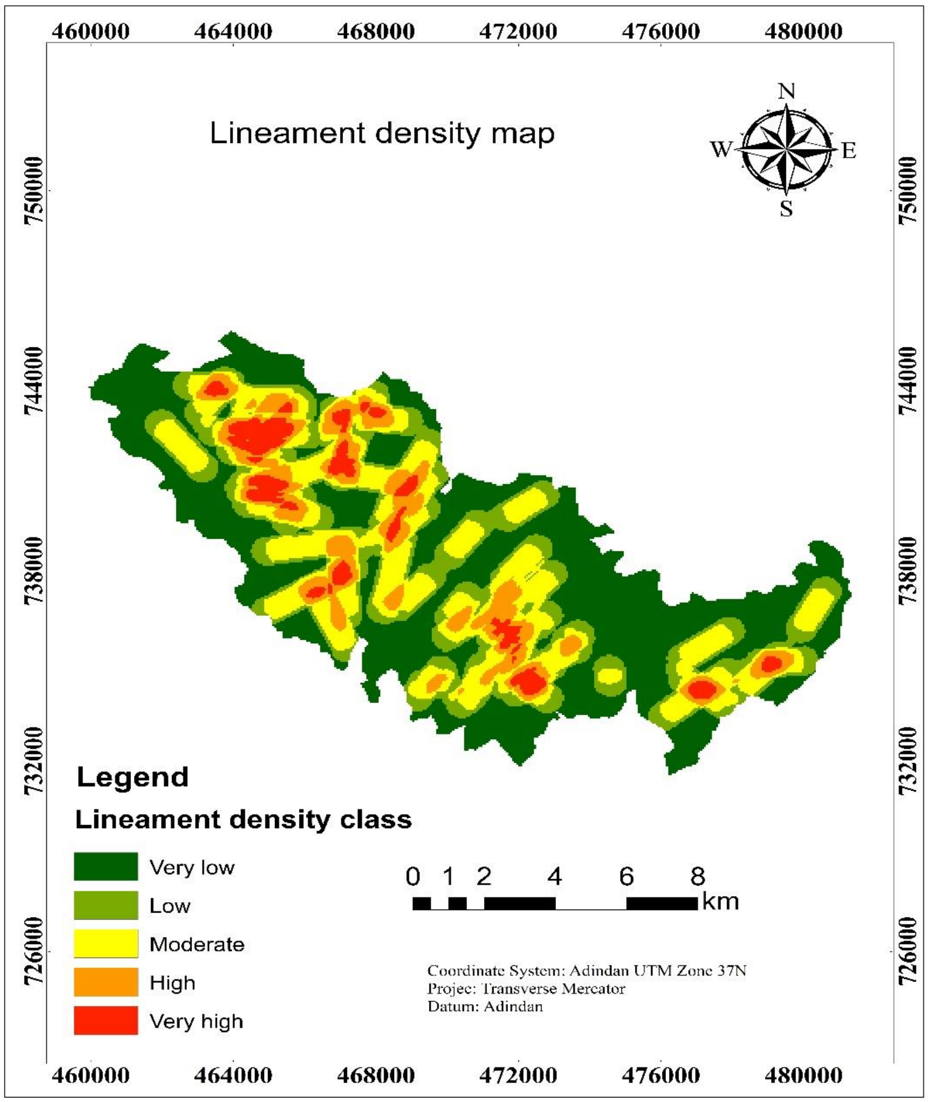


Figure 20: Lineament density map of the study area

5.1.4 Soil Type

Soil type is an important parameter in landslide analysis because the type of soil determines the tendency of soil particles to resist sliding across each other. The nature of the movement is, controlled by the earth materials involved (Peter, 1970). Soil types with large particles, such as sandy soils, are less cohesive than clayey soils with fine particles almost cohesively. The friction force is dependent on the load placed on the soil surface. The greater the load, the greater the likelihood that the force of friction will overcome. This results in the movement of soil particles within the soil layer and the potential for slope failure (Ramakrishna et al., 2002). Four different soil types exist in the study area. Although, the presence of different soil type in the area determine the nature of mass movement and slope failure. The soil type observed in the study area has different soil properties and area coverage. The total area coverage and soil type exist were; presented in the table 5 below.

Table 5: Soil type and area coverage

S.No.	Soil type	Area coverage (km^2)	Area (%)
1	Chromic Luvisols	34.56	26.57
2	Pellic vertisols	36.52	28.08
3	Eutric fluvisols	33.36	25.65
4	Eutric nitisols	25.63	19.70
Total		130.07	100

From the table above, the most common soil type in the area is Pellic vertisols covers (28.08%) of the total area. This type of soil has a high content of expansive clay minerals, many of which are montmorillonite or bentonite clay, which form deep cracks in drier seasons or years. It is; found at western, central, northern and northwestern of the study area.

The second most common is Chromic Luvisols, which account (26.57%) of the study area. This type of soil is composed of organic materials (HWSD). This soil type has a loam texture. Clay is a naturally occurring firm earthy material, composed primarily of fine-grained (diameter less than 0.002mm) plastic when wet and hardens when heated and that consists primarily of hydrated silicates or aluminum. It was, mainly exposed at Northwestern of the study area. The third soil type that dominates the area was Eutric fluvisols, accounting for only 25.65% of the total area. This soil type is located from the south to southeastern part of the study area by covering a small area compared with pellic vertisol and chromic luvisol (Figure 21).

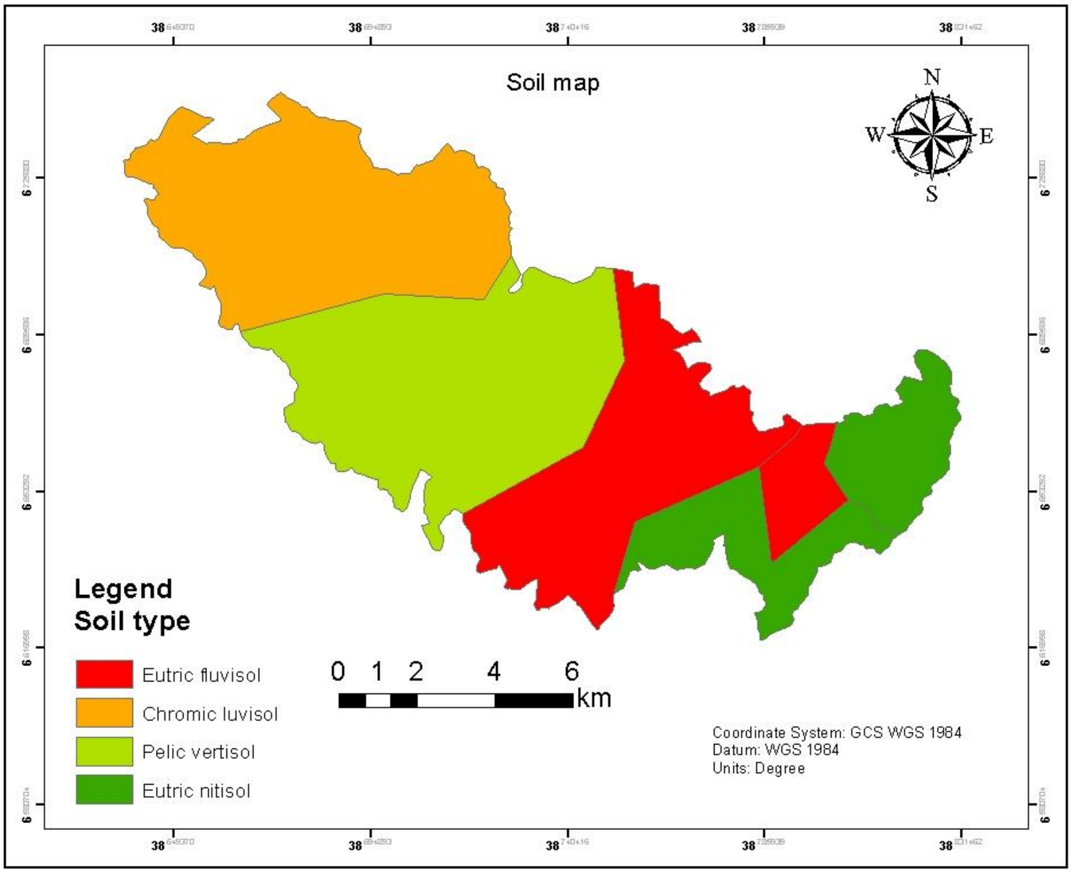


Figure 21: Soil map of the study area. (Digitized from Sidama region soil map)

5.1.5 Aspect

Aspect shows the inclination or orientation of slope in a given area. Although, the aspect strongly influences potential direct incident radiation and thus temperature. Therefore, the moisture of the soil on the ground may alter. Aspect as a landslide-conditioning factor has been, considered in various studies (Ercanoglu and Gokceoglu, 2004). Aspect severely affects hydrological processes such as evapotranspiration, weathering, and vegetation growth particularly in arid environments and areas with weak soil types. As a result, this parameter was, also considered as a conditioning factor for the present study area. The slope aspect for the study area was, divided into five categories: south, southwest, north, northeast and southeast.

Table 6: Aspect class and area coverage

S.No.	Aspect class	Area coverage (km^2)	Area (%)
1	South	21.94	16.87
2	Southwest	29.63	22.78
3	North	30.83	23.70
4	Northeast	27.06	20.80
5	Southeast	20.61	15.85
	Total	**130.07**	**100**

From the table 6, most of the area was, dominated by slope facing to the north, which accounts for 23.70% of the total area. This aspect class commonly covered the western part of the study area. The second aspect class that dominates the area was the southwest-facing slope, which covers 22.78% of the total area. It was, distributed to the southeastern part of the study area. In the present study area, this aspect class falls on high topography and agricultural land. The slope facing the northeast in the study area covered 20.80% of the total area. This aspect class is mainly distributed in the southeast and southern parts of the study area. It was the third dominating aspect class in the area. The fourth dominant aspect class in the area was, aspect class aspect facing to south direction. It covers 16.87% of the total area. This aspect class in the study area mostly falls on a highly elevated area located at western and northwestern of the study area. Slope facing the southeast of the study area was; scattered in all parts of the study area by covering 15.85% of the total area. It is located on terrain covered by bare land and agricultural land (Figure 22).

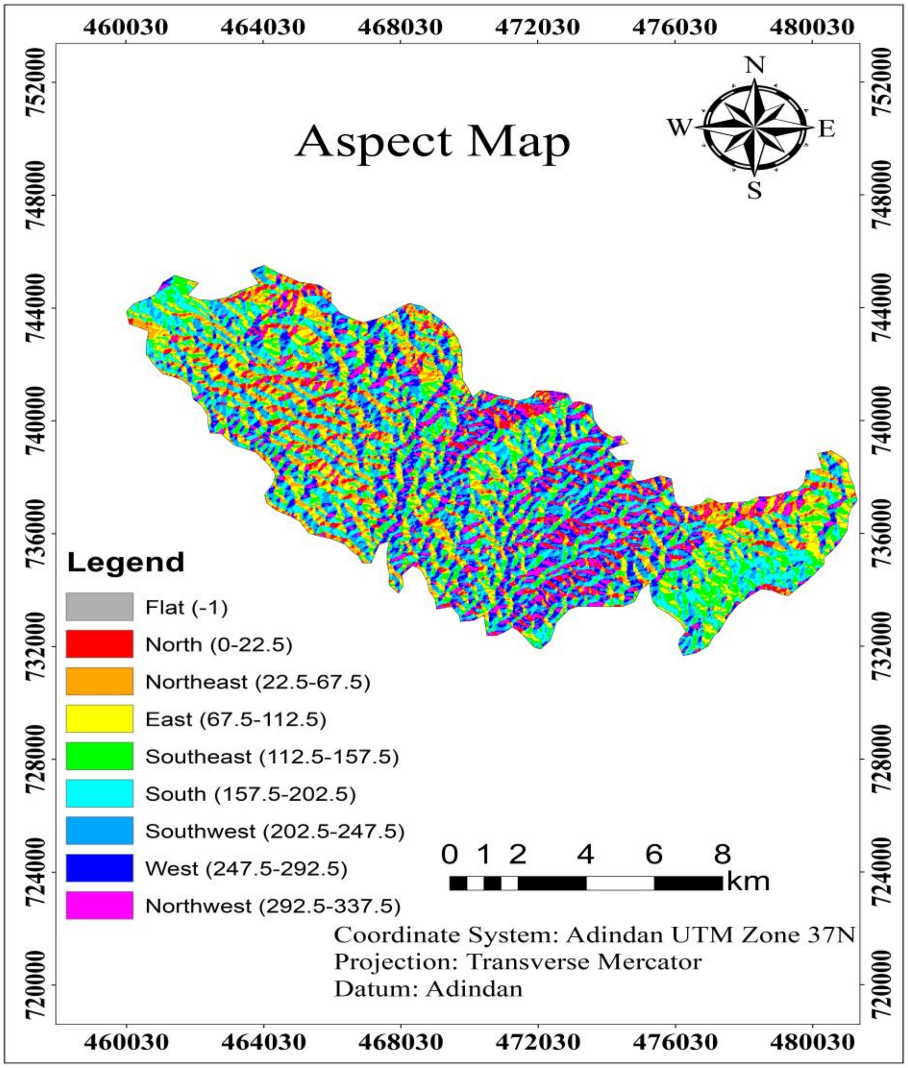


Figure 22: Aspect map of the study area

5.1.6 Land Use Land cover

Land use and land cover play a significant role in influencing landslides**.** Many landslides occur mainly due to improper activities such as deforestation and an increase in urbanization over a period. Areas with little or no vegetation cover and areas degraded by inappropriate logging, pastoral, agricultural or construction practices are predisposed to landslides and mass-wasting events (Varnes, 1978). Although, Rapid changes in land use land cover, as well as land degradation processes, are precursors to mass movement events (Alcantara et al., 2006). Therefore, for the present study, land use land cover was, considered a contributing factor for landslide hazard analysis. The identified land cover types that were, reclassified included the following: Agriculture, Bare land, built-up, Forest, Grassland, Waterbody, and Wetland.

Table 7: Land use lands cover type and area coverage

S.No.	LULC Type	Area coverage (km^2)	Area (%)
1	Agricultural land	48.44	37.24
2	Bare land	13.15	10.12
3	Built up	9.42	7.24
4	Forest	0.50	0.38
5	Grass land	41.60	31.98
6	Wetland	0.49	0.37
7	Waterbody	16.47	12.67
Total		130.07	100

As indicated in the table 7, large parts of the study area were, covered by agricultural land, which accounts for 37.24% of the total area. It is, found mainly in the northwestern, southeastern and southern directions. Agricultural land in the area was, observed in a different range of slope angles. Due to the suitability of soil type for different crops, a large area was, used for cultivation. The second land cover that dominates the area is grassland, which accounts for 31.98% of the total area. This is distributed to almost all parts of the study area (Figure 23). The area is also characterized by a water body, which accounts for 12.67% of the total area. It is, mainly found in southern and northwestern parts of the study area. In addition to this, it has significantly distributed almost all parts of the study area. Bare land also the area covers 10.12% of the total area. Mostly bare land in the area is located in the central and northern parts of the study area. Area, which is unsuitable for agricultural purposes and other activities are, covered by wetland and forest. Forest in the northwestern part of the area was a natural forest. While forest scattered in another part of the area was planted by the community environment.

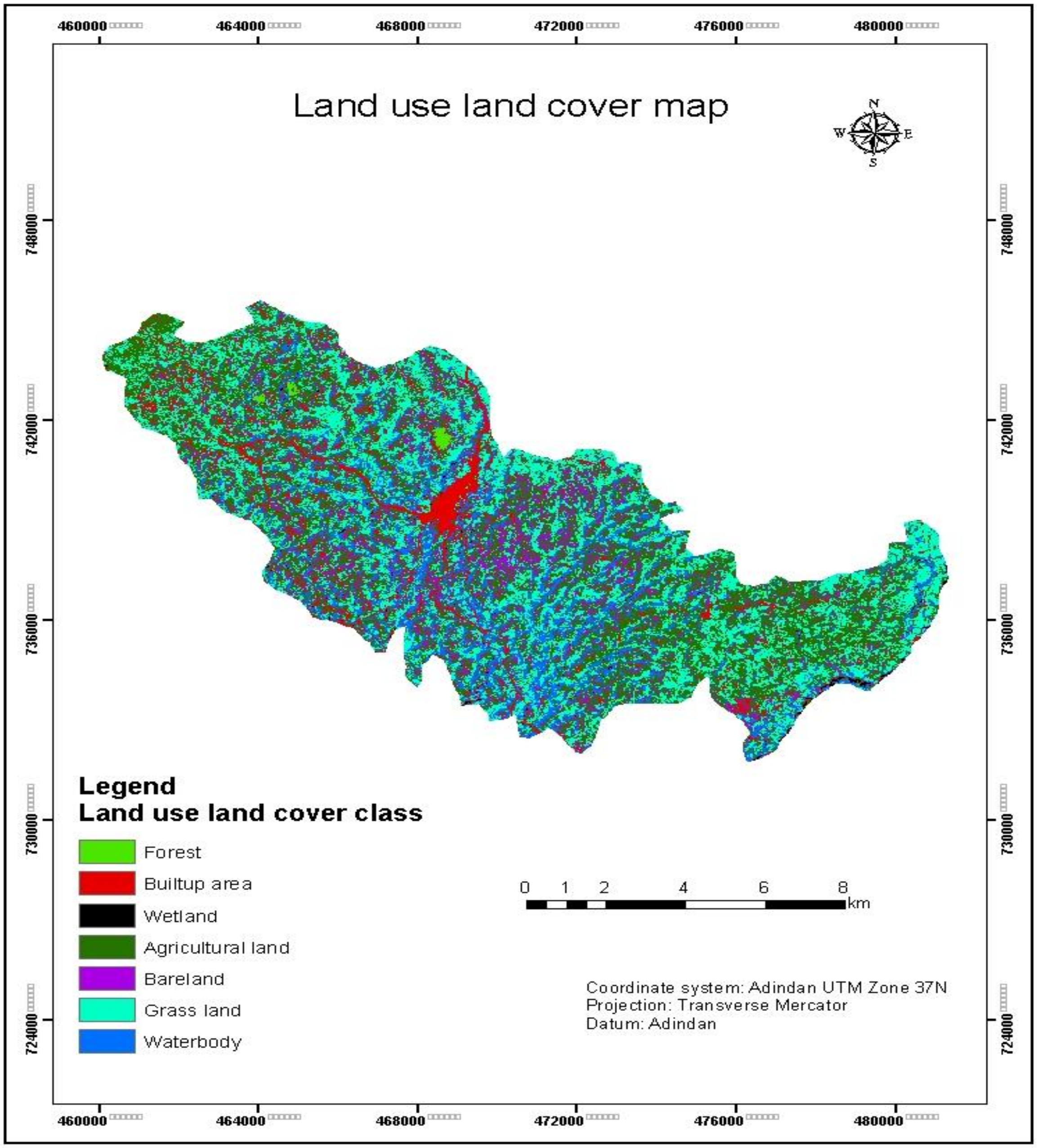


Figure 23: Land use /land cover map of the study area

Accuracy Assessment

To know the exactness of the prepared land cover map, an accuracy assessment should be, done for the classified image. This is because image classification without accuracy assessment is inadequate. Land cover maps derived from remote sensing imagery always contain errors due to several factors, ranging from classification technique to method of satellite data capture. Therefore, accuracy assessment performed for image classification was, used to tell how accurately the land use /land cover maps were, classified correctly. The present study used 54 randomly selected pixels for the 2020 land use /land cover map, which were, also checked with reference data (ground data collected by handheld GPS and by seeing more cleared images using Google earth map with global mapper) to assess the accuracy of the classification. The current study revealed an overall accuracy of 83.33% and a kappa index of agreement of 0.800. The kappa coefficient implies that the classification process is avoiding 80% of the errors that a completely random classification generates.

Table 8: Accuracy assessment of the classified land use /land cover map

Classified data	Agricultural land	Bare land	Built-up	Forest	Grass land	Waterbody	Wetland	Total (user)
Agricultural land	6	0	0	1	3	0	0	10
Bare land	0	8	0	0	2	0	1	11
Built up	0	0	5	0	0	0	0	5
Forest	0	0	0	5	0	0	0	5
Grass land	2	0	0	0	8	0	0	10
Water body	0	0	0	0	1	10	0	11
Wetland	0	0	0	0	0	0	3	3
Total(producer)	8	8	5	6	14	10	4	

Overall accuracy= (Total number of correctly classified pixels (Diagonal))/ (Total number of Reference pixels)*100… (1)

$$= \frac{(6+8+5+5+8+10+3)}{54} = 0.8333 = \underline{83.33\%}$$

User accuracy= (Number of correctly classified pixels in each category)/ (Total number of classified pixels in that category (raw total))*100… (2)

- Agriculture= (6/10)*100= 60%

- Bare land = (8/11)*100= 72.72%
- Built up= (5/5)*100= 100%
- Forest= (5/5)*100= 100%
- Grass land= (8/10)*100= 80%
- Water body= (10/11)*100= 90.90%
- Wetland= (3/3)*100 = 100%

Producer accuracy= (Number of correctly classified pixels in each category)/ (Total number of classified pixels in that category (column total))*100… (3)

- Agriculture = (6/8)*100 = 75%
- Bare land = (8/8)*100 = 100%
- Built up = (5/5)*100=100%
- Forest = (5/6)*100 = 100%
- Grass land =(8/14)*100 =57.14%
- Water body = (10/10)*100 = 100%
- Wetland = (3/4)*100 =75%

Kappa coefficient (k) $=\frac{\mathbf{N(\sum_{i=1}^{r} x_{ii})-(\sum_{i=1}^{r}(x_{1+} \dots x_{+1})}}{\mathbf{N^2-\sum_{i=1}^{r}(x_{i+} \dots x_{+1})}}$………………… ………………... (4)

Where r = number of rows in the error matrix

X_{ii} = number of observations in rows i and column i (on the major diagonal)

X_{i+} = total of observations in row i (shown as marginal total to right of the matrix)

X_{+i}= total of observations in column i (shown as marginal total at the bottom of the matrix)

N = total number of observations included in the matrix

$N(\sum_{i=1}^{r} x_{ii}) = 54 * (6+8+5+5+8+10+3)$ =54*45 =2,430

$(\sum_{i=1}^{r}(x_{1+} \dots x_{+1})$ = (10*8+8*11+5*5+6*5+14*10+10*11+4*3) = 485

Kappa coefficient value $=\frac{2430-485}{54^2-485}$ = 1945/2431 =0.800 = <u>80%</u>

5.1.7 Drainage/stream network

The drainage pattern of the study area is dendritic and parallel, which belongs to the Ganale basin. In the dendritic pattern, the river channel follows the slope of the terrain. The parallel drainage network is formed in the hill area of the study. The name of the main rivers in the study area includes Goronte and Tare River. When these rivers join, they form the Logita River, which is the largest river around the study area. This river flows in the south direction. Most of the rivers in the study area flow towards the southeast direction.

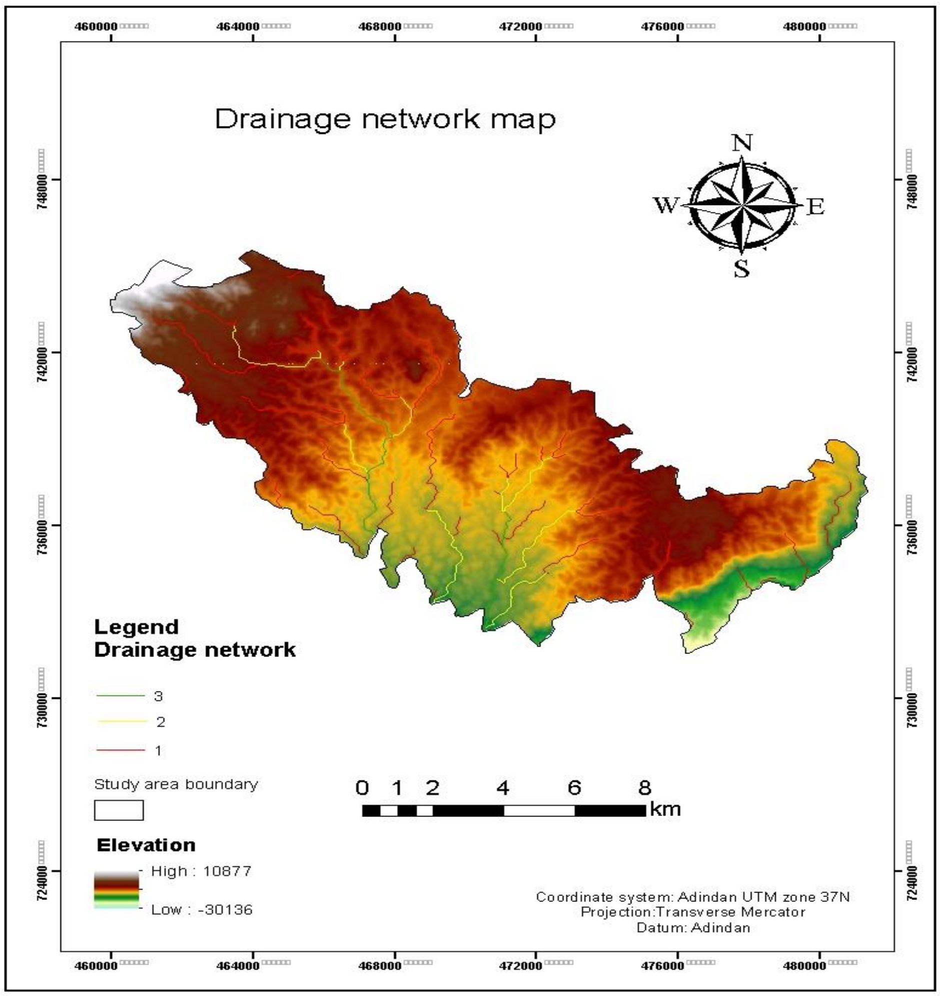


Figure 24: Drainage network map

5.1.8 Drainage Density

Drainage density is the drainage by streams of the watershed into the mainstream. It indicates the closeness of spacing of channels, providing a quantitative measure of the average length of stream channel for the basin. Moreover, drainage density is highly affected by the physiography of the particular area and is an important factor for landslide occurrence. This is a result of on steep slope; surface water accelerates and rock erosion increases, while on lower slope surface flow decreases and sediment accumulation increases, and therefore, probability of landslide occurrence increase. Although; impermeable rocks were, exposed to the runoff, it resulted in poor drainage density, and high ragged terrain has more drainage density. High Drainage density erodes the soil and tends to break the rock resulting in a landslide. The drainage density of the study area was; produced from the stream network of the area (figure 24). In the study area, two types of stream networks were, observed they are dendritic and longitudinal stream networks. Dendritic stream network reflects areas with steep slopes, low precipitation, and a high rate of rock erosion. Longitudinal stream network reflects areas with gentle slopes, high precipitation, and accumulation special around the southern and southeastern part of the study area. Based on the drainage density the area divided into five category zones as very low density (<0.0022km/km^2), low density (0.0022_0.0030km/km^2), moderate density (0.0030_0.0038km/km^2), High density (0.0038_0.0046km/km^2) and very high density (>0.0046km/km^2) (Figure 25). As we learned in hydrogeology, closer investigations of the processes responsible for drainage density variation have revealed that many factors like climate, topography, soil infiltration capacity, vegetation, and geology collectively influence stream density.

Table 9: Drainage density class and area coverage

S.No.	**Drainage density Class (km/km^2)**	**Density**	**Area coverage (km^2)**	**Area (%)**
1	<0.0022	Very low	5.91	4.56
2	0.0022_0.0030	Low	10.52	8.09
3	0.0030_0.0038	Moderate	32.52	25.01
4	0.0038_0.0046	High	47.78	36.75
5	>0.0046	Very high	33.27	25.58
		Total	130.07	100

The table 9 shown, most parts of the study area were, characterized by high drainage density, which cover 36.75% of the total area. It is mainly distributed northwest to southwest of the study area. High drainage density in the area is the result of impermeable subsurface material (clay material), sparse vegetation and high relief. Although, high drainage density gives rise to a fine drainage texture. Even though, high drainage density in the area may indicate high precipitation, low infiltration, greater flood, and thin vegetation cover.

The second dominant drainage density in the area is very high,-; it covers 25.58% of the total area. It is located on very high elevation and is-, found in southwestern, northwestern, and southern parts of the study area. In addition, low and very low drainage density in the area covers 8.09% and 4.56% of the total area, respectively;-,and is located scattered in all edge parts of the area. Low drainage density is generally characterized by highly resistant or permeable subsoil material, dense vegetation, and low relief.

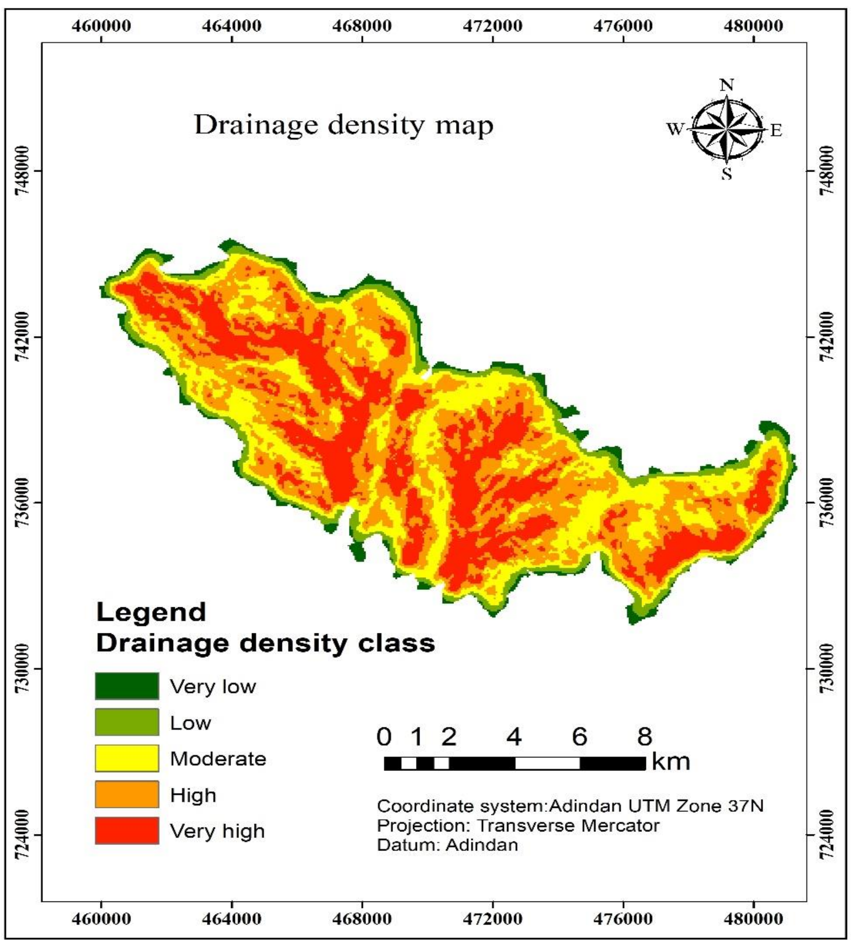


Figure 25: Drainage density map of the study area

5.2 Landslide inventory

The results of the 2020 landslide inventory map, which I was going to prepare by combining multiple techniques, were as follows.

In Arbegona, earth slide (typically rotational), earthflow (wet and dry), or combined complex earth slide and earthflow occur dominantly (Figure 26) and also training landslide photo captured from the study area (Figure 27). Additionally, earth fall in Arbegona woreda occurs in the cliff area.

In the present study area, a total of 209 landslide locations were identified and divided randomly into training and validation landslides by keeping their spatial distributions. The training landslides were used for training, and validation landslides were applied for validating the predicted image 146 (70%) and 63 (30%) of the area, respectively (Figure 28).

From the total landslides polygons, 19 landslides (Appendix 6) show active landslides collected from field investigations, and the rest 190 polygons were collected from Google Earth image interpretations.

Landslide locations in the study area are predominantly distributed in the northwest-southeast;-, in the south, and the central part concerning decreasing order of their landslide density, damage on crops and grasslands. This area consists of rugged and mountainous terrains, characterized by steep slopes, high stream network areas, fractured and high relative relief weathered rocks.

The common types of landslide occurrence in the study area include earth slide, debris slide and flow, rotational and translational soil slide, translational debris slide, rotational debris slide and complex types of slides.

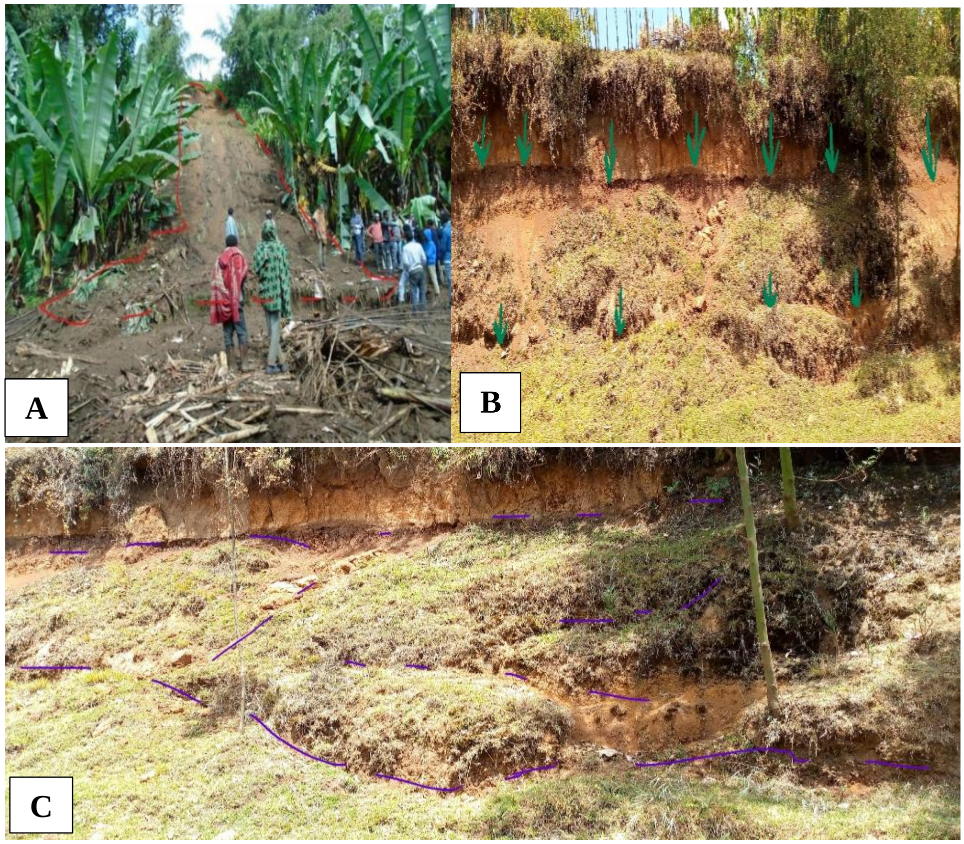


Figure 26: (A) At agricultural Earth slide (B) At steep slope landslide (C) Complex earth slide.

Figure 27: Training landslide at the study area

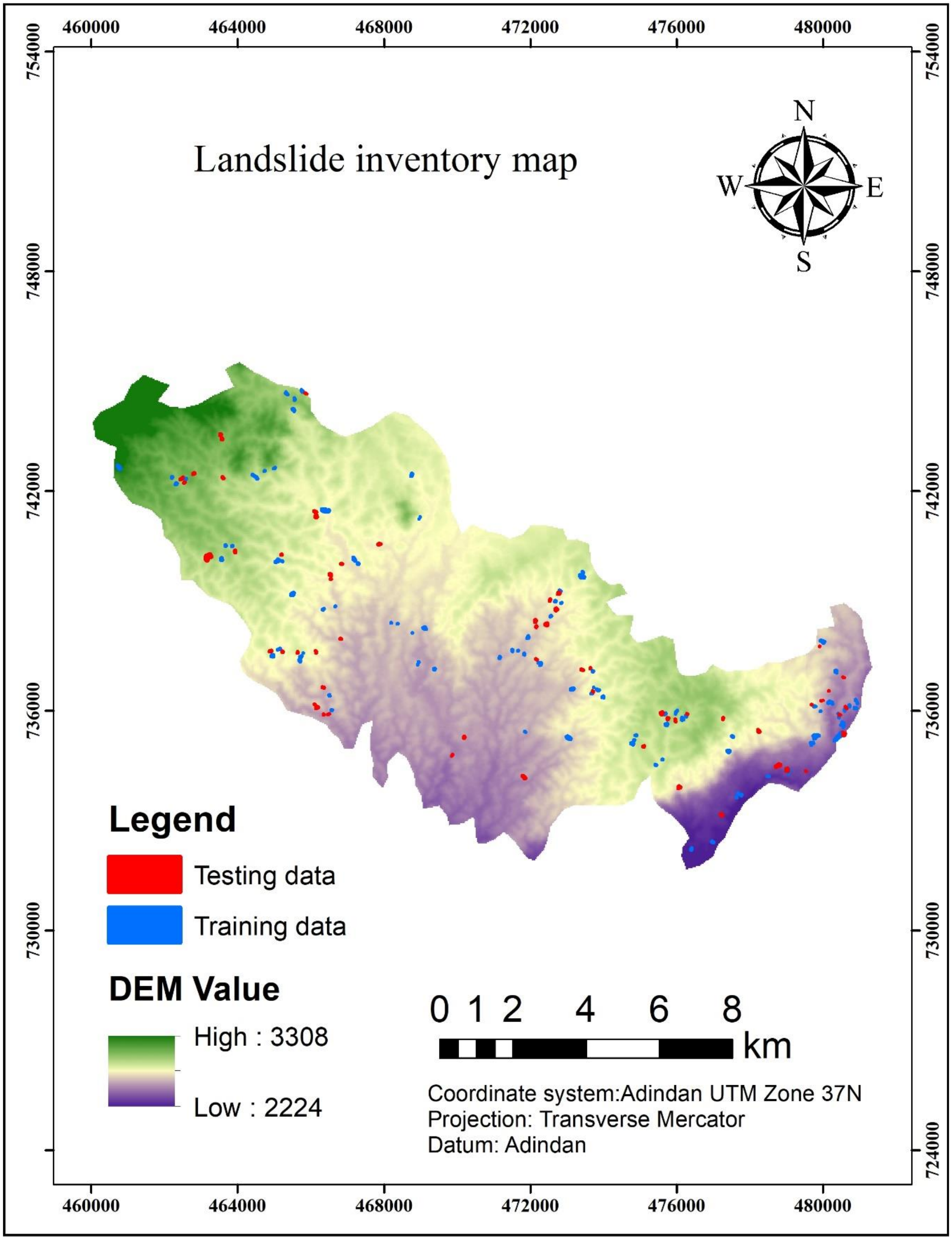


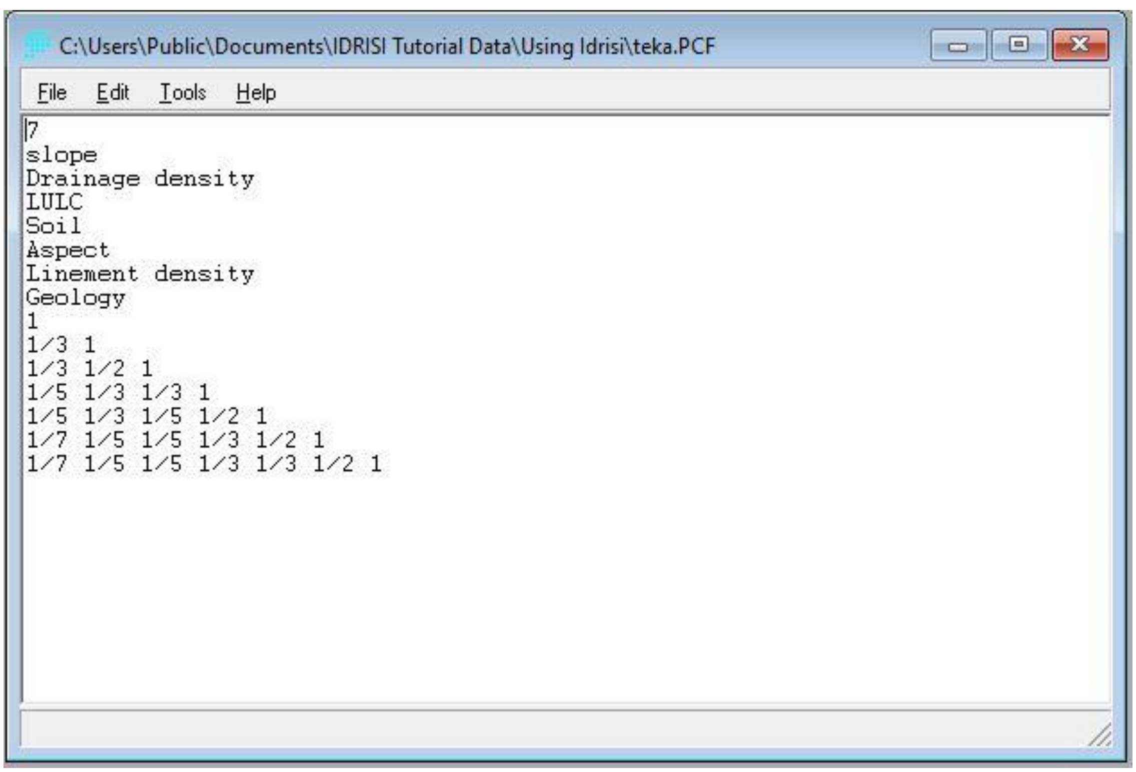
Figure 28 : Inventory map of the study area

5.3 Assigning Criteria Weight

After the standardization to a common scale (30*30m) of each causative factor, weight is, given for each layer based on pairwise comparison of two data layers simultaneously, using pairwise comparison of 9-point continuous rating scale in IDRISI selva 17. Moreover, the weight module is; used to develop a set of relative weights for a group of factors in a multi-criteria evaluation.

The weights were; developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being; evaluated. Consequently, these pairwise comparisons are then; analyzed to produce a set of weights that sum to one. The larger the weight means, the more influencing is the factor. Accordingly, the weights developed to each factor are, given based on the analytical hierarchy process proposed by Saaty (1980), utilizing providing a series of pairwise comparisons of the relative importance of factors. In each cell of the matrix, the relative significance of the row variable to its corresponding column variable was, considered and the appropriate rating was; given. The resulting consistency ratio of the pairwise comparison matrix is 0.04, indicating an acceptable consistency range because the acceptable consistency ratio of the pairwise comparison matrix is less than 0:10).

Table 10: Analytical Hierarchy Process weight derivation module



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slope
Drainage density
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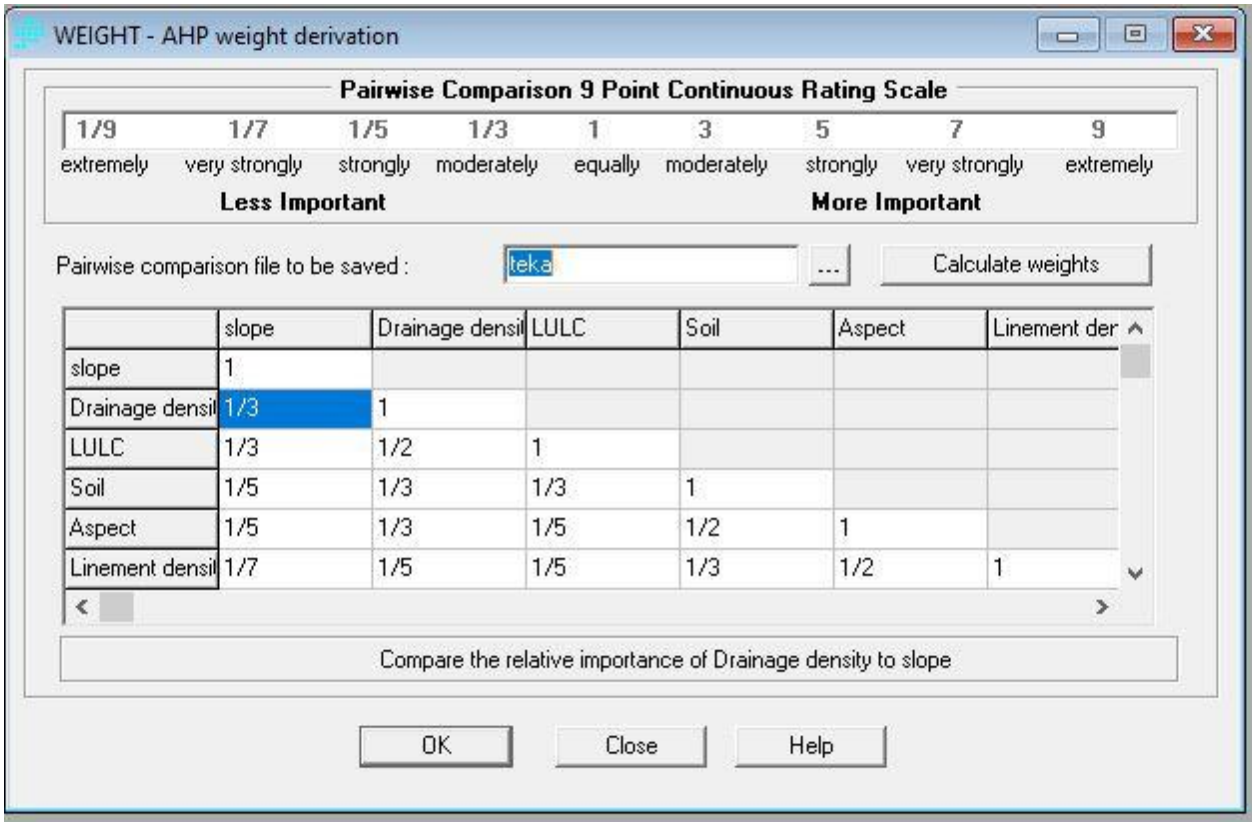
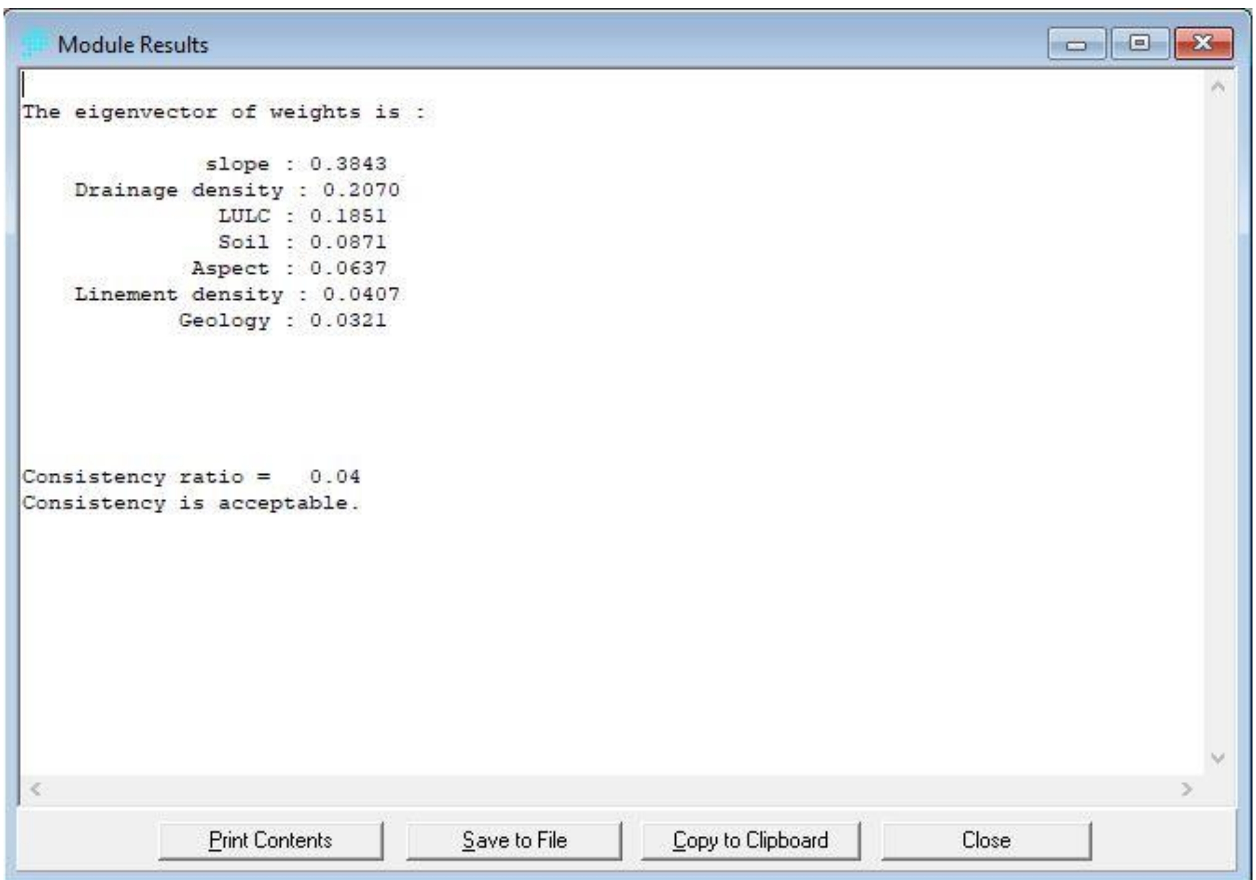


	slope	Drainage densi	LULC	Soil	Aspect	Linement der
slope	1					
Drainage densi	1/3	1				
LULC	1/3	1/2	1			
Soil	1/5	1/3	1/3	1		
Aspect	1/5	1/3	1/5	1/2	1	
Linement densi	1/7	1/5	1/5	1/3	1/2	1




```
The eigenvector of weights is :

             slope : 0.3843
 Drainage density : 0.2070
              LULC : 0.1851
              Soil : 0.0871
            Aspect : 0.0637
 Linement density : 0.0407
           Geology : 0.0321

Consistency ratio =   0.04
Consistency is acceptable.
```

The weights calculated indicate the relative significance of the factors in contributing to a mass movement. From the obtained result, the highest weight was, given to slope. The next highest weight has been, drainage density, land use land cover, and soil (Table 10).

Finally, less weight has been, given to geology and lineament density compared to others, although they play a reasonable contribution to the existing mass movements in the study area.

5.4 Weighted Overlay

The weightage overlay method is applied to quantify landslide hazard zonation for the present study area. Through a Multi-Criteria Evaluation, these causative factors (aspect, drainage density, land use land cover, geology, lineament density, slope, and soil maps) are combined to form a single hazard map. Every (above-mentioned) preparatory parameter layer is prepared on a GIS domain to prepare hazard zonation mapping. Then, all spatial data layers are overlapped using weighted overlay tools in the ArcGIS platform. After that, these layers are prepared a composite image that provides information on the area normalized landslide initiation hazards. The landslide hazard zone of the study area was prepared and reclassified using a spatial analysis tool; available in ArcGIS 10.8. Conversely, the hazard rating selection was somewhat subjective. The rating of hazard indicates that the likelihood of a landslide occurrence.

Thematic layers are processed for the seven landslide influencing factors with a ranking scale of given as follows:

- ✓ Rank 1 – stable (very low hazard zone)
- ✓ Rank 2 – moderately stable (low hazard zone)
- ✓ Rank 3 – moderately unstable (moderately hazard zone)
- ✓ Rank 4 – highly unstable (high hazard zone)
- ✓ Rank 5 – critical (very high hazard zone)

For the present study, due to limited landslide inventory data, records were made available during the analysis,-; the hazard class was; first reclassified by equally dividing the maximum score into five classes; namely very low, low, moderate, high, and very high hazard zone.

5.4.1 Mapped Landslide Vulnerable Zones

As overlay analysis is a multi-criteria analysis, where analysis can be carried out with complex things for finding out certain themes with the help of assignment of rank to the each parameters. Then by assigning weightage to the individual feature considering its influence over theme. All the thematic maps were converted into raster format and superimposed by weighted overlay analysis, which consists of rank and weightage wise thematic maps and their integration through GIS (Table 11). Integration of thematic maps for carrying out multi-criteria analysis in a GIS environment was done using ArcGIS software.

Table 11: Ranks and Weightages of parameters given for Landslide Vulnerable Zonation Map

S. No.	Parameters	Classes	Rank	Weightage (%)
1	Slope	0-10	1	38.43
		10-20	4	
		20-30	3	
		30-40	4	
		>40	5	
2	Geology	Residual soil	2	3.21
		Basalt	4	
		Colluvial deposit	3	
		Alluvial deposit	5	
		Tuff	4	
		Ignimbrite	2	
		Rhyolite	4	
3	Lineament density	<0.0027	1	4.07
		0.0027_0.0055	2	
		0.0055_0.0082	3	
		0.0082_0.011	4	
		>0.011	5	
4	Soil type	Chromic Luvisols	5	8.71
		Pellic vertisols	4	
		Eutric fluvisols	3	
		Eutric nitisols	5	
5	Aspect	South	5	6.37
		Southwest	4	

		North	4	
		Northeast	1	
		Southeast	3	
6	LULC	Agricultural land	5	18.51
		Bare land	1	
		Built-up	2	
		Forest	3	
		Grassland	3	
		Waterbody	5	
		Wetland	3	
7	Drainage density	<0.0022	2	20.70
		0.0022_0.0030	3	
		0.0030_0.0038	4	
		0.0038_0.0046	5	
		>0.0046	5	

5.4.2 Landslide Hazard Map

The landslide hazard map prepared for the present study area revealed a very high hazard zone covering 10.49km^2 or 8.06% of the total area. Very high hazard zone consists of Waterbody and agricultural land, which is located on more than 20^0 slope angle and chromic luvisols, eutric fluvisols and eutric nitisols soil type and Alluvial deposit, colluvial deposit and basalt. The drainage density found in very high hazard zone is very high and high drainage density. The high percent of the very high hazard zone is located on a steep slope and an Agricultural area. High hazard zone cover 38.03km^2 or 29.24% of the total area. High hazard zones are located at various land use land covers, namely forest, agricultural land, and grassland, and Water body. The slope varies from 0^0 to 40^0. Moderate hazard area covers 57.08km^2 or 43.88% of the total area. Moderate hazard zone located on slope 10^0-20^0.

The land use land cover located on moderate hazard zone is mainly agricultural land and grassland. The distribution of moderate hazard zone in the area is predominantly on a gentle slope.

Low hazard area covers 15.33km^2 or 11.79% of the total area. Low hazard zone located on a slope less than 10^0 and greater than 40^0. The land use land cover located in low hazard zone is mainly Grassland and forest. The distribution of low hazard zone in the area is predominately on a gentle slope and a steeper slope. Very low hazard zone cover 9.14km^2 or 7.03% of the total area. Land use land cover type located on very low hazard zones is built-up area and grassland area. A very low hazard zone is located on a gentle slope in the study area (Teble 12).

Table 12: Landslide hazard class and area coverage

S.No.	Landslide hazard zone	Area coverage (km^2)	Area (%)
1	Very low	9.14	7.03
2	Low	15.33	11.79
3	Moderate	57.08	43.88
4	High	38.03	29.24
5	Very high	10.49	8.06
	Total	130.07	100

The distribution of different landslide hazard zone in the study area produced in the present study was, presented in figure 29. Very high hazard zone are; distributed in the central part from northwestern (Mayu Tulicha Kebele) to western (Toshene Kebele) of the study area and highly concentrated in the southeast (Mikicho and Bursa Kebele). High hazard zone is, distributed in the northern (Muchuche Kebele), southern (Raro Jawaro Kebele), northwestern (Mayu Tulicha Kebele), and western (Taga Kebele) and are mainly concentrated in the Southeastern (Mikicho and Bursa Kebele) of the study area. Moderate hazard zone distributed on all study parts. The low hazard zone is highly distributed in the north, northwestern and southwestern parts of the study area. The very low hazard zone is mainly concentrated in the northwestern region (Hafursa Nemeto kebele) and northern (Yaye Town and Chuche Kebele) region of the study area. The hazard map shows the areas of very highest hazard represented by the highest elevation, water body, or more stream connected area and agricultural land. Especially, agricultural land on terrain and high drainage density in the area is more prone to landslide.

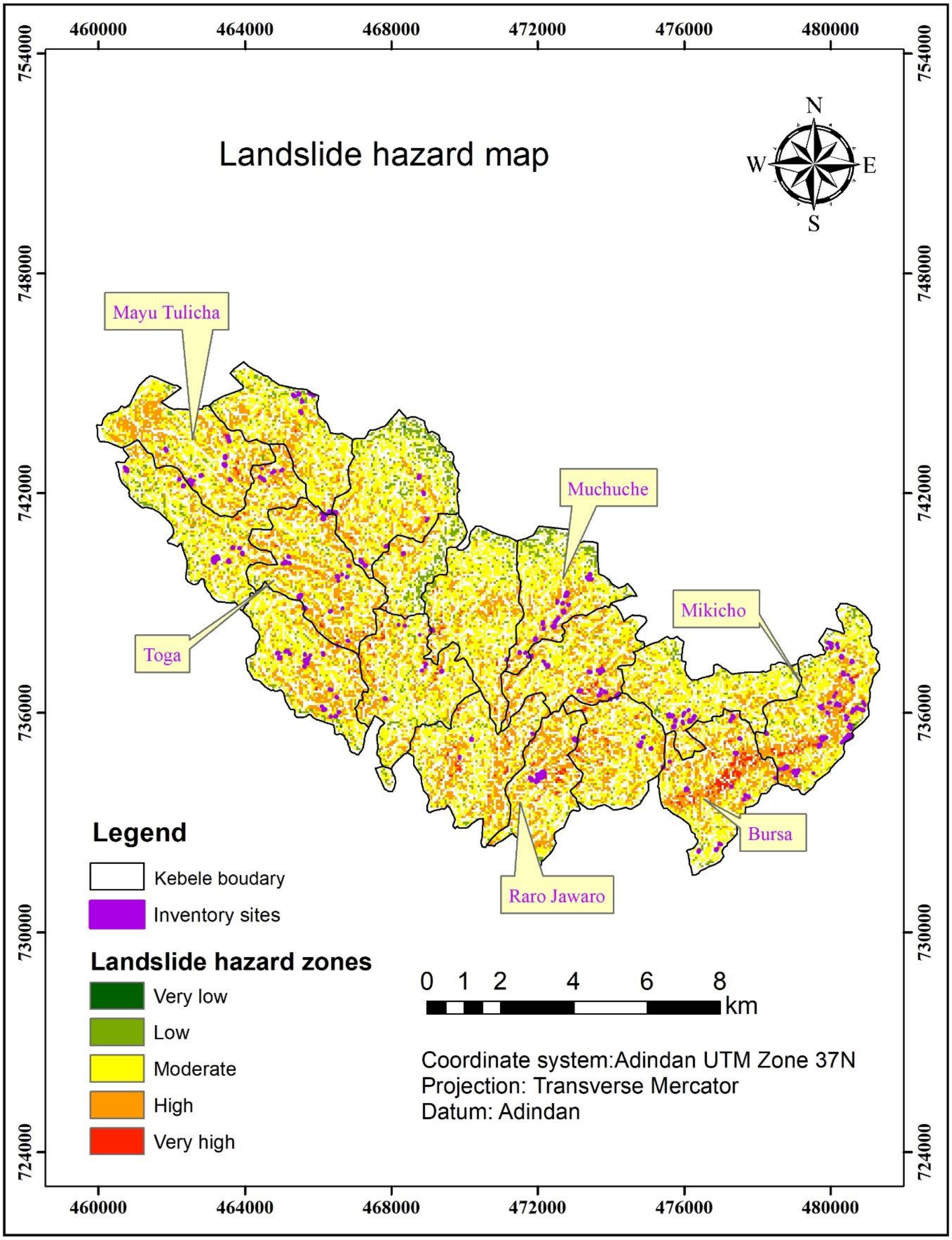


Figure 29: Verification of inventory data with the Landslide hazard map

5.5 Validation

Without validation, landslide hazard maps are meaningless. As a result, validation of predictive landslides is an important part of the procedures for landslide hazard mapping (Bui et al., 2012). A training map constructed using the 70% of the landslides with the causative factors was validated using the 30% of the validation landslide dataset. There are various types of validation techniques of landslide hazard maps.

In the current study, the performance of the landslide hazard map produced by weighted overlay approaches was evaluated using Receiver operating characteristics (ROC) and Area under the Curve (AUC).

5.5.1 Area under the Curve (AUC)

The area-under-curvature (AUC) method works by creating success rate and prediction rate curves (Lee, 2005). Landslide hazard map can be validated by comparing the hazard map with both the training landslide (70%) and validation landslide (30%). The rate curves can be created for both techniques.

The success rate curve is based on the comparison between the prediction map and the training landslide. Moreover, the prediction rate curve is based on comparing the predicted map and the validation landslide. The Area under the Curve (AUC) of the success rate represents the quality of the model to reliably classify the occurrence of existing landslides, whereas the AUC of the prediction rate explains the capacity of the proposed landslide model for predicting landslide hazard (Pamela et al., 2018).

In this study, AUC was prepared a combination of result maps (landslide hazard map) with a landslide inventory. The result showed that both the training and validation (testing) exhibited above 0.6; therefore, it is acceptable (Figure 30).

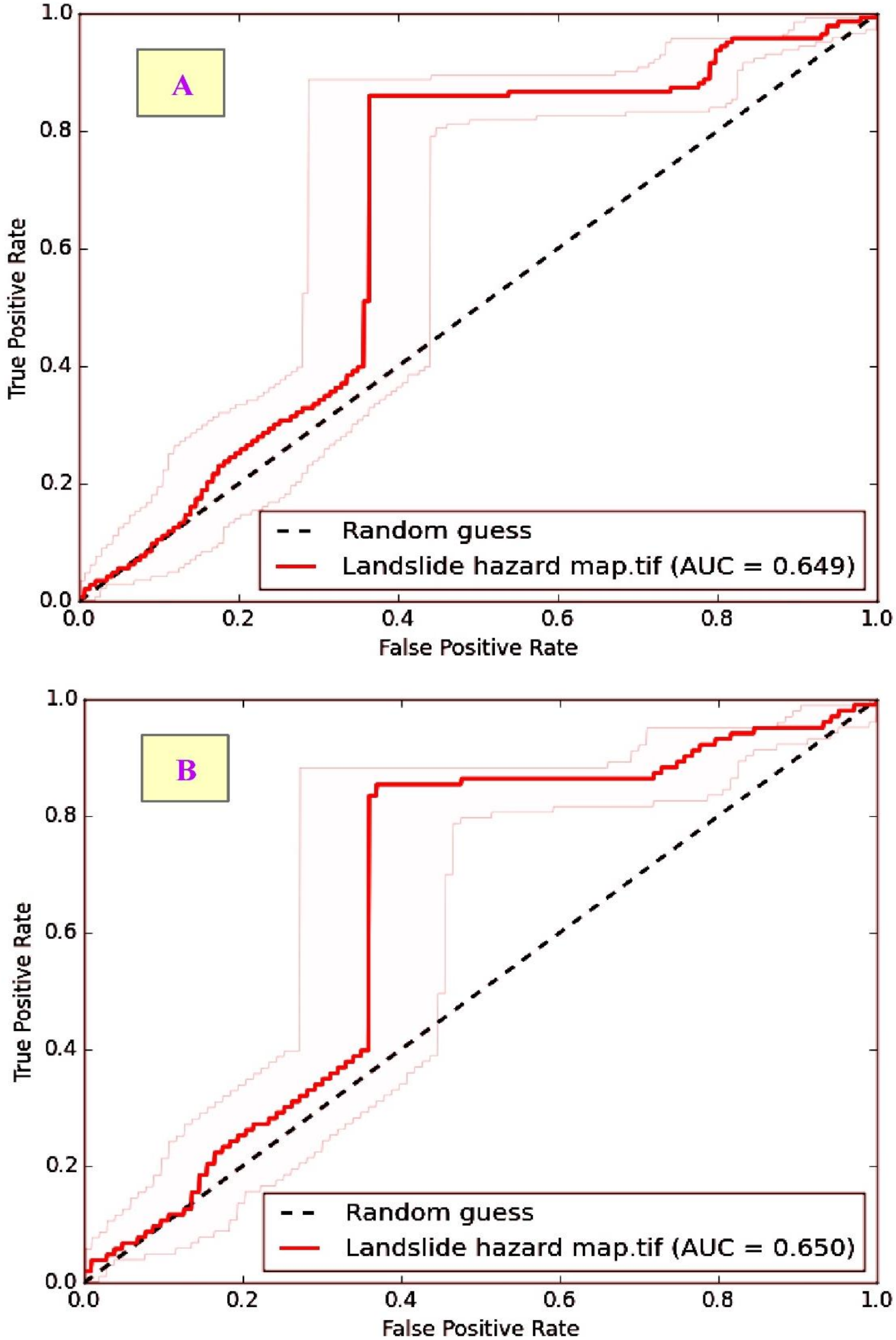


Figure 30: Shows Area under the Curve (AUC) A).Training and B).Testing (Validation).

5.6 Mitigation Measures

Mitigation is an action taken to prevent or reduce the risk of life, property, social and economic activities, and natural resources from natural hazards. Mitigation of landslide hazard can be successfully undertaken when detailed information about frequency, magnitude and character of slope failure within a particular area is, known (Vijith et al., 2009; Liu et al., 2006). For these reasons identifying landslide-prone areas represents a cheap and fast method in understanding this hazard and ensuring that appropriate mitigation strategies are implemented (Bai et al., 2009). Landslide hazard can be; mitigated by both physical countermeasures such as slope stabilization, reforestation, and water management and non-physical countermeasures such as evacuations and road closures. Nevertheless, every class has some distinct characteristics and mechanism of failure,-; therefore mitigation measure is, proposed to overcome the effect of each class on slope stability (Bhim et al., 2017).

The landslide hazard map of the study area was; generated from the most predominating factors causing landslide hazards in the area. Landslide hazard class was; analyzed by considering slope morphology, stream network, drainage density, aspect, and soil and land use land cover of the area corresponding to hazard class. Landslide hazard information in this study provides a solid practical, policy and legal foundation that will enable local government planners to avoid or mitigate landslide hazards and help build sustainable, hazard resilient communities in the study area. Therefore, selection of the most appropriate mitigation measures to be adopted in hazard zone take into account the factor that affects the hazard in terms of the probability occurrence of movement or landslide, such as the morphology of the area, the actual or potential causative processes affecting the geosystem, which can determine the occurrence of movement or landslides. Thus, mitigation measures proposed were, based on different predominating factors, overlapped in every cell unit of landslide hazard map by considering the area's topography relative to hazard zone. When the landslide hazard map overlapped with causative factors, the landslide hazard class was observed in a different class of causative factors. The concise mitigation representation of hazard zone in the study area was presented depending on the causative factor class with landslide hazard class. Mitigation measures taken in this study are used to increase resisting forces and retain potentially unstable material, decrease pore pressure, reduce soil saturation and weathering, avoid erosion, reinforce soil, and protect the hillside foot in the area (Table 13).

Table 13: Below present mitigation measures given for specific zones with suggestion action

S.No.	Hazard zones	Suggested action	Mitigation measures
1	Very High	▪ Construction (settlement) and other activities should be restricted. ▪ Existing property owners in this zone should be, notified of the landslide hazard.	✓ Avoiding excavating on or at the base of steep slopes ✓ Avoid placing fill soil on or near steep slopes ✓ Warning signs ✓ Stop cultivation on a steep slope ✓ Slope Netting ✓ Channelizing the surface and sub-surface runoff ✓ Vegetative turfing ✓ Plant native ground cover on slopes
2	High	▪ Construction and other activity should be restricted. ▪ Consult with a professional before significantly altering existing slopes uphill or downslope.	✓ Channelizing the surface and sub-surface runoff ✓ Protecting the base of the slope from erosion ✓ Slope Netting

3	Moderate	▪ Existing property owners in this zone should be notified of and educated about the hazard.	✓ Check Dams ✓ Retaining wall
4	Low	▪ Construction and other activities need only consider landslides as a minor threat	✓ Spraying ✓ Channelizing surface drainage.
5	Very low	▪ Construction and other activities need not take landslide hazards into account	✓ Vegetation ✓ Channelizing the surface and sub-surface runoff

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study was conducted in Arbegona Woreda, Southern Ethiopia, with the aim to evaluate landslide hazards and produce a landslide hazard zonation map by using GIS-based multi-criteria analysis.

Seven landslide-conditioning factors, namely, slope, lineament density, soil type, geology, aspect, land use land cover, and drainage density, were considered for the evaluation of landslide hazards. The weight derived by the analytical hierarchy process shows that the most contributing factor to landslide occurrence in the area is the slope. The obtained hazard map indicates that the west, northwest, south and southeast region of the areas were more prone to landslide.

The conducted correlation analysis between landslide occurrence and causative factor reveals that, causative factor class of alluvial deposit, colluvial deposit, some part at residual soils and lower basalt; high and very high drainage density; slope facing to the south, southeast and north; slope angle greater than 100; pellic vertisols, eutric nitosols, and fluvisols soil type; high and very high lineament density; water body and agriculture causative factor class has a strong correlation with landslide occurrence.

While the remaining causative factor classes have, weak and others do not correlate with landslide occurrence. This indicates that each causative factors has a different contribution to landslide occurrence in the area. The landslide hazard map showed, mainly very high and high hazard zones are located on steep topography, and low and very low hazard zones were, located on steep to gentle slopes.

The validation of the landslide hazard map showed that the predicted landslide hazard coincided with areas that had recently experienced a landslide. This reveals that the adopted methodology (GIS-based multi-criteria analysis) provide reasonable result in predicting landslide hazard in the area. Therefore, the produced landslide hazard map can be considered for future disaster management, planning and development of the study area.

The very high and high hazard zones are potentially dangerous for any future habitation and development. Thus, there is an immediate need to implement mitigation measures such as slope stabilization, reforestation, water management, etc., to protect people and property in the area and minimize the adverse effects of landslides.

6.2 Recommendations

Landslide in the study area has affected the local people who are living nearby. Their animals were died, houses and agricultural lands were destroyed and both social and economic activities were affected. The present study reveals that the integration of various factors was responsible for causing landslide in the study area. Consequently, in addition to preparing landslide hazard map of the area; suggesting the necessary preventive measures on high and very high hazard zones of the mapped area are essential in order to reduce the impact of landslide hazards in the future.

Based on the present study finding the following recommendations were forwarded:

- The landslide hazard map produced in this work highlights information about landslide hazard-prone areas; however, further works with additional methods are recommended.
- Further slope stability analysis works considering the intrinsic factors such as structural discontinuity characteristics, shear strength of the material, groundwater condition, etc. needed to be carried out.

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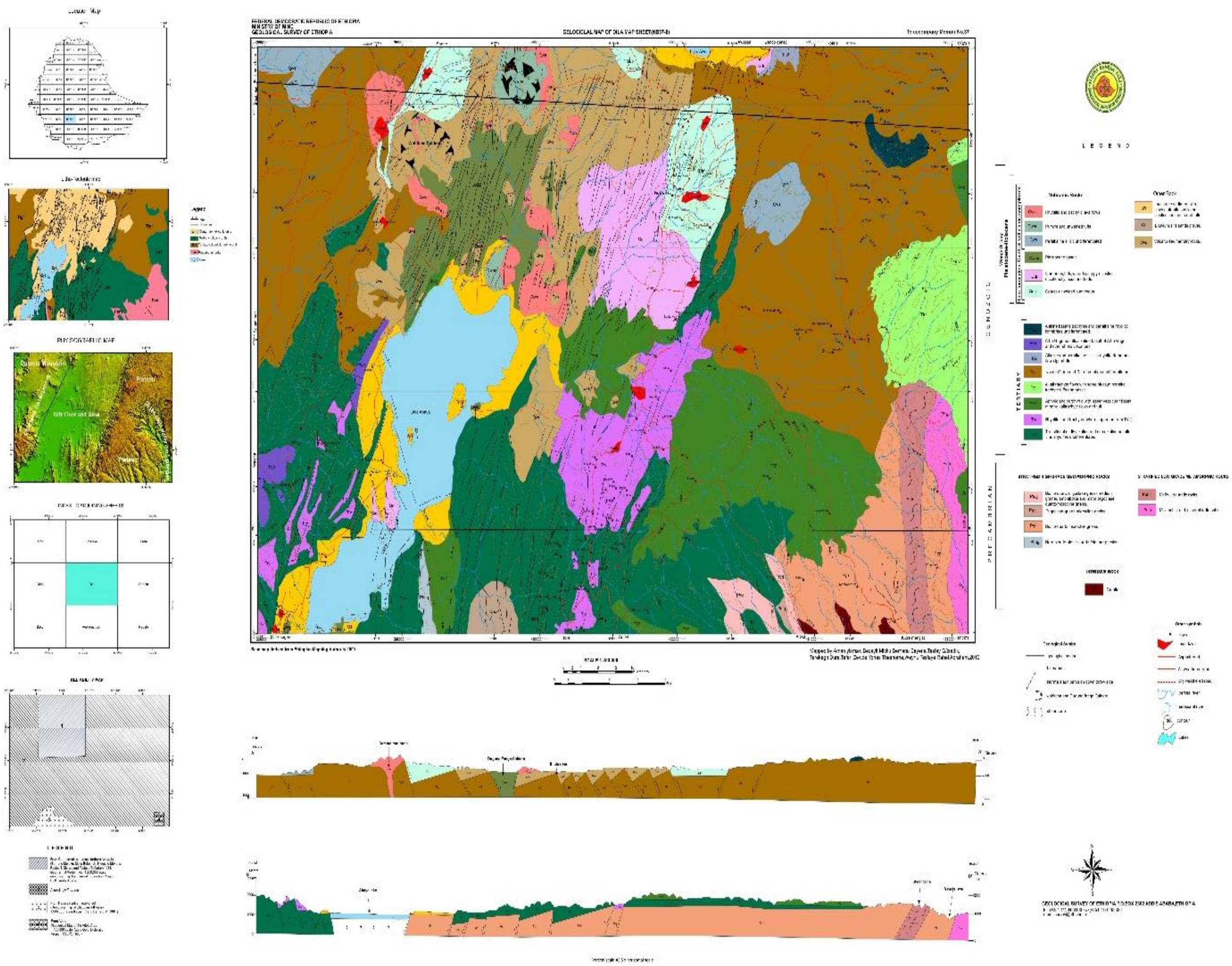
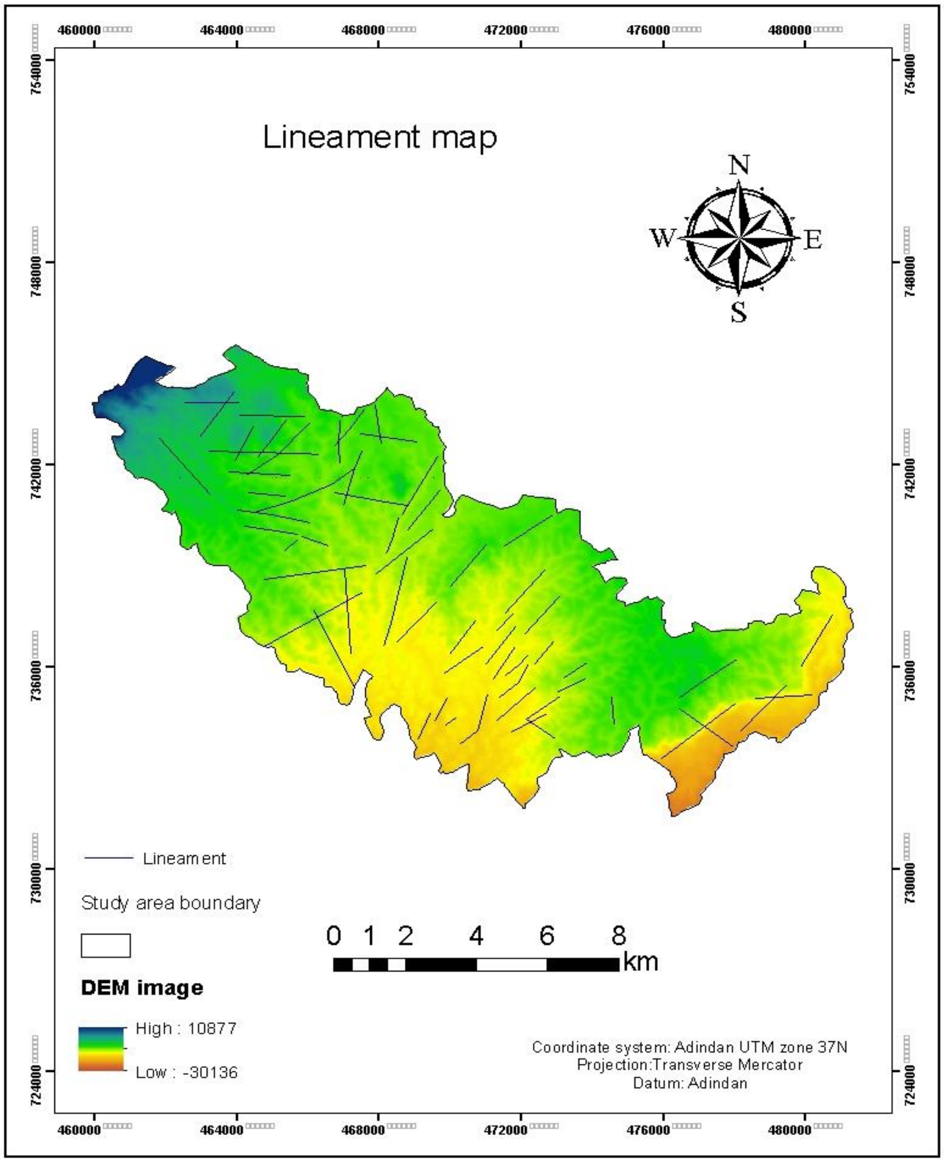
Appendices

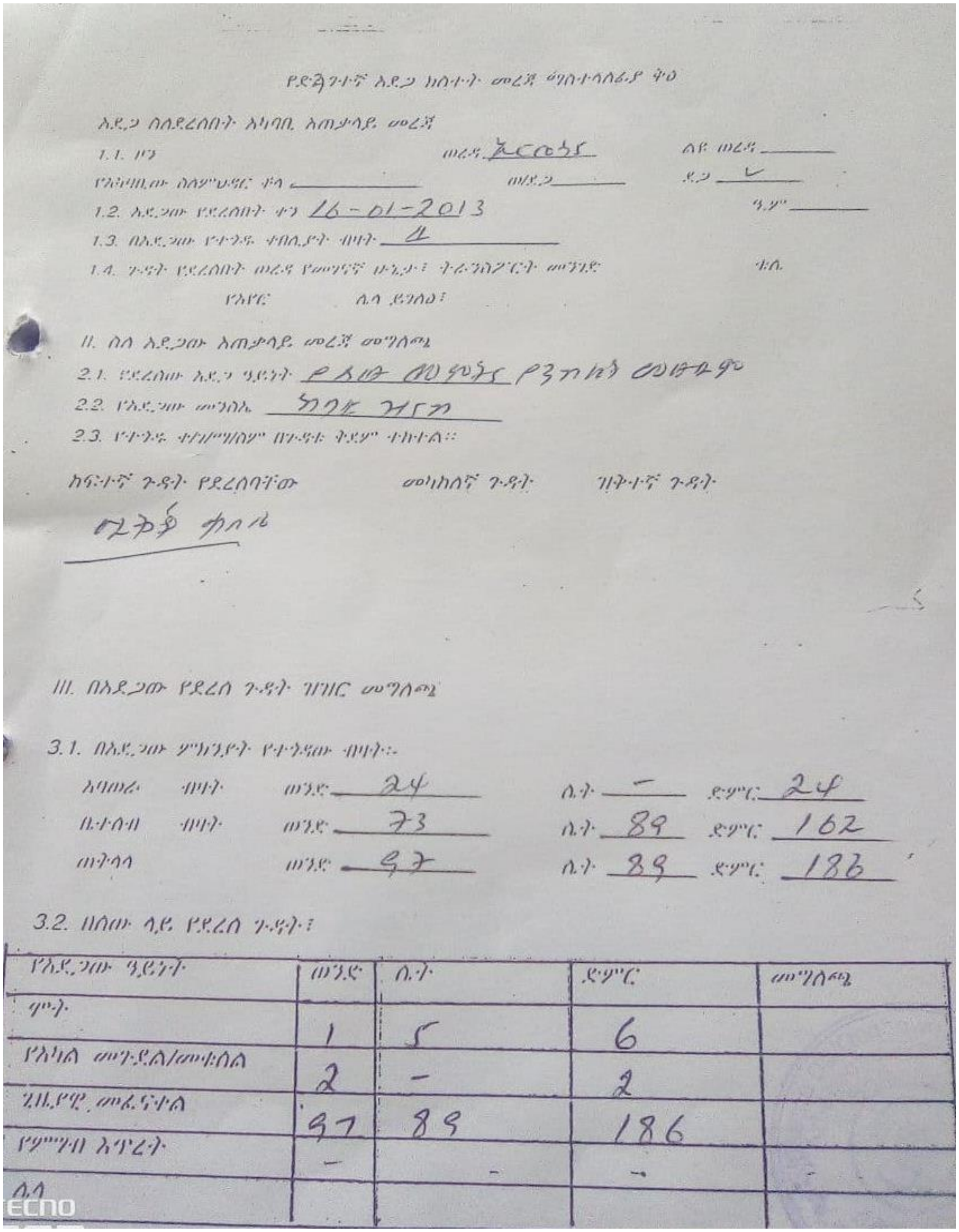


Appendix 1: Geological map of around Arbegona woreda area (EGS)



Appendix 2: Lineament map of study area

Appendix 3: Reports on damages resulted from landslide and heavy rainfall on 25-09-2020/21 (Arbegona Woreda Agricultural Office).



የድንገተኛ አደጋ ክስተት መረጃ ማሰባሰቢያ ቅፅ

1.2. አደጋው የደረሰበት ቀን 16-01-2013

1.3. ... ብዛት 4

III. በአደጋው የደረሰ ጉዳት ዝዝር መግለጫ

3.1.

አባወራ ብዛት	ወንድ 24	ሴት –	ድምር 24
ቤተሰብ ብዛት	ወንድ 73	ሴት 89	ድምር 162
ጠቅላላ	ወንድ 97	ሴት 89	ድምር 186

3.2. በሰው ላይ የደረሰ ጉዳት፣

የአደጋው ዓይነት	ወንድ	ሴት	ድምር	መግለጫ
ሞት	1	5	6	
የአካል መጉደል/መቁሰል	2	–	2	
ጊዜያዊ መፈናቀል	97	89	186	
የምግብ እጥረት	–	–	–	
ሌላ				

Continued…

3.3 በሰብል ላይ የደረሰ ጉዳት

የተዘራ ሰብል	የተዘራ በሄ/ር	የሚጠበቅ ምርት ኩ/ል/በሄ/ር	ጠቅላላ የሚጠበቅ ምርት በኩ/ል	በአደጋው የወደመ ሰብል በሄ/ር	የጉዳት መጠን		የጉዳቱ መጠን በገንዘብ ሲተመን
					በመቶኛ	በኩ/ል	
እንሰት	0.52[illegible]			0.525			51732

2

Continued….

3.4. በአደጋው የተጎዳ ሕዝብ የሚገኝበት ሁኔታ

3.5. በእንስሳት ላይ የደረሰ ጉዳት

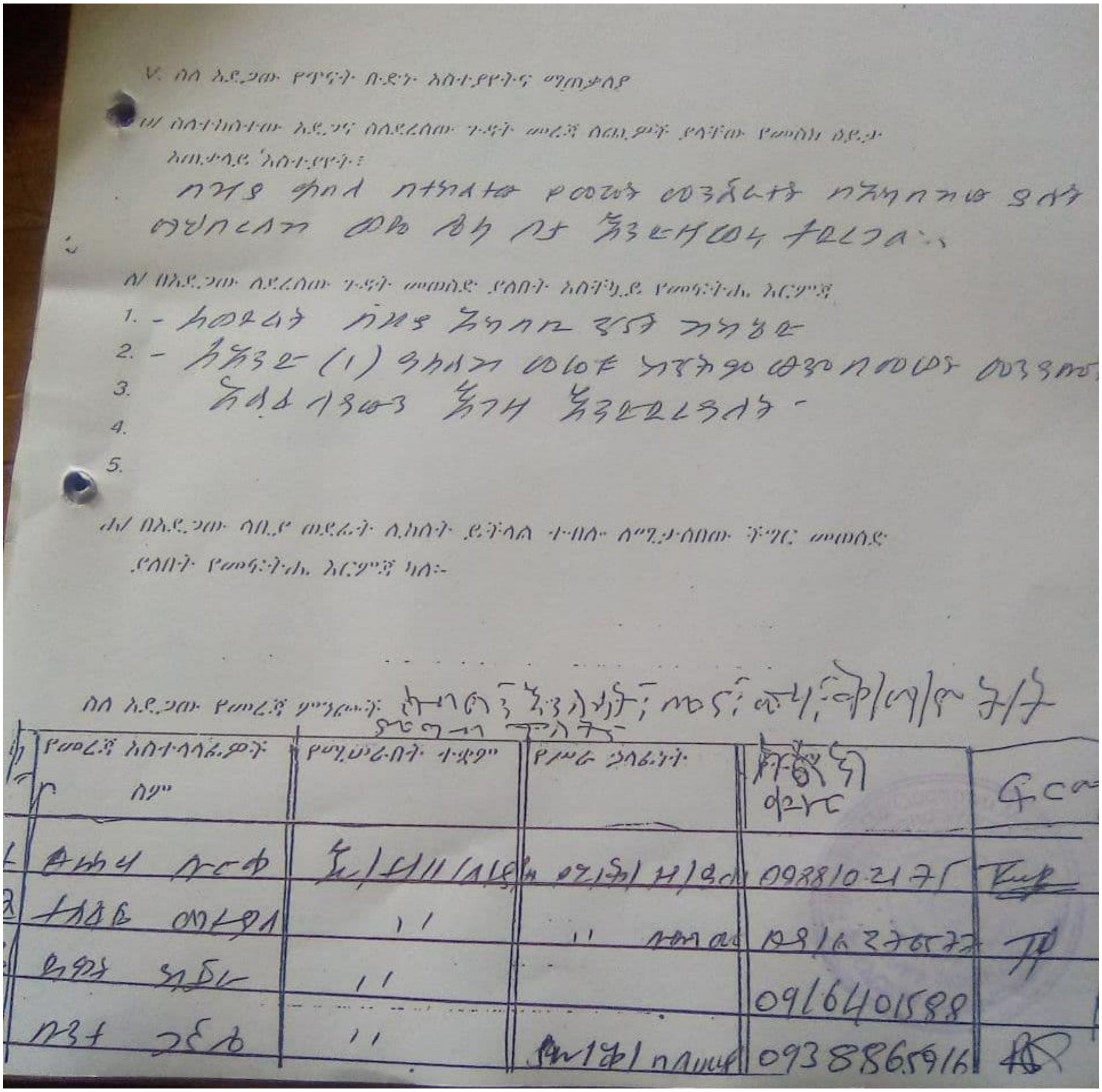
የደረሰበት እንስሳት ዓይነት	የአደጋው ዓይነት	ብዛት	የአንዱ አማካይ ዋጋ ግምት ብር	ሣ	ጠ/ዋጋ ግምት ብር	ሣ	መግለጫ
ላም	[illegible]	14	13,000	–	182,000	–	
በሬ	"	–	–	–	–		
ጥጃ	"	–	–	–	–		
በግ	[illegible]	10	2500	–	25000	–	
ፍየል	[illegible]	7	3200	–	22400	–	
ግመል	"	–					
ፈረስ	"	–					
በቅሎ	"	–					
አህያ	"	–					
ዶሮ	[illegible]	7	250	–	1750	–	

3.5 እንስሳት ላይ የደረሰ ሌላ ጉዳት ካለ ይገለፅ

3.6. በቤተሰብ ደረጃ በንብረት ላይ የደረሰ ጉዳት

የንብረት ዓይነት	ብዛት	የአንዱ የጉዳት መጠን የዋጋ ግምት ብር	ጠቅላላ የጉዳቱ መጠን የዋጋ ግምት በብር
[illegible] ቤት	1	17 050	17050
ቆርቆሮ ቤት	—	—	—
የተለያዩ ንብረቶች	—	84950	84950
ጥሬ ገንዘብ			
[illegible]		120,000	120,000

Continued….



V. ስለ አደጋው የጥናት ቡድን አስተያየትና ማጠቃለያ

ሀ/ ስለተከሰተው አደጋና ስለደረሰው ጉዳት መረጃ ሰጪዎች ያላቸው የመስክ ቡድኑ አጠቃላይ አስተያየት፤

[illegible]

ለ/ በአደጋው ለደረሰው ጉዳት መወሰድ ያለበት አስቸኳይ የመፍትሔ እርምጃ

1. - [illegible]
2. - [illegible]
3. [illegible]
4.
5.

ሐ/ በአደጋው ሳቢያ ወደፊት ሊከሰት ይችላል ተብሎ ለሚታሰበው ችግር መወሰድ ያለበት የመፍትሔ እርምጃ ካለ፡-

ስለ አደጋው የመረጃ ምንጮች [illegible]

	የመረጃ አስተላላፊዎች ስም	የሚሰሩበት ተቋም	የሥራ ኃላፊነት	ስልክ ቁጥር	ፊርማ
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	,,	,, [illegible]	[illegible]	[illegible]
3	[illegible]	,,		0916401588	[illegible]
4	[illegible]	,,	[illegible]	0938865916	[illegible]

Appendix 4: landslide inventory database

S No	Landslide location coordinate		Elevation(m)	Landslide location	Landslide type	Land use land cover present in the slide
	X	Y				
1	477091.535	735405.994	2830.54	village	Transitional slide	Agriculture
2	476430.217	733658.225	1697.41	village	Transitional slide	Agriculture
3	480161.939	738807.057	2841.43	village	Transitional slide	Grassland
4	476619.165	737531.658	2839.91	village	Earthflow	Forest
5	475060.345	735925.6	2863.43	village	Earthflow	Agriculture
6	467596.901	734461.254	2663.53	village	Debris flow	Agriculture
7	461786.752	742963.911	2763.39	village	Earth flow	Agriculture
8	462684.254	743908.651	2832.03	village	Transitional slide	Forest
9	460794.775	734414.017	2597.16	Town	Transitional slide	Grassland
10	461456.093	735169.809	2500	village	Transitional slide	Forest
11	463036.986	747665.392	2503	village	Debris flow	Agriculture
12	470140.17	739188.926	2568	village	Debris flow	Agriculture
13	462468.731	742409.036	2508	village	Debris flow	Agriculture
14	460148.358	741035.754	2499	village	Transitional slide	Agriculture
15	479326.954	734500.824	2506	village	Transitional slide	Agriculture
16	478758.7	734595.534	2533	village	Transitional slide	Agriculture
17	463179.05	734121.988	2536	village	Transitional slide	Forest
18	468151.278	734879.661	2533	village	Transitional slide	Grassland
19	471986.998	731470.133	2525	village	Transitional slide	Grassland

Appendix 5: The minimum Temperature data at study area in (1983-2017) (National Metrological Agency)

Date	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1983	7.255	9.082	10.586	10.151	10.471	9.693	9.354	10.422	9.526	9.537	8.113	7.308
1984	6.234	5.762	7.813	8.196	9.08	8.553	8.648	9.101	8.703	6.772	7.908	6.968
1985	5.535	6.411	7.336	8.46	8.152	7.805	9.014	8.594	8.659	7.69	7.784	6.421
1986	5.322	8.032	7.66	9.245	9.031	8.901	8.637	7.379	8.429	7.631	6.705	6.382
1987	6.404	7.347	9.302	8.238	8.939	8.663	8.411	7.909	8.006	8.738	7.217	6.405
1988	7.514	8.405	8.362	9.454	8.8	8.948	9.695	8.827	9.047	9.228	6.109	5.74
1989	6.68	6.955	8.421	8.56	7.465	7.381	8.896	8.131	8.525	8.08	7.544	8.768
1990	6.46	9.472	8.746	9.127	8.748	8.101	8.802	8.932	8.479	8.2	7.726	6.827
1991	8.704	8.615	9.299	8.659	9.264	9.85	9.452	9.798	9.344	8.919	8.754	8.891
1992	8.218	9.22	8.997	9.461	9.328	9.123	9.055	9.57	9.455	9.954	9.597	9.734
1993	8.45	9.723	9.719	10.818	10.077	9.724	9.633	9.47	8.79	9.145	8.999	8.149
1994	7.873	8.766	9.914	10.006	9.997	10.187	9.869	10.043	9.849	8.647	8.826	7.502
1995	7.079	8.241	8.964	9.84	9.436	9.636	9.964	10.013	9.506	9.47	7.828	8.002
1996	8.852	8.38	8.867	8.946	9.108	9.584	9.659	9.628	9.842	8.878	7.424	7.073
1997	8.319	6.819	8.359	7.996	8.116	8.433	9.021	8.773	8.524	9.25	8.741	8.472
1998	9.201	9.067	8.913	9.657	9.65	9.47	10.155	10.448	9.629	10.027	7.294	5.756
1999	6.448	7.076	8.893	8.696	8.922	9.125	8.766	8.657	8.095	8.293	6.964	5.697
2000	5.862	6.177	7.748	9.372	9.793	9.109	9.294	9.08	9.105	9.373	8.413	6.702
2001	6.654	6.71	8.67	8.265	8.775	9.147	9.883	9.777	9.619	9.923	8.537	7.242
2002	8.297	7.732	10.186	10.04	10.907	10.996	11.117	10.618	9.872	9.896	8.305	9.515
2003	8.443	8.381	9.254	10.237	9.763	9.817	10.116	9.734	9.474	9.086	8.3	7.709
2004	9.111	8.263	8.371	10.242	10.289	8.023	9.366	8.733	10.45	8.737	8.354	8.157
2005	8.504	8.826	10.508	10.187	10.449	10.228	10.363	10.382	10.366	10.778	9.004	7.357
2006	8.76	9.259	10.241	10.512	10.521	10.424	10.659	10.658	10.377	10.374	9.698	9.702
2007	9.77	9.591	9.514	10.359	9.786	9.937	10.204	10.43	10.565	9.769	9.945	8.114
2008	8.764	7.857	9.223	9.45	9.443	9.661	10.041	9.72	9.632	9.459	8.804	8.688
2009	8.656	8.817	9.138	9.556	8.636	8.407	8.477	8.658	8.511	8.769	8.611	8.898
2010	8.377	9.323	8.885	9.558	9.976	9.278	10.12	10.639	10.121	10.102	8.105	7.607
2011	8.767	8.965	9.653	9.974	9.868	10.264	9.694	9.867	10.34	9.413	9.757	8.103
2012	7.156	7.342	8.553	8.589	10.153	10.2	10.515	9.838	10.478	9.345	9.421	7.32
2013	7.376	7.33	9.543	9.099	8.968	9.322	9.594	9.508	9.596	10.022	9.824	6.908
2014	8.406	9.511	9.233	9.325	9.273	9.089	10.436	9.345	9.596	10.204	9.041	7.822
2015	11.661	9.163	9.999	10.534	12.253	12.235	12.228	11.795	12.002	12.149	12.879	8.179
2016	13.122	13.467	14.408	13.831	13.172	12.407	13.33	11.575	9.371	9.486	7.891	9.35
2017	13.572	14.257	14.935	14.603	13.742	12.928	13.804	12.473	12.359	11.207	9.734	10.421

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1983	22.365	20.818	22.985	20.42	20.034	21.007	19.047	19.369	19.015	19.277	20.522	21.032
1984	22.278	22.761	23.706	22.858	19.727	18.224	18.171	18.218	19.356	21.248	21.256	21.923
1985	21.539	21.099	21.579	18.219	17.929	18.157	17.864	17.587	18.861	19.732	20.58	21.409
1986	20.994	20.087	19.83	18.016	18.557	17.965	17.399	17.951	18.335	19.187	19.839	20.194
1987	20.617	21.064	19.405	19.413	19.012	19.064	19.114	18.746	19.368	19.295	20.601	21.129
1988	21.558	21.15	21.576	19.87	19.754	18.717	17.409	17.562	18.691	18.524	19.911	20.218
1989	20.612	20.273	20.322	18.323	19.297	17.852	17.485	18.385	18.3	18.871	19.611	19.103
1990	20.257	19.798	20.309	19.977	20.518	19.735	18.677	18.016	18.885	19.767	20.163	20.307
1991	22.371	20.99	20.864	20.642	20.672	20.555	17.989	18.866	19.19	20.124	20.621	21.314
1992	20.36	20.218	21.945	20.721	20.393	20	18.752	18.325	19.041	18.931	20.228	20.153
1993	19.777	19.55	21.408	19.848	19.225	18.592	17.414	17.497	17.919	18.498	20.783	21.654
1994	23.348	24.24	22.568	20.075	18.836	18.725	17.787	18.239	19.179	19.872	20.268	21.522
1995	23.303	22.714	20.243	19.171	20.359	20.556	19.016	18.586	19.493	19.729	20.9	21.487
1996	21.511	23.301	21.383	19.747	20.111	18.468	18.611	18.224	19.541	19.951	21.178	21.509
1997	21.893	23.069	23.118	20.784	20.777	19.94	18.855	19.725	20.309	19.847	20.178	20.575
1998	20.984	21.792	21.907	21.887	21.113	20.232	19.17	19.319	19.735	19.508	20.844	21.871
1999	22.875	23.449	21.48	20.88	20.667	20.149	18.275	18.896	19.383	19.209	20.753	21.648
2000	23.125	24.16	24.002	21.5	19.845	19.596	18.957	18.993	19.484	19.925	20.799	21.991
2001	22.355	22.803	22.074	20.968	20.337	19.522	19.314	19.92	19.718	19.614	20.909	22.256
2002	21.982	23.299	21.633	21.316	20.77	20.19	19.551	19.124	20.173	20.474	21.868	21.291
2003	21.742	22.85	22.787	21.409	21.474	20.63	19.545	19.989	19.999	20.871	21.311	21.205
2004	22.017	21.943	22.32	20.686	21.042	19.941	19.924	19.425	19.967	19.492	21.47	21.596
2005	22.193	22.899	21.608	21.599	20.27	19.978	19.011	19.119	19.795	19.999	20.978	21.718
2006	22.143	21.886	21.199	20.371	20.604	20.077	18.997	18.858	19.397	19.747	20.564	20.719
2007	21.475	21.957	22.196	20.904	20.795	19.98	19.621	19.458	19.484	19.986	20.645	21.966
2008	22.267	22.796	23.249	21.1	20.144	20.12	18.87	18.739	19.889	19.937	20.558	21.582
2009	21.945	22.352	23.606	20.753	21.091	21.23	19.637	19.854	20.317	20.225	21.546	20.882
2010	21.175	20.784	20.366	20.983	20.793	20.747	19.005	19.132	19.732	20.835	21.031	21.344
2011	22.433	23.016	22.765	22.689	20.526	20.133	20.258	19.286	19.883	21.322	21.04	20.637
2012	23.175	24.03	24.404	20.966	21.435	20.238	19.991	19.728	19.632	20.991	21.737	23.064
2013	22.712	23.683	22.467	21.049	19.885	19.893	19.39	18.973	20.312	19.936	20.897	21.436
2014	22.358	21.1	21.9	21.187	20.784	20.911	19.596	19.834	19.803	20.398	21.189	21.941
2015	25.187	23.746	23.655	22.048	22.914	23.12	22.334	22.59	23.329	23.351	22.267	19.88
2016	25.15	25.559	26.384	23.755	22.558	22.601	23.964	22.331	21.214	20.55	21.774	20.85
2017	26.25	26.024	26.875	23.975	23.074	22.978	24.834	23.236	22.206	21.583	22.628	21.689

Appendix 6: The maximum Temperature data at study area in (1983-2017) (National Metrological Agency)