

Analyzing Landslide Hazard and Risk Using Geospatial Technology: A Case of Kindo Didaye Woreda, Wolaita, SNNPR, Ethiopia



Amanuel Melese Milkias

A thesis Submitted to the Department of Geomatics Engineering School of Civil Engineering
and Architecture Presented in partial fulfillment of the requirement for the degree of master's
in geo-informatics

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

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DECLARATION

I hereby declare that this master thesis entitled “Analyzing Landslide Hazard and Risk Using Geospatial Technology: A Case of Kindo Didaye Woreda, Wolaita, SNNPR, Ethiopia” is my own work and has not been submitted to any university for a similar purpose. The references used in this proposal are duly recognized by proper citations.

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ACRONYM

AHP	Analytical Hierarchy Process
ALOS	Advanced Land Observational Satellite
CSA	Central Statistics Agency
DEM	Digital Elevation
ETM	Enhanced Thematic Mapper
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resources Data Analysis System
ESA	European Space Agency
ESRI	Environmental System Research Institute
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
LULC	Land Use / Land Cover
MCE	Multi-Criteria Evaluation
NMA	National Meteorological Agency
UTM	Universal Transverse Mercator
WLC	Weighted Linear Combination

ABSTRACT

Landslides are commonly known natural hazards that lead to infrastructure destruction, property damage, and human loss. Kindo Didaye woreda is characterised by its mountainous and the settlement of people near steep slopes. In the Kindo Didaye area, landslides have been seriously threatening human and animal lives as well as economic activity. The objective of this study is to prepare the landslide hazard and risk map of Kindo Didaye area using geospatial technologies. Ten (10) causative factors elevation, slope, lithology, rainfall, land use land cover, soil type, lineament, NDVI, distance from rivers (streams), and TWI, are developed in GIS to prepare a landslide hazard map. Then, multi-criteria evaluation method was used to produce a landslide hazard map depending on the Analytical hierarchy process (AHP) pairwise comparison of eigenvector values. IDRIS software was used to compute the weight of each factor. Finally, a landslide risk map of the study area was prepared by overlaying the landslide hazard map, population density, proximity of roads, and land use land cover. The result shows that 98.55 (36.24%), 48.69 (17.90%), 55.67 (20.48%), 41.96 (15.43%), and 9.93% (26.99)sq.km were subjected to very low, low, moderate, high, and very high landslide hazard zones respectively, as well as 37.04 (7.62%), 41.59 (15.30%), 50.50(20.57%), 47.67 (19.52%), and 36.98% (95.12) sq. km of the study area were, respectively subject to very high, high, moderate, low, and very low landslide risk levels respectively. The landslide hazard and risk maps that are produced in this study will be useful to provide important information about the locations of landslide-prone areas. Concerned bodies such as land use planners and engineers should implement risk management programs and appropriate policies to reduce landslide threats in the current study area.

KEYWORDS: *Geospatial technology, Multi-Criteria Decision Making, hazard and risk, Landslide*

CHAPTER I: INTRODUCTION

1.1 Background

The term natural hazard is described by (EVANS, Bevis, et al. 2001) as the occurrence of a natural condition or phenomenon that appears dangerous in a defined space and time. Globally, landslides are one of the most devastating geo-hazards, seriously threatening human lives and economic conditions through endless socio-economic stress (Chang, Merghadi, et al. 2019). Earth is dynamic, the surface of the earth is always under change due to various geo-processes causing natural hazards and threats to mankind (Woldearegay, 2013).

Landslides cause extensive property damage and occasionally result in the loss of life (Lee, 2004). Landslide is caused by rain, earthquakes, volcanic activity, and human activity. (TESFAYE, 2020) classifies the factors that cause landslides into intrinsic and extrinsic or dynamic. Understanding these causative factors and the historical landslide nature of the terrain allows us to subdivide the terrain into uniform area domains and rank them according to actual or potential landslide vulnerability (Wachal, Hudak, et al. 2000). When planning, developing, or implementing land use strategies, planners, developers, and engineers can use landslide susceptibility maps to provide valuable information (Pourghasemi, 2003). The study of landslides has gained international attention as a result of the harm they do to public works projects, buildings and structures, private property, human and animal life, and transportation networks (EVANS, Bovis, et al. 2001)

In an area with specific local topographical characteristics, "landslide susceptibility" refers to the possibility or degree (e.g., low, moderate, or high) of landslides occurring (Lai and Tsai 2019). The most frequent natural disasters, landslides harm both infrastructure and ecosystems. To assist with controlling hazards for land use planning and risk reduction, landslide susceptibility maps (LSM) are extremely important (Dou, Bui, et al. 2015). In addition, modern (LSM) studies frequently define landslide potential areas using remote sensing (RS) and geographic information system (GIS) technology. Due to the detrimental effects that landslides have on settlement areas, a landslide risk assessment must also be taken into account in urban development schemes (Akgun, Kınca, et al. 2012).

One of the major geological risks that are prevalent in many regions of the world is landslides. In steep and mountainous places, they pose a serious threat to the inhabitants, property, and infrastructure. Each year, they cause tens of billions of dollars worth of property damage in addition to thousands of fatalities and injuries. Currently, the frequency of landslides is on the rise throughout the world, with devastating effects on villages, development projects, and agricultural land (Damtew, Tsigi, et al., 2017). Around the world, there are more landslides, which can result in fatalities, the death of livestock, damage to or destruction of villages, towns, and residential and industrial developments, as well as the destruction of agricultural and forested land, as well as poor water quality in rivers and streams. Human activities have been compelled to migrate to practices like deforestation, urban expansion, and agriculture in potentially dangerous places because of the rising population and economic pressures in mountainous regions (Kitutu, 2010).

Due to the terrain characteristics, their associated undersurface conditions, and other natural and man-made triggering variables, floods and landslides are the most frequent natural hazards that occur in Africa. According to (Zepeda, Maybew, et al. 2010), these dangers are the most deadly and destructive on a continental scale, and occasionally their integrations and connections make the dangers worse.

According to (Lu, Stumpf, et al. 2011) research, landslide issues are also prevalent in Ethiopia's central, northern, and southern highlands as well as the neighboring rift valley edge. Around 300 people were killed by landslide-related dangers in the Ethiopian highlands between the years of 1990 and 1998 alone, in addition to damaging over 100 kilometers of asphalt roads, more than 200 homes, and more than 500 hectares of land (Yamagishi, marui et al. 2005). In the highlands of Ethiopia between 1998 and 2003, 135 people lost their lives, 3500 were evacuated, and an estimated 1.5 million US dollars of property was damaged (Kifle Woldearegay,2005).

More than 58% of Ethiopia is made up of mountainous and hilly terrain that is higher than 1500 meters (Abay and Barbieri et al. 2012) and these highlands, including the rift margins, are home to 90% of the people and 90% of the arable fields (Abay, Barbieri et al. 2019). Approximately 388 fatalities, 24 injuries, and significant damage to agricultural lands, homes, and infrastructure are reported between 1960 and 2010 (Meten, PrakashBhandary, et al. 2015)

Ethiopia is currently engaged in major natural resource management, urban growth, and massive infrastructure construction (including roads and railways). Ground failures caused by landslides must receive adequate attention in this entire socioeconomic development to avoid losses from such hazards and build safe geo-environments (Woldearegay, 2013). In May 2016, in our country Ethiopia landslides resulted in a loss of lives, livelihoods, and infrastructure in Amhara, Somali, Afar, Oromia, SNNPR and Hareri Region, and Dire Dawa Administrative Council. The flood incident caused the displacement of over 195,000 people in flash and river flood-prone areas (Partners, 2016), (Emergency Protection and food security, 2016).

Kindo Didaye woreda, the subject of the present study, is severely impacted by landslide threats in 2016. According to Kindo Didaye Agricultural and Natural Resource's woreda report, landslides have been seriously affecting the woreda's human life, animal life, agricultural life, and property. Among these, a landslide in Kindo Didaya Woreda in mid-August 2007 caused by heavy rainfall resulted in 16 fatalities and more than 200 home displacements (zerihun, 2007). Landslides danger on August 31, 2010, resulted in the deaths of 8 persons and the destruction of homes and other property. More than 340 households were forced to leave their homes on May 9, 2016, and 35 houses were destroyed. Additionally, 839.5 hectares of various crop types, 15.5 hectares of pasture grounds, and 250 coffee plants were harmed (zerihun, 2007). 51 individuals lost their lives and 51 agricultural areas, homes, and infrastructures were damaged or destroyed by landslides from 2005 to 2016 alone, according to a report from the locals and the Office of the woreda agriculture and natural resources.

Even though Kindo Didaye Woreda is prone to landslides, there hasn't been a lot of effort made within and surrounding the research area to accurately assess landslide hazards and risks. Investigating by RS and GIS may provide effective information within a short period and with minimum financial inputs when compared to conducting an investigation in this area by ground survey techniques which is practically difficult due to the ruggedness of the topography. The present study determines that multi-criteria analysis with GIS is a powerful tool for predicting landslide hazards and risk mapping in the area.

1.2 Problem Statement

According to (Martens, 2021) and (Shana, 2020), landslides are common known natural hazards that can cause infrastructure failure (road failure), property damage, and even fatalities around the world. Landslides killed 66,438 people worldwide between 1900 and 2020 and cost the economy over \$10,8 billion (Emerson et al., 2020; Fang et al., 2021). Landslides are estimated to cause \$4 billion in property damage globally each year or account for about 1,000 fatalities, according to statistics on damage (Lee & Parana, 2007).

In recent years, the number of victims of landslides in Africa has increased. Loss of life, devastation of agricultural land and crops, and damage to infrastructure are the principal social, economic, and environmental effects. Over 4,000 people have died in similar incidents over the past 10 years and millions of dollars of resources are lost each year in Africa, according to (Newbie, 2012).

Among the environmental issues, Ethiopia faces with landslides, soil deterioration, land degradation, vegetation loss, overuse of fuel forests, groundwater contamination, sanitation issues, and flooding during the rainy season (Woldearegay, 2013). In Ethiopia, Landslides significantly harm buildings, agricultural land, habitations, road infrastructures, and result in fatalities (Amare et al., 2018; Ayalew, 1999). Landslides often harm crop and animal productivity (Parham, Chaudhari, et al. 2012).

Kindo Didaye was one of the landslide-prone areas in the southern nation nationality region of Ethiopia. Numerous lives were lost as a result of it. Kindo Didaye woreda is characterized by its mountainous, rough, and hilly terrain, as well as its large plain valleys and gorges and the settlement of people near steep slopes. It also lacks mechanisms for conserving soil and water, and its overuse of natural resources hurts the hazards that have already occurred. In the Kindo Didaye area, landslides have been seriously threatening human lives, animal life, crop production, and property. According to (Tesfaye, 2020) eight people were killed and numerous homes and other pieces of property were destroyed by a landslide on August 31, 2010. According to (zerihn, 2016) 39 persons lost their lives and 192 were displaced by a landslide on May 9, 2016. According to (Tesfaye, 2020) landslides in the Kindo Didaye area alone resulted in 51 fatalities from 2005 to 2016 and devastated agricultural grounds, homes,

and infrastructure. Because of its highland and steep slope, the current study region is prone to landslides. In the research area, slope failure, property damage, and fatalities have been increasing occasionally for many years.

There hasn't been a study done yet that attempts to predict the landslide hazard and risk in the Kindo didaye, even though (Tesfaye, 2020) completed a study on the causes of landslides, but failed to study landslide risk and landslide hazard. However, this study provides both landslide hazard and landslide risk assessment with mitigation measures for the landslide problem in the current study area. The results of the earlier studies are mostly manual and the absence of a thorough investigation into the use of geospatial technologies, including remote sensing and GIS.

The current research is significant because it will reveal details on places that are vulnerable to landslides. Geotechnical engineers, land use specialists, and urban planners who are concerned about development plans and efficient land management for a safer society can utilize this as a basic source of information. Therefore, this study will offer the most insightful analysis in a time and money-saving manner to reduce future landslide-related property damage, infrastructure damage, and fatalities.

Thus, the goal of this study is to assess landslide hazards and risks for study areas to locate hazard-prone areas and aid planners in selecting suitable sites for development projects like building and road construction. Determining landslide hazard areas is necessary before the design and implementation of any development activity in high terrain (Raghuvanshi, 2014; Meten, 2016). GIS technology has emerged as a key contemporary tool for identifying regions at risk of disaster (Varnes, 1984). Therefore, a crucial tool in the correct management of this terrible environmental hazard is the use of multi-criteria decision analysis and GIS for spatial analyses and identifying landslide-prone zones inside the research area.

1.3 Objective

1.3.1 The *General Objective*

The General Objective of this study is to analyze landslide hazard and risk using geospatial technology.

1.3.2 The Specific Objective

The Specific Objectives of this study is to:

- To identify the main landslide-generating factors in the study area,
- To determine landslide hazard area,
- To identify a landslide risk area and analyze the level of landslide,
- To propose suitable mitigation that reduces the disaster of landslides in the study area.

1.4 Research questions

- What are the main factors that triggers landslide in study area?
- How landslide hazard area is determined?
- What are the levels of landslide hazard and risk in the study area?
- How to mitigate the disaster of landslides in the study area?

1.5 Significance of the Study

The research area's landslide hazard and risk map can be utilized to identify landslide spatial likelihoods for strategic planning of subsequent development operations. The results of this study can benefit Kindo Didaye woreda for land use planning, environmental planning, farming, strategic urban growth, the construction of public facilities like hospitals, sports fields, schools, and avenues, and the approval of policymakers and officials in charge of government agencies. The outputs of this research will help the zonal Disaster Risk Management group in preparing for potential hazard study tasks for the future. Educators, environmental resource preservation organizations, and coordinators of outdoor activities are also among the beneficiaries of this research output. Once more, nongovernmental organizations (NGOs) use the research's findings to help people living in landslide-prone areas.

1.6 Scope of the Study

Kindo Didaye woreda is the only area covered by the study. The current study concentrates on mapping the Kindo Didaye woreda's hazard and risk to landslides utilizing a multi-criteria evaluation method based on geospatial technology. A landslide hazard and risk map for the

Kindo Didaye woreda utilizing the MCE approach in a GIS environment is mapped as part of the study, which also includes organizing the necessary materials and processes for conducting the study, identifying factors, and mapping. The landslide hazard and risk mapping in this study used the land use land cover classes, lineament, elevation, slope, rainfall, proximity to the river, NDVI, TWI, and lithology as input parameters.

1.7. Organization of the thesis

The problem statement, study objectives, research questions, significance, and study scope are all covered in the first chapter of the thesis. A review of related literature that is pertinent to the research topic, including publications, studies, booklets, and notes related to landslide hazards and risk mapping that are pertinent to the thesis, is included in the second chapter.

The third chapter, on the other hand, provides information on the study area's background, including physical settings like location, topography, soil types, climate, and population. The materials also go into great detail about the data and software needed for this study. Additionally, a thorough description of the data collection procedures and research methodology is provided. The fourth chapter covers data collection and analysis as well as the development of factors for mapping landslide hazards and risks. The outcome and discussion, which cover all of the output discussions of landslide hazards and risks, are examined in Chapter four. Finally, Chapter five gives a conclusion and possible recommendations based on the results of the study.

CHAPTER II: LITERATURE REVIEW

This chapter explores theoretical, conceptual, and empirical frameworks. A Comprehensive review of landslide hazard and risk mapping using the geospatial technology-based multi-criteria evaluation method

2.1 Theoretical concept

2.1.1 Natural Hazard

All harmful geophysical events, including earthquakes, flooding, and landslides, are considered natural hazards (Pradhan, 2013). Although there are landslides everywhere, their frequency and intensity are higher in nations with mountainous and hilly terrain (Lee & Pradha, 2006). The risk of landslides is one of the major environmental constraints on the development of both developed and developing nations, including Ethiopia, and it serves as a preventative measure for organizations and urbanization. In hilly areas, landslides can result in significant economic losses and fatalities. Innovative methodologies are necessary to grow a better understanding of landslide hazards and to make fair decisions on the distribution of funds for the administration of landslide risk to effectively reduce landslide hazards (Lan, 2004; Chimidi, 2017).

2.1.2 Landslide

A landslide, according to (Cruden, 1991), is type of natural hazard described as a large-scale movement of debris, rock, or earth down a slope that alters the geomorphology of the Earth's surface. Slope instability is the propensity of a slope for morphologically and structurally destructive landslide processes. Landslides are a symptom of slope instability. According to (Chau, 2004), it may take the form of rock falls, rockslides, debris flows, soil slips, rock avalanches, and mudflows, among other forms and combinations of these. In contrast to earthquakes, major floods, hurricanes, and other natural disasters, individual slope failures are typically as large or severe. Slope failures are more common than other geological hazards, and they could cause more property damage over time. Rugged topography, weak geological structure, and variations in bedrock lithology are the primary causes of landslides (Varnes, 1978; Abebe, 2010). Due to growing awareness of the socioeconomic impact of landslides and

the increasing pressure of urbanization on the highland environment, landslide research has attracted attention from around the world (Aleott & Chowdhury, 1999).

2.1.3 Landslide in Global Perspective

The term "landslide" refers to any gravity-driven downslope movement of rock and regolith close to the earth's surface with little or no real sliding and causing destruction of property around the world (Reda, Sisay, et al. 2022). Landslides frequently result in the loss of life and substantial property damage inter globally (Lee, 2004). It is triggered by rainfall, earthquake, and volcanic and manmade activity (Günther, Reichenbach, et al. 2008, Choine, O'Connor et al. 2015). Hamza and Raghuvanshi et al. 2017 categorized the external or dynamic variables and intrinsic or inherent factors that cause landslides. It is possible to split the terrain into homogeneous area domains and rank them according to existing or projected landslide susceptibility by studying these causative variables and the nature of prior landslides of the terrain (Erener and Lacasse et al. 2007). When planning, developing, or implementing land use strategies planners, developers, and engineers can use landslide susceptibility maps to provide valuable information Study of landslides is now receiving interest on the globe (Abay, Barbieri, et al. 2019).

2.1.4 Historical Background of landslide hazard and Risk in Ethiopia

Landslide issues are also prevalent in Ethiopia's central, northern, and southern highlands, as well as the neighboring rift valley edges (Yodit, 2005). They cause serious damage to agricultural lands, the environment, and loss of life and property. Various studies have revealed that landslides significantly affect human lives, infrastructure, arable farmland, and the environment (Ayalew,1999). Ethiopia is a developing nation that is particularly susceptible to both natural and man-made threats. These significant occurrences, including floods and landslides, have been hurting communities and destroying property worth millions of dollars over the past several years (Mulugeta, 2019).

2.1.5 Geospatial Technology

Information technology that focuses on the geographic, temporal, and spatial context of data is called geospatial technology. Geospatial data refers to all features displayed on maps or

arranged in a digital database that is connected to the surface of the earth using coordinates, addresses, or other methods. These facts are also referred to as geographic or spatial facts. Global Positioning Systems (GPS), Geographic Information Systems (GIS), and other tools are used to achieve this. The development of GIS was greatly influenced by remotely sensed data. Dealing with the massive amount of data produced by remote sensors required efficient analysis and management, which sped up the development of GIS. Consequently, it should be clear how remote sensing and GIS are related. Noting that either from GPS positions of the satellites themselves or positions of ground points that are in the image, GPS is the most accurate and effective way to relate images to the ground (Bossler, et al, 2005). GIS can handle a wide range of tasks using spatial and attribute data.

2.1.6 Role of GIS and Remote Sensing for Landslide Assessment

Today, GIS is emerging as a powerful tool for risk assessment and natural hazard management. Recent years have seen a rise in the importance of geographic information systems (GIS) and remote sensing (RS) data applications for landslide disaster management (Ercanoglu 2005). By giving information on the primary landslide causative elements, remote sensing data (optical and microwave) can be used to designate landslide susceptibility areas and produce landslide susceptibility maps (Highland and Bobrowsky 2008). The sites of landslides and the selected causative factors in the research area are correlated using analytical hierarchical analysis (AHP) with the aid of GIS. Currently, the GIS is used for environmental protection along highways and railroads, as well as for the assessment and forecasting of geological hazards, urban planning, transportation, and other purposes (Wang, Du et al. 2009). Due to its capacity to provide comprehensive and current geospatial information, remote sensing is increasingly recognized as a key technique for managing natural disasters. Today, remote sensing data (satellite images and aerial photography) are useful for geo-hazard studies (Pathak et al., 2014; Tehrany et al., 2014; Devanthéry et al., 2018). An important step in the process of hazard evaluation is the extraction of pertinent spatial data related to the landslide and its occurrence. It has been demonstrated that RS data combined with a GIS is an effective for processing and producing spatial data. Landslide mapping, identification, monitoring, and hazard assessments are now more effective to improvements in earth observation techniques (Psomiadis et al., 2020). For landslide investigations, remote sensing data is a key source of

information. Satellite imageries with high spatial resolution can be used to extract terrain features, which is a major source of data for the creation of multiple thematic layers and spatial data analysis in GIS. Some of the thematic layers that used for landslide mapping include land use, lithology, slope, lineament density, precipitation distribution, altitude, slope aspect, drainages, and roads (Chau et al., 2004).

2.1.7 Concept of Landslide Hazard and Risk

Even though risk and hazard are frequently used synonymously, they have different meanings. For controlling and safeguarding environmental geo-hazards, it is essential to understand the differences between risk and hazard depending on several variables, including the degree of exposure, the amount of vulnerability, and the efficiency of control measures in place. A hazard is anything that could cause harm and, the risk is a combination of two things the chance that the hazard will cause harm and how serious that harm could be (corominas,mavrouil et al. 2011). Risk is the probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted, or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable/capable conditions. The degree of risk can change and ensure a safe and healthy workplace. Without hazard, there is no risk (Marrapu and Jakka, 2019). Vulnerability is a set of conditions and processes resulting from physical, social, economical and environmental factors which increase the susceptibility of a community to the impact of hazards (Akgun et al.2012).

Risk = Hazard (H) x Vulnerability (V).....equation 2.1

2.2 Conceptual Framework

The criteria that are pertinent to the specific situation under consideration must be identified to produce a landslide hazard and risk map. Risk is a function of hazard and vulnerability parameters, which are derived from elements at risk, according to (Akgun et al. 2012). In this study, hazard and vulnerability at risk were combined to create the study area's risk. This study uses a weighting factor map, which assigns weighting and rankings for each class of each theme, to summarize the hazards and risks associated with landslides. Based on their impact on landslides, each class has been given a weighting and ranking. Using a landslide inventory

map, the influence of each class and each theme has been determined. The weights were created by making several pairwise comparisons of the relative weights of various elements that affect whether or not pixels are appropriate for the activity being evaluated. The analysis of these pairwise comparisons results in a set of weights that add up to one. The more weight a factor has, the more influencing it is. The factors and the weights they produce can be used as input for other MCE modules as well as the MCE module for weighted linear combinations.

2.2.1 Landslide Causative Factors

Landslides are caused by a variety of variables that interact in different ways (Varnes, 1984). There is no established procedure for choosing these elements (Yalcin 2008). In our case, ten factors are considered for landslide hazard evaluation based on the landslide occurrences and their characteristics of an area and published information (Abay and Barbieri, 2012; Meten et al., 2015). These include ten (10) causative factors which are elevation, slope, aspect, rainfall, land use land cover, soil type, lineament, NDVI, distance from rivers (streams), and distance from the road that triggers a landslide. Those factors are discussed in detail below;

I Slope: Slope is very often utilized in susceptibility studies since land sliding is immediately associated with slope perspective. It is the one influential factor that directly affects soil formation, erosion potential, soil water content, and slope stability. The slope instability tendency increases as the slope angle increases, leading to higher shear stress (Shano et al., 2021). Landforms having a higher angle of the slope are usually more susceptible to collapse, which is closely correlated to landslides. The slope gradient is one of the geomorphologic factors that matter for a study of landslide susceptibility because it plays a significant part in gravitational movements. The slope angle regulates the shear forces acting on hill slopes, making it one of the influential factors for landslide modeling. (Chung and Fabbri 2003; Lee 2014; Lepore et al. 2011; Mezughi et al. 2011; Mohammady et al. 2012; Pimiento 2010; Torizin 2011).

II Aspect: Numerous other studies view aspect as a landslide regulating factor (Saha et al., 2005; Yalcin, 2011). A mountain slope's aspect, in general, relates to the direction it faces. The slope's aspect can have a big impact on local meteorological variables like rainfall, which in turn affects the likelihood of landslides occurring. The occurrence of landslides may be

influenced by aspect-related variables such as exposure to sunlight, drying winds, rainfall (degree of saturation), and discontinuities (Dai and Lee, 2002). As a function of aspect, differential solar insolation is related to soil moisture and thickness. Due to variations in temperature and vegetation, aspect is a significant factor in landslide studies and is essential to slope stability (Guzzetti et al. 1999; Lepore et al. 2011; Lee 2014; Mezughi et al. 2011; Mohammady et al. 2012; Pimiento 2010; Yilmaz 2009).

III Distance to lineament: Slope stability is influenced by the distance to the lineament (Lee 2014). The geological structure reduces the strength of the rocks, causing them to weather and erode more quickly. Water will enter the fracture and cause soil movements, especially when it rains. By causing the slopes to erode or by sopping up the lowest portion of the material, proximity to lineament streams might compromise the stability of the slope (Dai et al., 2001). The majority of the recorded landslides have happened near streams or rivers that have been eroded by gullies. Drainage transports water, which induces material saturation, culminating in landslides in valleys (Shahabi and Hashim, 2015).

IV Elevation: Another key aspect that is taken into account by many researchers when determining landslide risk is the elevation (Dai et al., 2002; Yalcin et al., 2011; Dou et al., 2015). There may be a connection between elevation fluctuation and several environmental factors like vegetation and rainfall (Catani, Lagomarsino, et al. 2013). Elevation has an impact on the geomorphological and geological processes (Raja et al., 2017). It affects both the distribution of vegetation and topographic features, which support spatial differences in numerous landform processes. Elevation has a significant impact on climate, which includes rainfall quantity, intensity, and distribution (Catani, Lagomarsino, et al. 2013).

V Land Use land cover: One of the key factors affecting slope stability is land use land cover. The degree of variation in vegetation cover affects how likely the slope will fail. Through its roots, which bind soil sediments, vegetation improves the cohesion and strength of the soil. Lack of vegetation on the soil surface makes the slope more prone to failure, especially during heavy rainstorms that cause surface runoff (Fell et al. 2008; Lepore et al. 2011).

VI Distance to the river: In general, the potential of landslides increases with a reduction in the distance to rivers because the river could wash away the slopes or saturate the bottom

portion of the material, raising water levels that may be unstable. "In areas with steep slopes, drainage networks create valleys, creating susceptible sites for mass movements. The rough material on the surface is ruptured as water moves through space. The water is drawn into the fine-grained material by the lateral pressure. This penetration could lead to the process as a whole crashing. The shear force of a material decreases as the proportion of water in it increases (Segoni et al., 2020).

VII Normalized vegetation index: In landslide susceptibility assessment research, the vegetation index is also regarded as a determining element (Tseng et al., 2015). NDVI is used to reflect vegetation density. Understanding the amount of vegetation cover is crucial for interpreting the NDVI to determine the strength of the slope and the likelihood of landslides. The NDVI value illustrates the deterrent effect of landslide occurrence (Huang et al., 2020).

VIII Rainfall intensity: Rainfall becomes one of the factors influencing ground motion because it raises the pore pressure and soil moisture levels on the slope, which leads to a reduction in the forces that keep the slope stable. Significant temporal and geographic variations in rainfall quantity and intensity result from changes in rainfall characteristics caused by climatic conditions and geographic characteristics. This has the potential to cause landslides to start in both large and specific smaller areas (Fell et al. 2008).

IX soil type: According to several studies (Das 2011; Fell et al. 2008; Mezughi et al. 2011; Rossi and Reichenbach 2016), the particle size, shape, and pore distribution of the soil matrix affect slope stability. Water infiltration, interflow, base flow rates, and the soil's ability to hold water are all influenced by the properties of the soil. According to (Lepore et al. 2011), soils with smaller (finer-textured) particles, like clay and silt, have a larger surface area than soils with coarser textures and tend to hold large amounts of water. Cohesion, permeability, and other factors are significant in both the bedrock and the soil cover. Rock and soil will both become weaker as pore pressures rise (Fell et al. 2008).

X Topographic wetness index: An important configuring factor is how topography affects the distribution and quantity of saturated runoff source areas (Pourghasemi et al., 2012). TWI calculates a location's soil moisture distribution and the total amount of accumulated water. Higher TWI values may indicate a greater potential for landslides.

XI Distance to roads: Roads are a significant man-made factor influencing the occurrence of landslides due to road construction and clear-cutting activities (Dunning et al., 2009).

2.2.2 The AHP Model

A set of mathematical tools and techniques called multi-criteria analysis allows the assessment of various alternatives based on a wide range of criteria (Chakhar and Mousseau, 2008). The AHP Model as developed by (Marrapu and Jakka 2014), is a tool for making difficult judgments and includes multiple criteria. It is a multi-criteria decision-making process that is very well-liked and has a wide range of applications, including site selection and appropriateness analysis (Abay, Barbieri, et al. 2019) regional planning (Jankowski, 1989), urban land use planning (Chau, Sze et al. 2004)), and environmental impact assessment (Kiker, Bridges et al. 2005), and design and engineering (Abay, Barbieri et al. 2019). One of its wide applicability in recent years is in the field of landslide study. Several landslide studies have been published using the AHP approach (Ayalew, Yamagishi, et al. 2004); (Abay, Barbieri, et al. 2019). The analytical hierarchy process (AHP), weighted linear combination (WLC), and spatial multi-criteria evaluation (SMCE) methodologies were used to conduct a land-slide susceptibility analysis (Shahabi and Hashim 2015).

2.2.3 Multi-Criteria Analysis

MCDA is a collection of methods (such as weighted summing or concordance analysis) that allow a variety of issue-related criteria to be scored, weighted, and then prioritized by experts, interest groups, and stakeholders to locate or situate a certain facility or service (Malczewski, 2004). The application of multi-criteria analysis and integration with spatial data allows for the description of the causal variables behind a given phenomenon (Russo and Camanho 2015, Darko, Chan, et al. 2019).

2.2.4 Pairwise Comparison Method

Satty (1980) developed the pairwise comparison approach for calculating factor weights in the Analytic Hierarchy Process (AHP). Pairwise comparison is used in this technique to produce a ratio matrix. It outputs the relative weights after receiving the pairwise comparisons as input. The weights are established by normalizing the eigenvector of the reciprocal ratio

matrix that is connected with its greatest eigenvalue (Malczewski-1999). The method uses a scale with values ranging from 1-9 to rate the relative preferences for criteria.

2.2.5 Landslide inventory

Many landslide hazard zonation and appraisal studies begin with a landslide inventory. In 2019 (Sendu Demise and Raghuvanshi et al.), it is simple to utilize landslide inventories to identify areas influenced by landslide processes based on their location, size, and type and material characteristics. According to (Tenalem Ayenew & Barbieri, 2005; Fall et al 2004) only the susceptibility to landslides in places where landslides have been documented is shown by the landslide inventory. It might, however, prevent us from being able to see the probable landslide area. Despite these drawbacks, landslide inventory is the most fundamental and straightforward approach to assessing the landslide hazard because it acts as the primary data source for understanding the factors that contribute to landslide occurrence, and when conducting field terrain assessments, it serves as a base map alongside a facet map (Casagli et al., 2004). The most crucial data layer is the landslide inventory map, which details the places where landslides have occurred. According to Corominas and Mavrouli (2011), it is important to keep track of each landslide's type, activity level and (if possible) the date it occurred and the damage it caused. "The past is the key to the future" (Michael and Samanta, 2016) is based on the rudimentary analysis and recording of landslides known as landslide inventories. The most crucial source of data for the quantitative and qualitative zoning of landslide susceptibility, hazard, and risk is a landslide inventory. It should provide information about the location, time, style, size, activity, and causes of landslides, as well as the damage they cause. In Kindo Didaye, there is so many past landslide inventories area. Some of the events in landslide inventories-prone areas were collected via field observation and are shown in the appendix-v.

2.2.6 Purpose of Landslide Zoning Map

(Awange and Kiema, 2013) state that there are two ways to monitor landslides: by comparing and analyzing different spatial maps and images, such as topographic maps, aerial photographs, remotely sensed imagery, cadastral maps, and digital elevation maps, which represent instantaneous views of an unstable site on different time epochs; and by performing

in-situ measurements of the surface displacements by combining a space and time resolution suited to the evolution (Corominas and Mavrouli, 2011).

2.2.7 Landslide inventory map

Landslide inventory maps are used for susceptibility zoning or as information for policymakers and the general public (Barbieri, 2005).

2.2.8 Landslide hazard zoning map

A landslide hazard zoning map can be used as information, advice, or legislation to regulate development in threatened areas, and it represents the most effective and cost-effective method of preventing further harm and fatalities. These maps also offer the right decision-making component for evaluating whether the development is feasible with or without stabilization or protection countermeasures (Michael and Samanta, 2016).

2.2.9 Elements at risk map

Elements at risk map are used to create the consequence scenarios map, which, when combined with the landslide susceptibility zoning map, can serve as guidance and information for public officials and policymakers. A consequence scenario map that identifies the areas that need quantitative risk assessment (QRA) may be used as guidance and information. This map uses quantitative methods to show each element the potential outcomes associated with its vulnerability and a particular landslide hazard; in such a situation, it may be used as informational, advisory, or statutory material (Sendu Demise and Raghuvanshi et al.).

2.2.10 Landslide risk zoning map

Landslide risk zoning map may be used as a legal basis to implement alert systems designed to safeguard human life. Additionally, it offers a global perspective of the anticipated yearly harm to the elements at risk from the landslide hazard. Based on a cost-benefit analysis, control or stabilization works can be identified and designed for the reduction of the risk of landslides (Fall et al. 2004).

2.3 Empirical literature review

A researcher must choose the technique that best fits the suggested methodology in the beginning. The choice of an appropriate method for data analysis may be based on some factors that can change from study to study. This research can be supported by the development of an empirical framework in three different ways: first, as a global, second, as continental, and third, as local empirical data based on research that is related to this study.

2.3.1 Global Experience

This empirical data is made up of globally applicable studies on landslide susceptibility, hazard, and risk that used geospatial technology like GIS, RS, and GPS with various methods and quality-of-data requirements.

According to (Shahabi, Ahmad, et al. 2012), the landslides hazard and risk map shows the distribution of landslides in the Zab basin in Turkey using geological maps and field research. Following that, the eight factors lithology, slope, slope aspect, yearly rainfall, land use, distance to a canal, distance to the fault, and road distance were researched and defined using other information sources, such as the current thematic map can have an impact on the landslide's incidence. All descriptive and spatial data were incorporated into the GIS system to increase analytical accuracy, speed, and facility. Additionally, their model provides suggestions for the important variables driving slope instability.

According to (Acharya, De Smedt, et al. 2006), the LSZ map shows the number of observed landslides and the regions with low, moderate, high, and extremely high landslide susceptibility zones.

According to (Begum, Islam, et al. 2020) researchers at the University of Aberdeen in Scotland, several elements, such as height, slope angle, slope aspect, rainfall, and land use and land cover, might cause landslides based on the application of GIS and Remote Sensing techniques. According to research done by the Scottish Geological Survey, rain is the primary cause of landslides.

Landslide hazard zone mapping has been done for a long time using a variety of methods and approaches in different parts of the world. For mapping landslide hazard zones, several

methods and procedures have been developed. They include statistical analysis, multi-criteria decision-making, probabilistic evaluation, deterministic approach, landslide inventory mapping, heuristic approach, and statistical analysis (Leroi, 1997; Fall et al., 2006). However, the superiority of one approach over another is dependent on some variables, including the size of the study area, the precision of the predicted results, the accessibility of data, and the parameters examined (Fall et al., 2006).

One of the easiest qualitative methods for mapping landslide hazards is inventory analysis. According to Dai and Lee, 2001; Dai et al., 2002; Fall et al., (2006) landslide inventory mapping is the identification and compilation of details of each landslide. Therefore, data about landslide patterns, location, amplitude, forms of mass movement, and other information may be gathered during inventory analysis. Thus, information is gathered by field research utilizing GPS, historical records or witness interviews, interpretation of satellite images, Google Earth, and aerial photograph. But according to Guzzetti et al. (2000), slope failure induced by a single incident or the cumulative effect of numerous events over a long period of time is depicted on landslide inventory maps. In landslide studies and landslide risk management, landslide hazard maps are essential tools. However, the accuracy of landslide analysis is influenced by the level of detail and quality of the landslide inventory map. By creating a link between geomorphological landslide maps and multi-temporal data, (Galli et al.2008) compared landslide inventory maps created for various parts of Italy. The findings indicate that the comprehensive landslip inventory map is very helpful for landslide analysis. Using universal frequency-area statistics (Guzzetti et al. 2003) compared three landslide inventories. The findings show that the frequency of landslides increased proportionally as the landslide area increased and dropped proportionally as the landslide area decreased. They talked about how crucial it is for landslide investigations that the inventory maps are thorough and clear. Due to the removal of landslide evidence by erosion, agriculture, or other factors, the landslide inventory map becomes incomplete during field-based data gathering. For a thorough mapping of the landslide inventory, historical data and witness interviews are therefore more important (Guzzetti et al., 2003).

To provide more objective and reproducible results and reduce subjectivity in the weightage assignment process techniques toward landslide hazard zonation have been, changed from

heuristic to statistical approach (Kanungo et al., 2009). The statistical approach, as described by (Dai, Lee et al. 2001), places focus on determining the relationship between previous landslides and the causal element. Different causal factors have been studied using univariate or multivariate statistical methods in statistical approaches (Fall et al., 2006; Dai and Lee, 2001). In contrast, the limitation of the statistical approach is the collection of data on landslide distribution and causative factors over large areas for a considerably prolonged period (Gram et al., 2015), and the outcome is dependent on the quality of the data and specifics of the landslide frequency data (Fall et al., 2006).

Bivariate and multivariate statistical analyses are the two types of statistical approaches used in the zonation of landslide hazards. Each layer of causal data for the zonation of landslide hazards has been assembled using this methodology. Its major goal is to calculate data weights based on class distribution and landslide density and to identify the density of landslide occurrences within each causative factor data layer and parameter of data layer classes (Suzen and Doyuran, 2004). However, the density of the landslides was used to determine the weight of the landslide causative component. The weights of the Evidence Model, Weighted Overlay Model, Frequency Analysis Approach, Information Value Model (IVM), and Fuzzy Logic method are the main bivariate statistical models used in landslide hazard mapping (Piacentini et al. 2012; Parise 2002; Lee and Pradhan 2006; Sarkar et al., 2006; Chung and Fabbri. 1998, 1999). A type of statistics known as multivariate statistics includes additional variables. Additionally, it is important to comprehend the purpose and history of various forms of multivariate statistical analysis as well as how they relate to one another (H. Shahabi et al. 2012). For the mapping of landslide hazard zones, multiple variate statistical analysis methods such as the logistic regression model, discriminant analysis, multiple regression models, conditional analysis, and artificial neural networks (ANN) are frequently used (Tolga et al., 2005; Guzzetti et al., 2005b; Clerici et al., 2002; Chang and Liu, 2004).

A technique that can pinpoint the location, timing, and severity of a landslide event is the probabilistic approach. According to (Guzzetti et al. 2005), a probabilistic technique has been used to determine the geographical, temporal, and magnitude probabilities of landslides. Using a frequency area distribution function, they calculated the likelihood of the size, timing, and

location of landslides. Nevertheless, a quantitative assessment of the landslide threat along a transit route in the Nilgiri Hills of India was done by Jaiswal et al. in 2010. To determine the probability of landslide magnitude for various return periods, they used frequency-volume statistics. In recent years, several studies (Ghosh 2011; Floris and Bozzano 2008; Das 2011; Jaiswal and Van Westen 2013; Guzzetti et al. 2006; Polemio and Sdao 1999; Chelboard et al., 2006) have attempted to apply the probabilistic technique for quantifying landslide hazard zonation.

2.3.2. Local experience: Researchers in Ethiopia have assessed landslide susceptibility and hazard using geospatial tools including GIS, RS, and GPS.

According to (Demessie and 2019), an integrated GIS-based Grid overlay statistical technique is used to study the area's landslide evaluation and zoning. Six causal factors were taken into account for landslide hazard zonation (LHZ): slope material, slope, aspect, elevation, land use/land cover, and groundwater-surface traces. These causal elements were discovered by field research, secondary maps, digital elevation models, and topographical sheets. Through overlay analysis, a quantifiable association between these contributing components and the region's historical landslides was established, and the LSI (Landslide susceptibility index) was calculated. Additionally, geo-processing was carried out in a GIS environment by overlaying a polygon grid (10x10 m) over each factor map.

According to (Mengistu, 2019), utilizing a bivariate statistical information value model, create a landslide hazard zonation (LHZ) map and use an INSAR technique to gauge local slope instability. Six criteria were taken into consideration for LHZ: slope, land use/land cover, slope material, elevation, aspect, and Normalized Difference Vegetation Index (NDVI). Weights were derived from the information value model for the subclasses of these causal components.

According to (Mulatu, 2009), an effort has been made to offer details on the areas along the new route that are prone to landslides. The landslide hazard evaluation factor rating scheme (LHEF) has been used to define the risky zones. The LHEF rating scheme is based on an empirical methodology that integrates prior knowledge from the investigation of the causes of landslides and their effects with conditions anticipated in the research region. Data on the

main intrinsic causes of slope instability, including geology, slope morphometric, relative relief, land use and land cover, and groundwater conditions, have been gathered for the LHEF rating method.

According to (Sisay et al. 2022), it is possible to evaluate landslide danger zonation by combining GIS and remote sensing methods.

After reviewing different literature, it is evident that the GIS-based multi-criteria analysis along with the AHP method plays a vital role in landslide-prone area delineation and landslide risk analysis. For the present study, a Multi-criteria evaluation method was used to prepare a landslide hazard and risk map of the study area. Because the variety of alternatives can be evaluated using a wide range of criteria due to the set of mathematical tools and procedures it contains (Chakhar and Mousseau, 2008). Experts, interest groups, and stakeholders can use a range of issue-related criteria to score, weigh, and then prioritize a facility or service by using MCDA, a collection of techniques such as weighted summation or concordance analysis (Malczewski, 2004). One of the primary decision-making issues is multi-criteria decision-making (MCDM), which seeks to identify the optimal alternative by taking into account multiple factors. An MCDA is carried out to identify the best possibilities, improving the effectiveness of the decision-making process. Along with offering a prioritized list of options, it also addresses the social aspects of decision-making to promote discussion among various decision-makers (Chakhar and Mousseau, 2008).

CHAPTER III: MATERIALS AND METHODS

3.1 Description of the study area

In Ethiopia's Southern Nations Nationalities and Peoples Regional State (SNNPRS), Wolaita is one of the administrative zones in the region. It is named for the Wolayta people, whose homeland is in the zone. Wolayita is bordered on the south by Gamo Gofa, on the west by the Omo River which separates it from Dawro, on the northwest by Kembata Tembaro, on the north by Hadiya, on the northeast by the Oromia Region, on the east by the Bilate River which separates it from Sidama Region, and on the southeast by the Lake Abaya which separates it from Oromia Region. The administrative center of Wolayita is Sodo. Other major towns are Areka, Boditi, Tebela, Bele, Gesuba, Gununo, Bedessa and Dimtu. Wolayta, one of Ethiopia's 16 Zonal Administrations, is located around 300 kilometers (190 miles) south of Addis Abeba. Wolayta is bounded by Tambaro to the northwest, the Bilate River to the east, which separates it from the Arsi-Oromo, Lake Abaya, the Kucha to the south, and the Omo River to the west.

Kindo Didaye woreda (district) is a part of the Wolaita zone. The woreda is located north of the equator between latitudes 6°40'11.48" and 6°51'54.18"N and longitudes 37°13'26.89" and 37°29'27.97"E. It is bordered by the Loma Bosa woreda of the Dawaro zone to the north and west, the Kindo Koysha woreda to the north and east, the Kucha woreda of the Gamo Gofa zone to the south, and the south-east to the east bay of a woreda. With a total area of 271.69 km², the elevation of woreda ranges from 648 to 2489 meters above mean sea level. Its 92.69 km land border is shared by the Loma Bosa woreda, which is 34.02 km (36.70%) of the Dawaro zone, Kindo Koysha woreda, which is 18.70 km (20.17%), Kucha woreda, which is 20.41 km (22.01%) of the Gamo Gofa zone, and Ofa woreda, which is 19.54 km or 21.08% (zerihun, 2007). The district has been divided into 10 kebeles for administrative purposes. Figure (3.1) show the location of the study area.

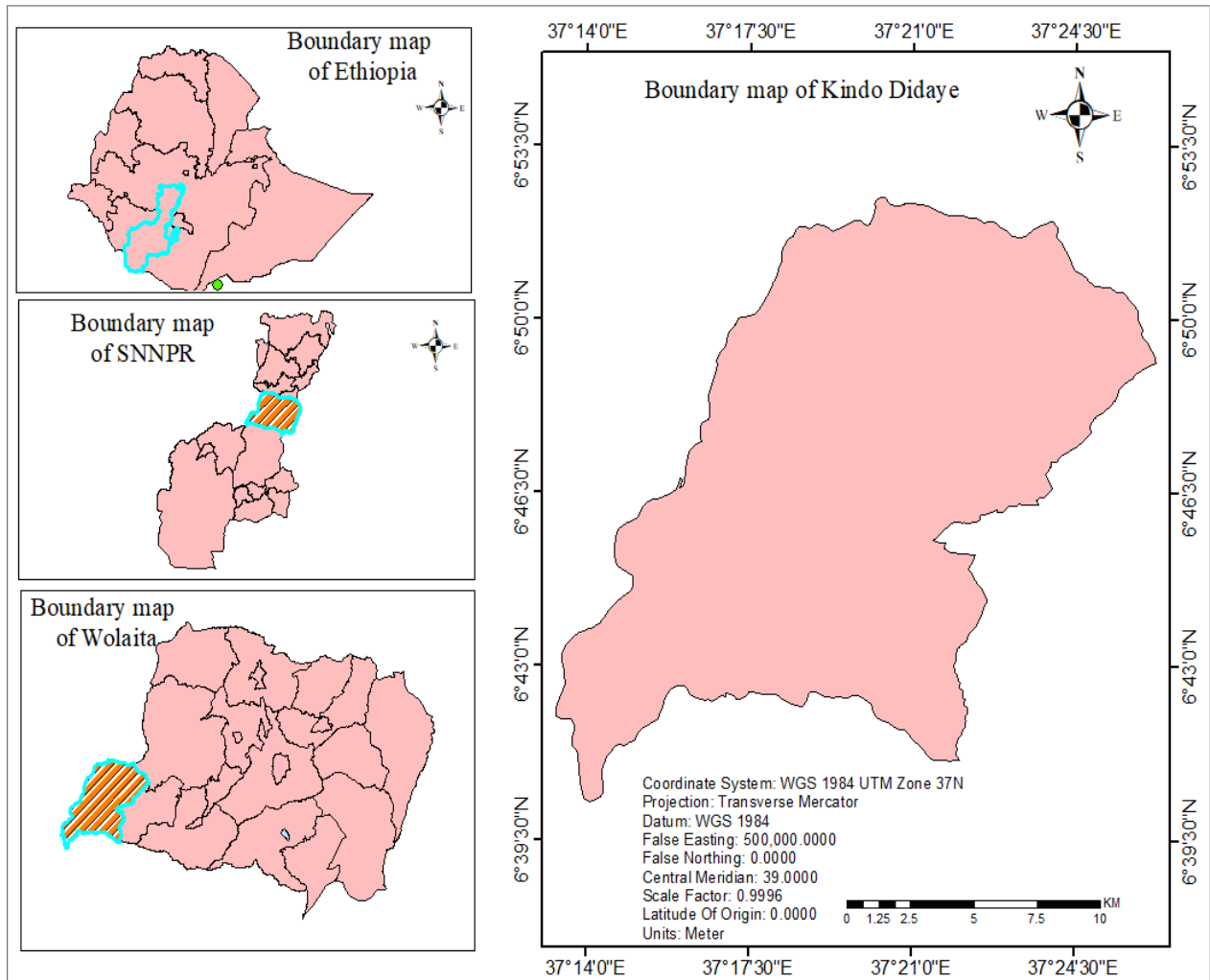


Figure 3.1 Location map of the study area

3.1.1. Climate of the study area

The temperature of the current study area during the daytime is between 24 to 30 °C and at night time between 16 to 20 °C. Between 1995 and 2015, the research area's monthly average temperature was 21 °C (Barana Babiso, 2017).

3.1.2. Vegetation of study area

The majority of the ridges in the research region are covered with plants, which include strewn shrubs, wild grass, and some trees. The foot of the mountain is covered in a variety of crops and vegetables, while the steeper areas are sparsely vegetated. The gorges and river sides are very heavily vegetated. Sorghum, maize, teff, enset, mango, banana, casaba, and vegetables are the area's main crops (Niguse, 2017)

3.1.3. Soil of study area

The research area's soil is a dark red tint that turns brown and black during rainstorms and has the brittleness and softness of sand. One of the reasons people can only plow and dig after the rains is that the dry season makes the soil as hard as a brick. Only on the riverbanks, where the soil is soft and easy to dig in, can one scarcely discover any stone. The depth of the soil layer, varies for both the plains and the hills, was confirmed through well drilling. When there are regular rains, the land is exceptionally productive and yields crops every year (Haleluya tesfaye, 2020).

3.1.4 Topography

The district has a diverse topography, with an altitude that varies between 654 and 2488 meters above sea level (M.S.L). The main agro-climatic zones of the region are lowland, mid-highland, and highland. Households in the district own fragmented agricultural land; and mixed farming is the main livelihood activity. The farming season is dependent on the summer ('Kiremt') rains that start in June and last until September and the main hunger season is from February to June (Zerihun dawit, 2016).

3.1.5 Demographics

According to the Kindo Didaye Woreda administration office report, Woreda has a total population of 136,631, of whom 68,795 are men and 62,511 are women; 1,427 or 1.46% of its population is urban dwellers. The majority of the inhabitants were Protestants, with 70.65% of the population reporting that belief, 19.08% practiced Ethiopian Orthodox Christianity, and 6.07% practiced traditional beliefs (Source: Kindo Didaye woreda administration office).

3.2 Data Collection and Data Sources

Here it needs the following major data that have to be collected and used in the process of the analysis. The data used for the current study are listed in the following tables(3.1).

Table 3.1 Data used for the study

No	Data	Source	Data type	Purpose
1	ALOS PALSAR DEM(12.5m)	https://asf.alaska.edu/data	Tiff	For extraction of DEM, aspect, and slope
2	Sentinel 2A (10m)	https://scihub.copernicus.eu/dhus/	Tiff	To classify land use land cover and NDVI
3	Soil data	Ministry of agriculture	Shapefile	To determine the soil type
4	Rainfall data	National meteorology agency	Tabular	To predicate the amount of rainfall
5	Population data	Kindo Didaye woreda admistration office	Tabular	To make population density map of study area
6	Roads	Wolaita Zone Transport & Rural Road Development Department	Shapefile	To make distance to a road map
7	River	Wolaita Zone Water Resource and Energy Department	Shapefile	To make distance to the river map
8	Lithology	Geological Survey of Ethiopia (GSE)	Shapefile	To make lithology map

Table 3.2 Software used for the study

No	Software	Source	Purpose
1	ArcGIS (10.8)	https://www.arcgis.org/en/site/forusers/download.html	Database creation and preparation of thematic layers, integration and management of spatial information, weighted overlay analysis.
2	ENVI	https://en.freownloadm	For classification of land use land cover

	(5.4)	anager.org//ENVI.html	
3	IDRISI-32	Https://idrisi32.software.informer.com/	Eigenvector computation for the selected factor
4	Google Earth	Https://www.wizcase.com/download/google-earth/	Used for visual interpretation tools for LULC classification
5	Handheld GPS	Kindo Didaye Woreda municipality	To collect origin and destination coordinate
6	Microsoft Word and Excel 2016	Https://softfamous.com/microsoft-office-2016/	Integrating attribute data and writing the report

3.3 Methods of data preparation and Analysis

3.3.1 Data collection

The first step in producing a landslide hazard and landslide risk map depends on obtaining suitable data on DEM, satellite image, population, soil, and road. To achieve the objectives, the study used different primary and secondary data. The study used GPS field data as primary data. The secondary data, like a satellite image, DEM, the boundary of the study area, metrology data, topographic map, and soil data were collected from the relevant sources.

3.3.2 Identification of major landslide triggering factor

The major criteria for landslide hazard and landslide were identified through a literature review and expert consultation. A personal discussion was carried out with Different professionals to identify which parameter has a major impact on landslide causing. Afterward, based on their idea, literature review, nature of study area, and researcher knowledge the major influential factors were included for analysis.

3.3.3 preparation of factor map

A. Preparation of Land use Land cover dataset: The Sentinel 2A images of 10m resolution were downloaded and layer stacked in ENVI software using four bands, and the image sub-setting was handled by the shape file for the study area. To improve image appearance, radiometric enhancement techniques like haze reduction and atmospheric noise reduction were used. A dataset with 8, 4, 3, and 2 NIR, Red, Green, and Blue bands, respectively were created for the study area's land use and cover classification.

B. Preparation of Soil dataset: Datasets on soil were obtained from Ethiopia's Ministry of Agriculture and digitized in ArcGIS environment according to the boundary shapefile of the current study area. The soil class, which encapsulates the type of soil in terms of texture, was the most pertinent attribute for determining information about soil texture. To prepare this dataset for analysis, vector datasets of the study area's soil were converted to raster datasets.

C. Preparation of DEM datasets: The ALOS PALSAR DEM (12.5*12.5-resolution) image of the study area and its surroundings was downloaded. Digital elevation models (DEMs) of the study area were extracted in an ArcGIS environment according to the boundary shapefile for the preparation of DEM datasets.

D. Preparation of Slope dataset: The slope datasets were produced using a digital elevation model of the surrounding area. Digital elevation models were processed using the arc toolbox in a GIS environment to create slope datasets and reclassified for further analysis

E. Preparation of Aspect dataset: From the area's digital elevation model, aspect datasets were created. A GIS environment's arc toolbox was used to process the aspect of the current study area. The aspect datasets were generated, and they were then ready for reclassification and additional analysis.

F. Preparation of Lineament density datasets: Line feature lineament datasets were used to create lineament density datasets in the ArcGIS environment using DEM. Lineament is a linear surface in a landscape and generally associated with faults, linear fault zones, bending deformation and increased permeability of the earth's crust. Lineament is also associated with

linear chains of several geological features. A GIS environment's arc toolbox was used to process the lineament density map of the current study area using DEM data.

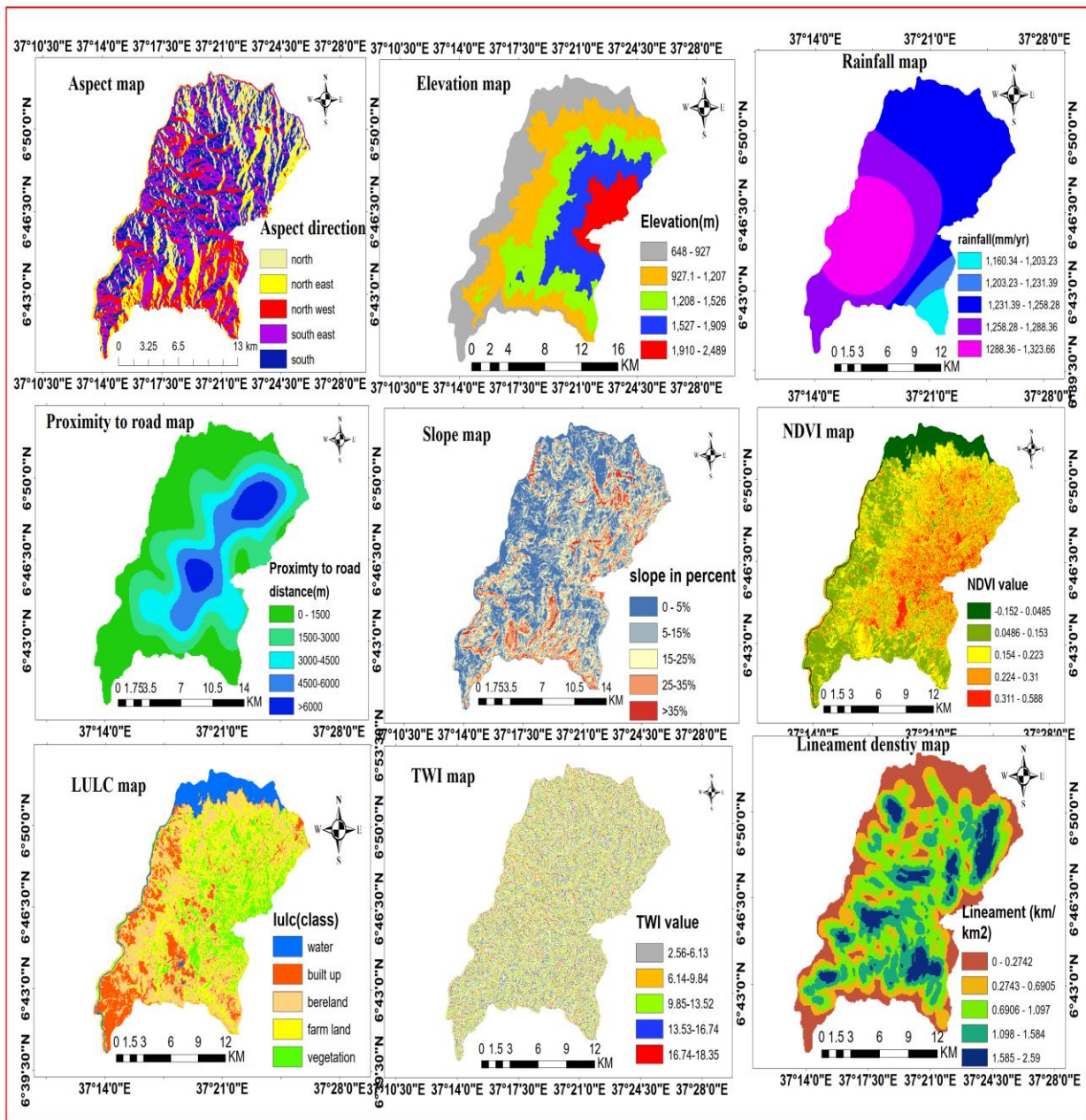


Figure 3.2 preparation of factor map used for the current study

3.3.4 Data analysis method

The landslide phenomenon, as well as its causes and triggering factors, can be studied and evaluated using a variety of methodologies. Several different factors determine slope stability,

many of which interact intricately (Varnes, 1984). Any landslide hazard and risk analysis must include the selection of conditioning factors and the creation of corresponding thematic data layers. In this study, all datasets were converted into the same projection system, and the Universal Transverse Mercator (UTM) projection was used for all the data sets before the factor datasets were created from the raw data. The datasets were stored in a personal geodatabase with UTM zone 37 as the common grid zone. The landslide hazard map was created using these causative elements together with lineament density, elevation, slope, land use land cover, rainfall intensity, soil type, topographic wetness index, and distance to the river, lithology, and NDVI. The landslide risk map was created using the generated landslide hazard map along with population density, land use land cover and proximity road. A land use and land cover map was made using a sentinel-2 satellite image. Weighted overlay analysis for each variable using Satty's Analytic Hierarchy Technique, which generates a pair-wise comparison matrix for each map based on a nine-point relevance scale. Engine vectors, which were produced by pair-wise comparisons, were used to calculate the weights for each factor. To calculate the weight, IDRIS Selva 32 was used to calculate engine vectors. Each factor's weight indicates how much of an impact it has on the likelihood of a landslide. An easy-to-use program called IDRIS can quickly determine weights. Additionally, it determines whether the supplied pair-wise weights are appropriate or whether a different configuration is needed by calculating a consistency ratio. By analyzing and utilizing a multi-criteria approach and geospatial-based technologies, landslide hazard and risk maps were produced in the GIS environment and remote sensing data. Figure 3.3 show the procedure for the current study.

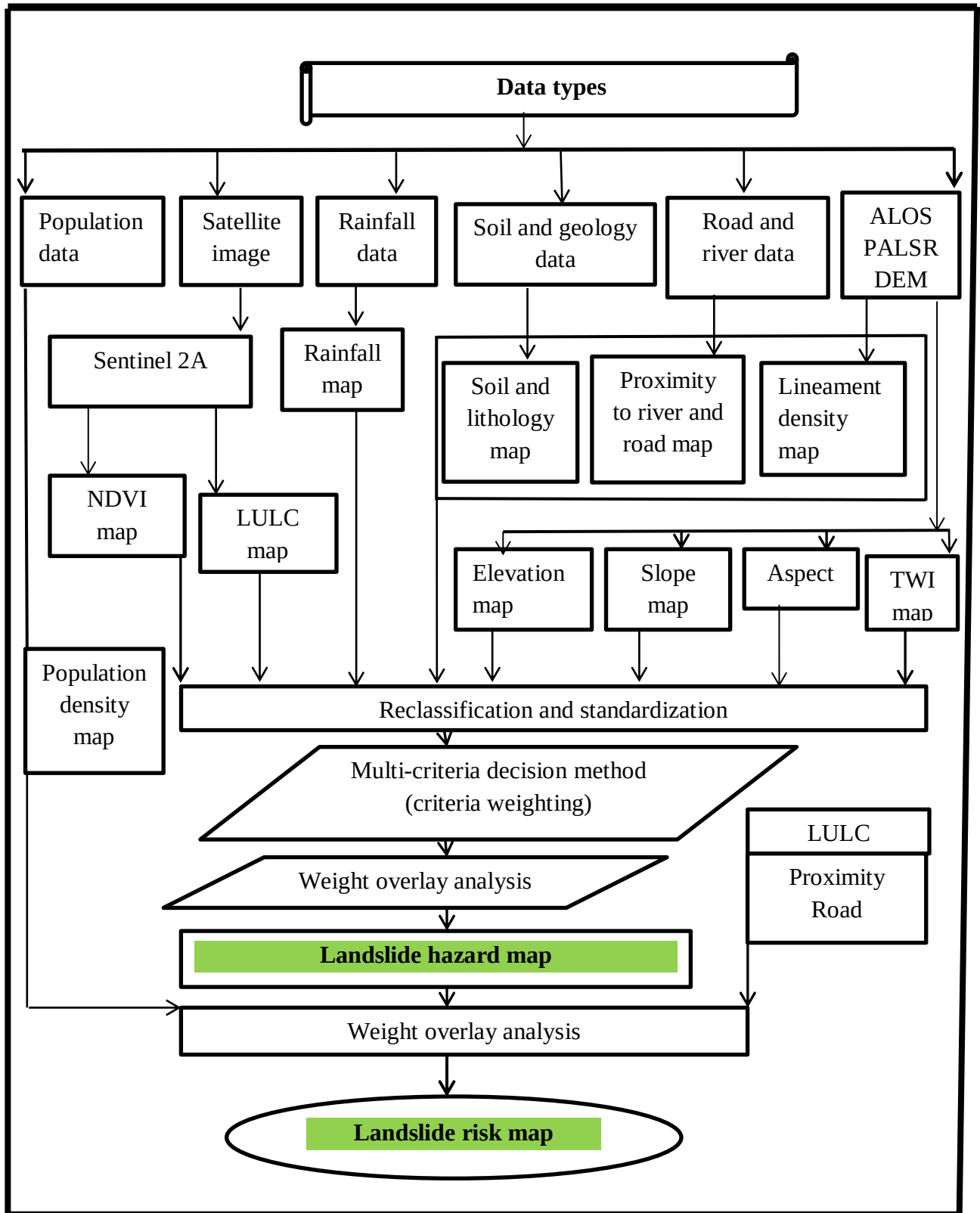


Fig 3.3 Technical scheme of study

CHAPTER IV: RESULTS AND DISCUSSIONS

4.1 Introduction

The main objective of this study is to create a Kindo Didaye woreda landslide hazard and risk map. Ten causal factors were selected for the study area to create this map after examining various types of relevant literature, doing personal observation, and consulting with others. The selected parameters were population density, distance from the river, aspect, NDVI, soil type, topographic wetness index, drainage density, elevation, slope, land use, and land cover. In a GIS environment, all of these datasets were standardized and structured. A personal geo-database was used to hold all of the datasets, and UTM zone 37 served as its common geographical reference. From these causative factors, drainage density, elevation, slope, land use land cover, rainfall intensity, soil type, topographic wetness index, distance from the river, lithology, and NDVI were used to generate the landslide hazard map. Population density, land use land cover, and the generated landslide hazard map is used to prepare the landslide risk map. Using a sentinel-2 satellite image, a land use and land cover map was created. Satty's Analytic Hierarchy Technique, which creates a pair-wise comparison matrix for each map based on a nine-point relevance scale, was used to allocate weighted overlay analysis for each variable (table 4.10). Weights for each factor were determined using engine vectors that were created via pair-wise comparisons. Engine vector calculations were performed using IDRIS Selva 32 to determine the weight. The weight of each factor shows how much the factor plays a role in landslide hazard occurrence. IDRIS software is an intuitive program that can calculate weights in a moment. Also, it calculates a consistency ratio that shows if the supplied pair-wise weights are appropriate or whether an alternative configuration is required.

4.2 Landslide hazard causative factor development

The most relevant landslide causative factors should be chosen to create a map of landslide risk and hazard for the study region. According to (Njoku et al., 2018), although it might be challenging to get a consensus on the variables that should be included in landslide risk assessments, some significant variables are crucial in landslide risk mapping. Since it provides a structured technique for assessing and combining the effects of numerous variables, involving several levels of dependent, qualitative, and quantitative knowledge, authors have

employed the multi-criteria methodology over time (Njoku et al., 2018). The landslide hazard factors for this study were generally selected based on their theoretical applicability to landslide risks as described in the literature. Based on the use of GIS and Remote Sensing techniques, (Begum, Islam, et al. 2020) examined how several factors, such as height, slope angle, slope aspect, rainfall, land use, and land cover, influence result in landslides. (Red, Sisay et al. 2022) assessed landslide threat zonation using remote sensing and GIS techniques. The factors that they used on landslide hazard and risk zonation are elevation, slope, aspect, drainage density, land-use land cover, and Normalized Difference Vegetation Index (NDVI). (Demessie and Raghuvanshi 2019) Use a combined statistical method based on a grid overlay and GIS to assess and zone the research region for landslides. Six cause factors were taken into account for landslide hazard zonation (LHZ): slope-material, slope, aspect, elevation, land use/land cover, and groundwater-surface traces. Furthermore, a comparison of the parameters used by different authors reveals that the geospatial datasets used are similar. Thus, independent variables such as distance from the river, rainfall, elevation, land use/land cover, slope, population density, topographic wetness index, lineament density, soil type, lithology, and NDVI were taken into account for this study. These are:

4.2.1 Lineament Density

Lineament is simple or composite linear surface features whose parts are aligned in a straight or slightly curved pattern and differ significantly from the pattern of adjacent features and reflect a subsurface phenomenon. Lineament can be interpreted as such linearly oriented fracture-controlled zones. As a result, a lineament with an open fracture allows more water to infiltrate, raising pore water pressure and triggering slides along weaker zones. As a result, landslides are more likely in fractured, faulted, and jointed zones (Anbazhagan et al., 2014). However, the probability of landslides occurring is higher in highly fractured areas than in areas with a lower fracture density. Lineament has structurally controlled linear or curvilinear features, which are identified from satellite imagery by their relatively linear alignments. These features express the surface topography of the underlying structural features. Lineaments represent the zones of faulting and fracturing. Lineament density, on the other hand, is used in landslide hazard assessment (Atkinson and Massari, 1998).

Based on the Lineament density, the area was divided into five category zone very low density (less than 0.2336 km/km²), Low Density (0.2337-0.5991km/km²), moderate density (0.5992-1.483 km/km²), high density (1.484-1.838 km/km²) and very high density (greater than 1.839/km²).

Table 4.1 Reclassification of Lineament Density of the Kindo Didaye

Lineament density(km/km²)	Ranking	Area in sq. Km	Percentage of area	Level of landslide
0-0.2336	1	152.82	56.24	Very low
0.2337-0.5991	2	58.67	21.59	Low
0.5992-1.483	3	33.47	12.32	Moderate
1.484-1.838	4	17.16	6.33	High
>1.839	5	9.25	3.49	Very high
Total		271.66	100	

Source: computation from GIS

According to Table 4.1, the majority parts of the study area were almost characterized by very low lineament density. Very low lineament density of the area was distributed in almost all parts of the area, but more dominate in northern and central parts of the area. Its lineament density is less than 0.2742 km/km² and covers 56.24% of the total study area. This demonstrates that a large portion of the area has a very low lineament density. The second dominant lineament density is low-level lineament density, accounting for 21.95% of the total area. It was mostly found in the study area's northwestern and southwestern corners. The third dominant lineament density in the area is moderate-level lineament density, with values ranging from 0.6906 km/km² to 1.097 km/km². It was mostly found in the study area's northern and central regions. In addition, high-level lineament density covers 6.33% of the total area. It was mostly found in the north and south of the region. It ranges between 1.098 km/km² and 1.584 km/km². Finally, the very high-level lineament density value was greater than 1.585 km/km² and cover 3.49% of the total area, and was mainly located in the northern and central parts of the study area (refer to Figure 4.1).

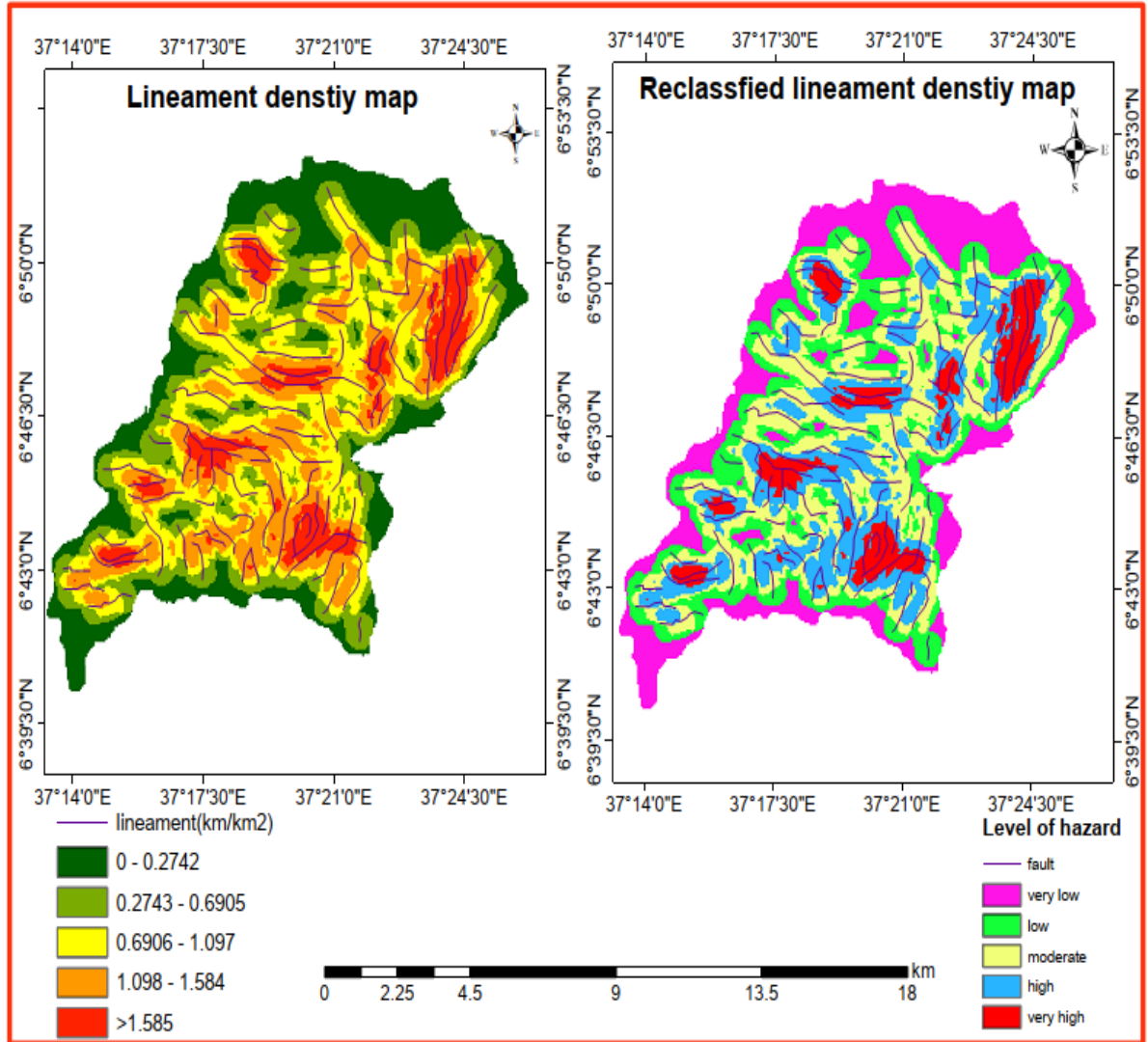


Figure 4.1 Lineament and reclassified lineament map of kindo didaye worda

4.2.2 Lithology map

Since lithological and structural variances frequently result in differences in the strength and permeability of rocks and soils, it is commonly acknowledged that geology has a significant impact on the occurrence of landslides. Thus, the nature and kind of regolith have a significant impact on landslide activity. a substance (Thomson, 1971). Because of this, the kind and makeup of the bedrock beneath the slope have a significant impact on its stability. The many mechanical characteristics affecting the slope's stability are entirely dependent on the rock formation and the kind of soil that makes up the slope.

The study area's geology was digitised from by the Geological Survey of Ethiopia (GSE). The study's geology is divided into two lithotectonic units: the metagabbro-amphibolite unit and the granitoid orthogneiss unit; Tertiary intrusive rock (Ti) and Quaternary volcanic flow rocks (Qv). Refer to (Fig.4.2) and (Table 4.2) for more information.

Table 4.2 Reclassification of lithology of Kindo Didaye woreda

Lithology	Ranking	Area in sq. km	Percentage of area	Level of landslide
Tertiary intrusive rock (Ti)	1	165.76	61.01	Less
Quaternary volcanic flow rocks (Qv)	2	105.93	38.98	High
Total		271.69	100	

Source: computation from GIS

Above table 4.2 revealed that ,Tertiary intrusive rock (Ti), which makes up the majority of the research area and accounts for 61.01%(165.76 sq.km) of the total area. It was widely distributed in the study area's southern,eastern and northern regions.. However, due to its instability to resist earth sliding, this type of rock has a high propensity to produce migratory flows of rock and the high porosity of this type of rock, makes it more likely to produce unusually mobile flows (Hutchinson, 2000). Quaternary volcanic flow rocks (Qv), which comprises 38.98% (105.93 sq.km) of the entire area, is the second most prevalent geologic type in the region. In large quantities, it was located in central of the research area. This rock type associated with the steep sedimentary hills and steep granite Shire. This alluvial material has been developed from stream bed deposits and therefore contains layers of river gravels intermixed with layers of fine sandy material and easily susceptible to landslide (Yesilnacar & Topal, 2005).

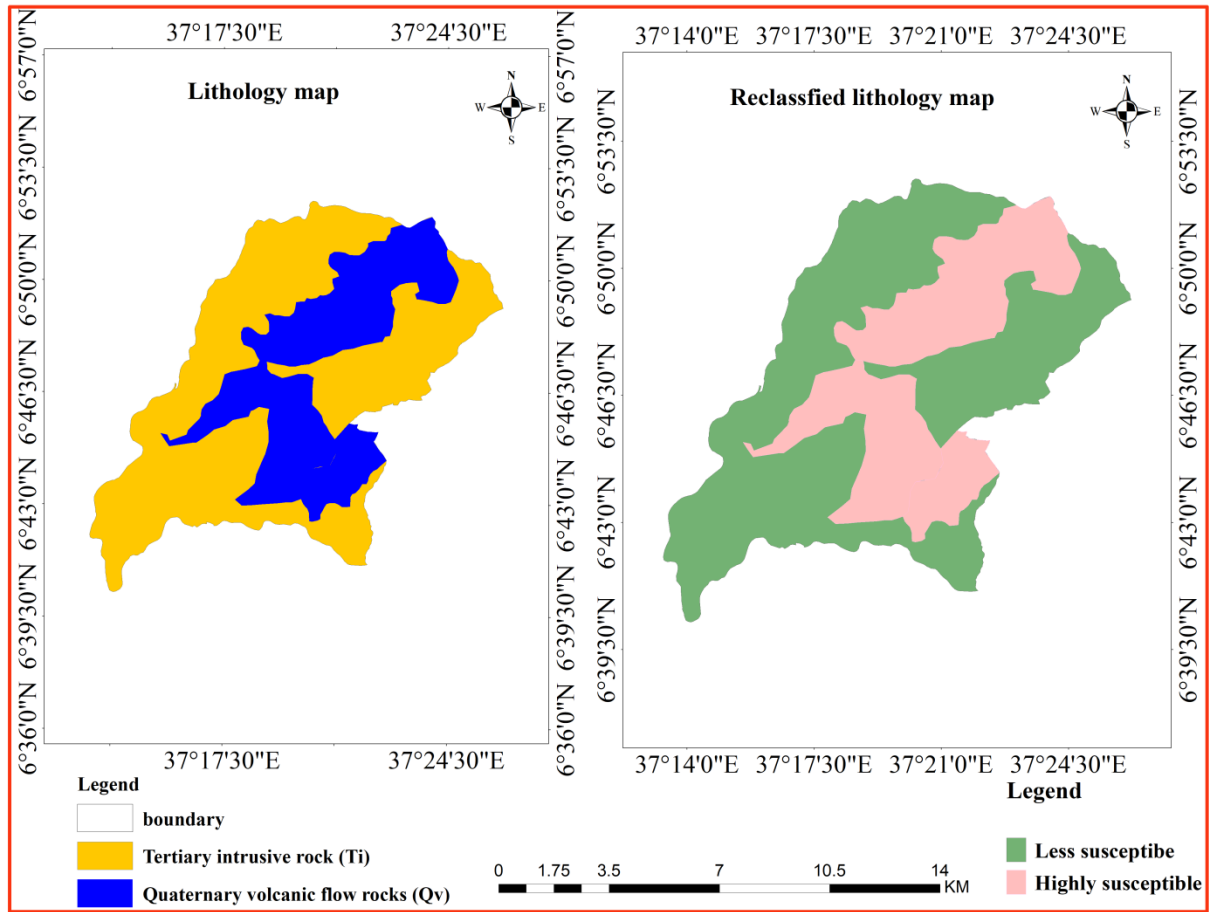


Fig 4.2 Aspect class with their distribution of Kindo Didaye woreda

4.2.3 Elevation

Elevation is a factor frequently utilized in landslide hazard assessment (Raghuvanshi et al., 2014; Hamza and Raghuvanshi, 2017). The elevation is a distance above sea level. Elevations are usually measured in meters or feet. They can be shown on maps by contour lines, which connect points with the same elevation; by bands of color; or by numbers giving the exact elevations of particular points on the Earth's surface. It is possible to relate elevation's involvement in causing slope instability indirectly. The influence of elevation can be explained in terms of weathering intensity, humidity change, hydrate response speed, erosion process, and weathering depth. Elevation is the distance above sea level, while depth is the distance below sea level. The elevation is therefore regarded as one of the causal factors for regulating the landslide process (Shimelis Ahmed, 2009). The elevation of the research region was downloaded from the Alaska Satellite Facility website (<https://search.asf.alaska.edu/#/>) and the 12.5-meter resolution of ALOS PALSAR DEM was reclassified using the Arc

GIS10.8 for further analysis. The study area's elevation map was divided into 5 class ranges. The minimum elevation is 654m, while the maximum is 2489m.

Table 4.3 Reclassification of elevation of Kindo Didaye woreda

Elevation(m)	Ranking	Area in sq. km	Percentage of area	Level of landslide
654 – 928	1	72.59	27.23	Very low
928.1 – 1,208	2	67.90	25.07	Low
1,209 – 1,526	3	62.16	23.05	Moderate
1,527 – 1,909	4	47.18	17.27	High
1,910 – 2,489	5	21.86	7.35	Very high
Total		271.69	100	

Source: computation from GIS

From table 4.3, among classified elevations for landslide analysis, a very low level of elevation (654m – 928m) covers 72.59 km² (27.23%) of the total area and is located in the western parts of the study area. The second dominating class of elevation in the current study is a low level of elevation ranging from (928.1m – 1,208m) which covers 67.90km² (25.07%) of the total area. The third dominating class of elevation is moderate level, it ranges between (1,209m – 1,526m) and covers 62.16km² (23.05%) from part of the study area. The high level of elevation from (1,527m – 1,909m) covers 47.18 km² (17.27%). Finally, the very high level of elevation class in the present study ranges from (1,910m – 2,489m) and covers 21.86 km² (7.35%) of the total study area. The distribution of landslides in the study area decreases as elevation decreases. Figure (4.3) shows the elevation class with their distribution of Kindo Didaye woreda.

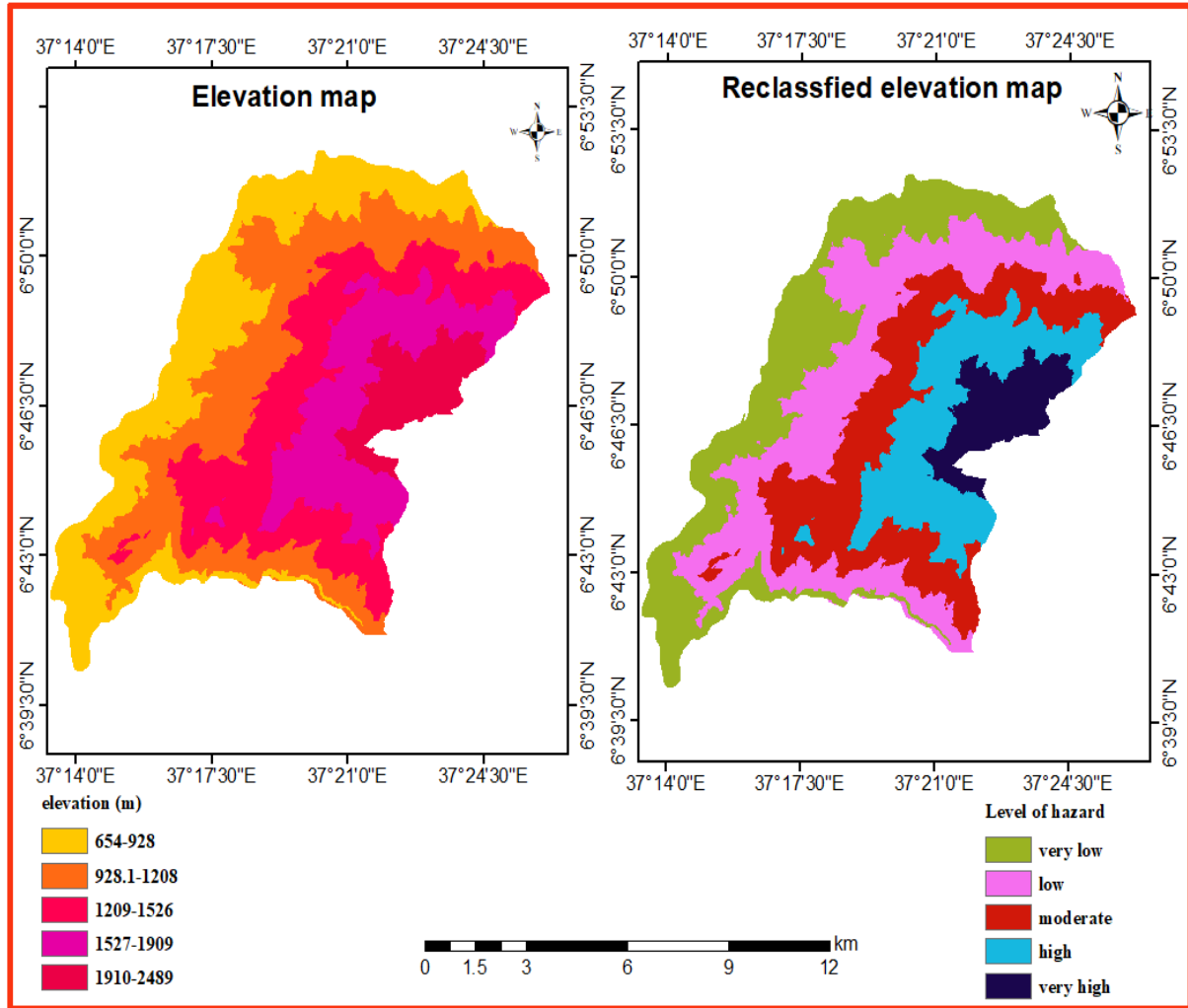


Fig 4.3 Elevation class with their distribution of Kindo Didaye woreda

4.2.4 Slope

The slope has a substantial impact on the landslide process (Ayalew and Yamagishi, 2003). If the slope is steeper, shear stress increases, and the tangential component of mass weight increases while the perpendicular weight decreases. As a result, when the shear stress exceeds the resisting force, the slope mass tends to slide down the slope (Ahmed. 2009). The slope angle, which indicates how steep the ground surface is, also it is an important component of the landslide influencing factor set. Because of its relationship with landslides, slope angle is an important factor in assessing landslide hazards and is frequently used in the creation of landslide hazard maps (Clerici et al. 2002; Lee et al. 2004; Lee 2005). The slope gradient influences subsurface water distribution, surface runoff rate, and soil water content during and

after rainfall. Low and near-vertical slope angles are less likely to cause landslides (Michael & Samanta, 2016; Guzzetti et al., 1999).

The slope of the study area was prepared using Arc GIS10.8 environment and a 12.5-meter resolution ALOS PALSAR DEM downloaded from the Alaska Satellite Facility website (<https://search.asf.alaska.edu/#/>). The flat sections had a minimum slope angle of 0°, while the steep slope had a maximum slope angle of 47.7°.

Table 4.4 Reclassification of the slope of Kindo Didaye Woreda

Slope	Ranking	Area in (sq. km)	Percentage of area	Level of landslide
0-5%	1	110.76	41.80	Very low
5-15%	2	56.41	20.83	Low
15-30%	3	41.56	15.10	Moderate
30-45%	4	45.26	16.52	High
>45%	5	17.70	5.72	Very high
Total		271.69	100	

Source: computation from GIS

For the current study, the slope was classified into five classes: The first dominating level of the slope is very low, ranging from (0-5%) which covers 110.76 sq. km (41.80%) of the study area and is almost located in all parts study area. The second dominating slope class of the study area is low ranges from (5-15%) which covers 56.41 sq. km (20.83%) of the study area and is mainly located in northeastern, northwestern, and central parts of the study area. The other and third dominating slope class of the study area is moderately level (15-30%) which covers 41.56 sq. km about (15.10%) of the total study area, the fourth level of slope in the current study area is high level (30-45%) which covers 45.26 sq. km (16.52%) and the final slope class of study area very is a high level greater than 45% which covers 17.70 sq. km about 5.72% from the total area. This indicates that the likelihood of failure increases as it approaches the escarpment. As shown in table 4.4, the majority of the area was dominated by gentle topography. The northwestern, southwestern, and central parts of the study area were characterized by gentle slope topography. Furthermore, the area was distinguished by a gentle

range facing northwest and southwest. When the slope becomes steeper, the probability of sliding material increases. The northeastern and southeastern parts of the study area, on the other hand, were dominated by a steep slope. A village with a moderate to steep slope occurs on agricultural land.

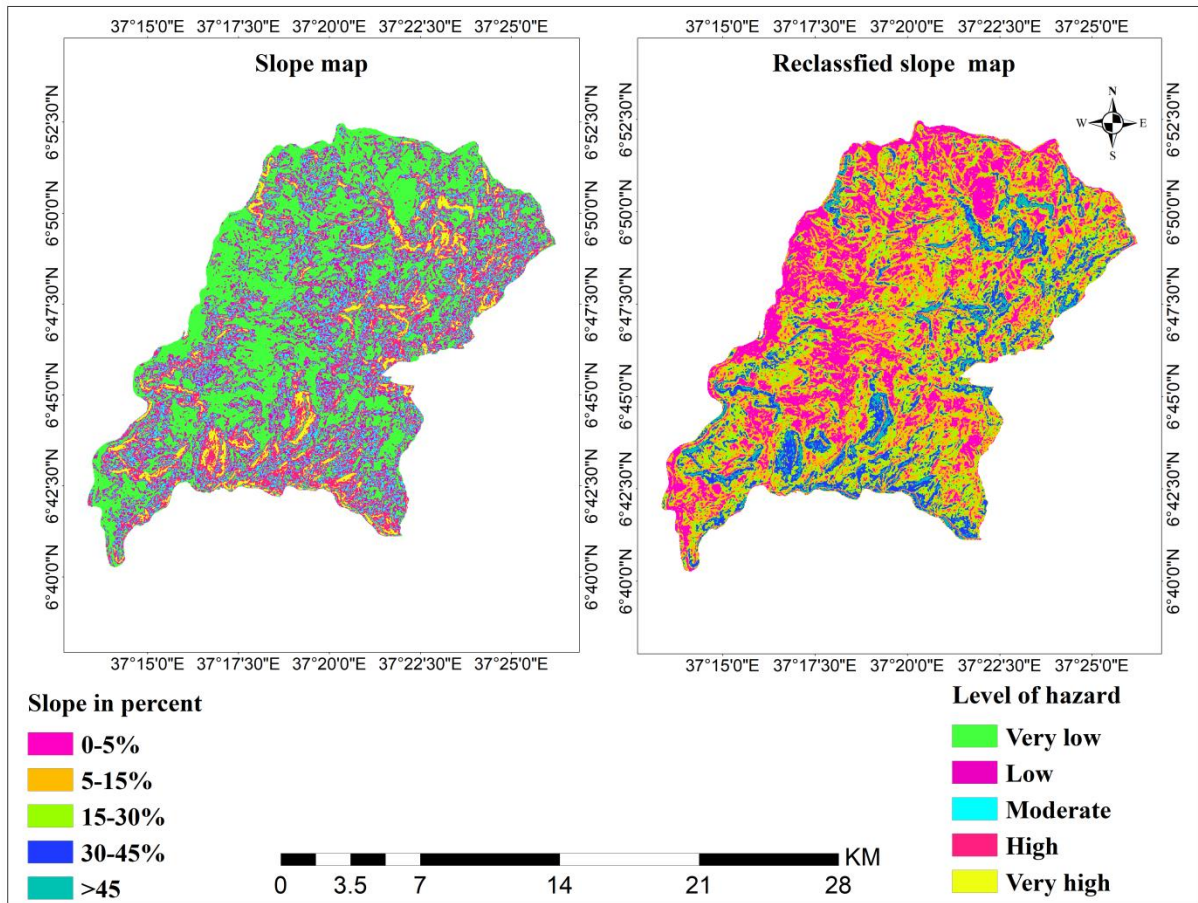


Fig 4.4 Slope class with their distribution of Kindo Didaye worda

4.2.5 Normalized vegetation index

In general, vegetation improves the slope's stability (Anbalagan & Singh, 1996; Raghuvanshi et al., 2014). The NDVI value is a representation for measuring the status of the area's vegetation condition. The probability of a landslide occurring decreases as the NDVI increases (Tseng et al., 2015). The Normalized Difference Vegetation Index for the present study was calculated using a 10-meter resolution sentinel 2A image to quantify vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). The NDVI scale is always between -1 and +1. If the NDVI value is

negative, it is likely water, and if the NDVI value is close to +1, it likely has dense green leaves. When the NDVI is close to zero, there are no green leaves and the area may be built-up. The NIR and Red channels are used in the NDVI formula (equation 4.1).

$$NDVI = ((Near\ (NIR) - Red(R)) / (Near\ InfraRed(NIR) + Red(R))) \dots \dots \dots \text{equation 4.1.}$$

Where NIR= near-infrared spectrum reflection, Red= visible infrared spectrum reflection of Red. Accordingly, the NDVI values of the study area are classified into five classes ranging from -0.28 to 0.74 refer to table (4.4).

Table 4.5 Reclassification of NDVI of Kindo Didaye Woreda

NDVI	Ranking	Area in(sq.km)	Percentage of area	Level of landslide
-0.28-0.015	5	25.78	9.89	Very high
0.015-0.14	4	42.74	15.04	High
0.14-0.27	3	83.97	28.35	Moderate
0.27-0.36	2	87.43	30.14	Low
0.36-0.74	1	31.77	16.58	Very low
Total		271.69	100	

Source: computation from GIS

The result presented in above table 4.5 indicates that NDVI classes falling between (-0.28-0.015) cover an area of 25.78sq.km (9.89%) from the total area and located in northern parts of the study area around GILGEL GIBE III, NDVI value from (0.015-0.14) covers an area of 42.74km² (15.04%) from the total area and mainly located in northwestern and southwestern parts of the study area. The third class of NDVI value ranges from (0.14-0.27) and covers an area of 83.43 sq. km (28.35%) of the total area. The fourth and most dominating NDVI class from (0.27-0.36) covers an area of 87.43 sq. km (30.14%) of the total area and is mainly found in northeastern and southeastern parts of the study area. The value from (0.36-0.74) covers an area of 31.77sq.km (16.58%) from the total area and mainly distributed in the eastern parts of the study area. The probability of a landslide occurring decreases as the NDVI increases (Tseng et al., 2015), So when the NDVI value increases the probability of a landslide

decrease i.e. there is a high chance for a landslide to occur around a water bodies area and barren lands than densely forest and vegetable area around the study area.

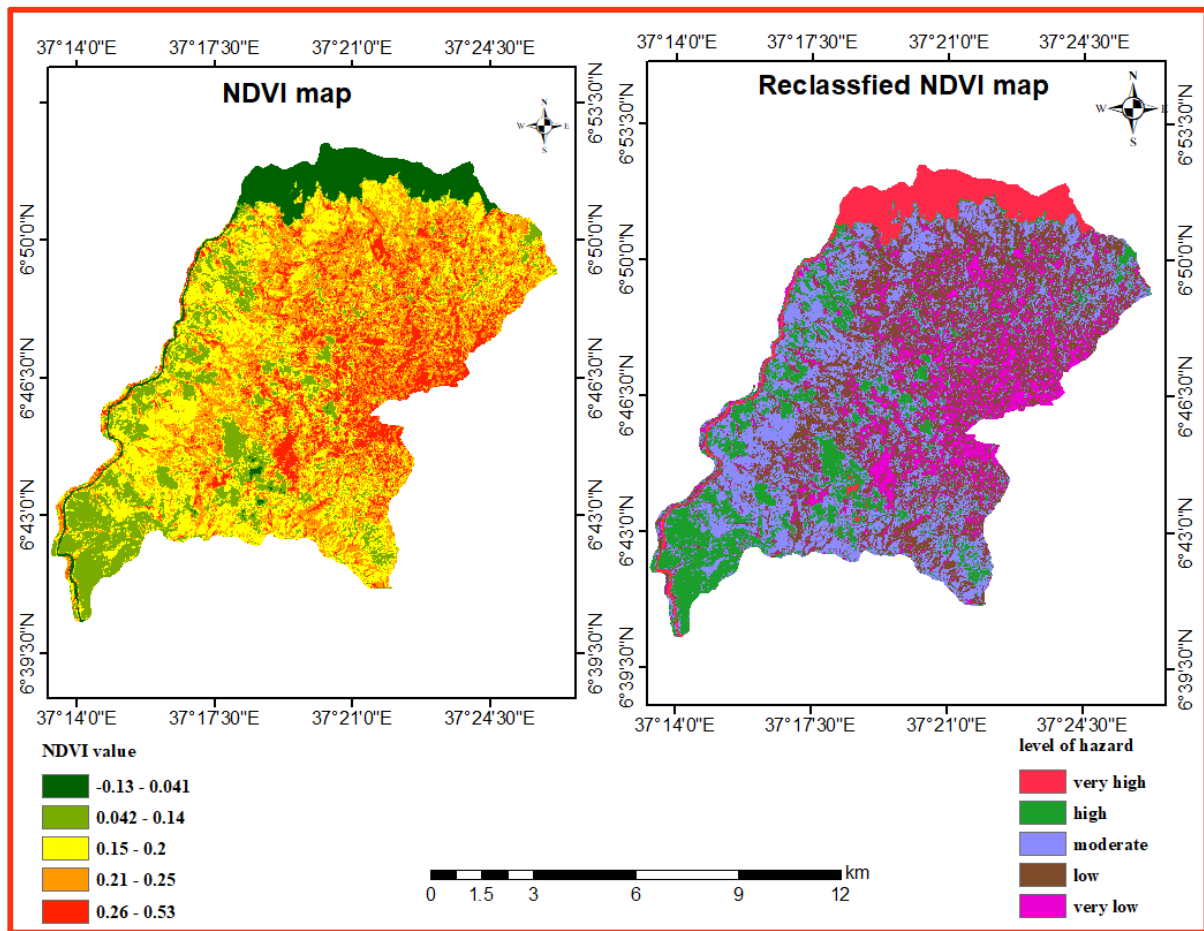


Fig 4.5 NDVI class with their distribution of Kindo Didaye woreda

4.2.6 Rainfall intensity

Rainfall has been identified as one of the most common causes of natural landslides. Rainfall triggering is defined as a decrease in shear strength caused by an increase in pore water pressure on the potential failure surface, which eventually results in slope failure and the formation process of geohazards is closely related to rainstorms (Ng et al. 2021; Rong et al. 2020). Rainwater infiltrates into the geotechnical body to change its physical properties and environment. Precipitation will cause the softening of rock and soil, reduce the mechanical strength of rock and soil mass, and the slope will become unstable and eventually form a landslide disaster. Rainfall infiltration is a well-known landslide trigger as it causes reduced soil suction (thus reduced shear strength of soil) and added hydrodynamic loading. The

climate conditions before a particular rain event have a significant effect on the pore water pressures in the slope (Terlien, 1998). Keefer (2002) described a real-time landslide warning system based primarily on developed precipitation intensity duration thresholds, with seasonal antecedent precipitation also taken into account. The study area's annual rainfall map was created using interpolations from Wolaita rain gauge stations. Mean annual rainfall for the last 30 years was considered and interpolated using the Inverse Distance Weighting (IDW) interpolation method to establish continuous raster rainfall data inside the boundaries. The resulting raster layer was then reclassified into five classes using an equal interval (Ogato et al., 2020; Ouma & Tateishi, 2014). The reclassified rainfall was given a rating from 1 to 5, with 1 representing the least rainfall and 5 representing the most rainfall.

Table 4.6 Reclassification of rainfall of Kindo Didaye Woreda

Rainfall (mm/yr.)	Ranking	Area in (sq. Km)	Percentage of area	Level of landslide
1160.34-1203.23	1	44.58	16.68	Very low
1203.23-1231.39	2	70.88	26.08	Low
1231.39-1258.28	3	48.47	17.84	Moderate
1258.28-1288.36	4	57.42	21.13	High
1288.36-1323.66	5	50.37	18.53	Very high
Total		271.69	100	

Source: computation from GIS

(Table 4.6) revealed that the highest rainfall class (1288.36-1323.66) covers 18.53 percent of the total area. The other 21.13, 17.84, 26.08, and 16.68 percent of the area subjected to high, moderate, and low and very low levels of hazard respectively. From the reclassified rainfall map, the northern part of the study area around the OMO River receives a maximum amount of rain, which indicates it is highly vulnerable to landslide hazards. The southern and central parts of the study area are under very low, low, and moderate rainfall amounts. The more precipitation fall, the more soil particles are moved or transported away. Land that has no vegetation including farm fields that are left barren after crop harvest is especially vulnerable to landslides. By considering the rainfall amount in the southern and central parts, we can say that these areas are less vulnerable to landslides than the northern parts of the study area. The

results of the raster rainfall layer or IDW interpolated data layer, and reclassified rainfall data are shown below in (figure 4.6).

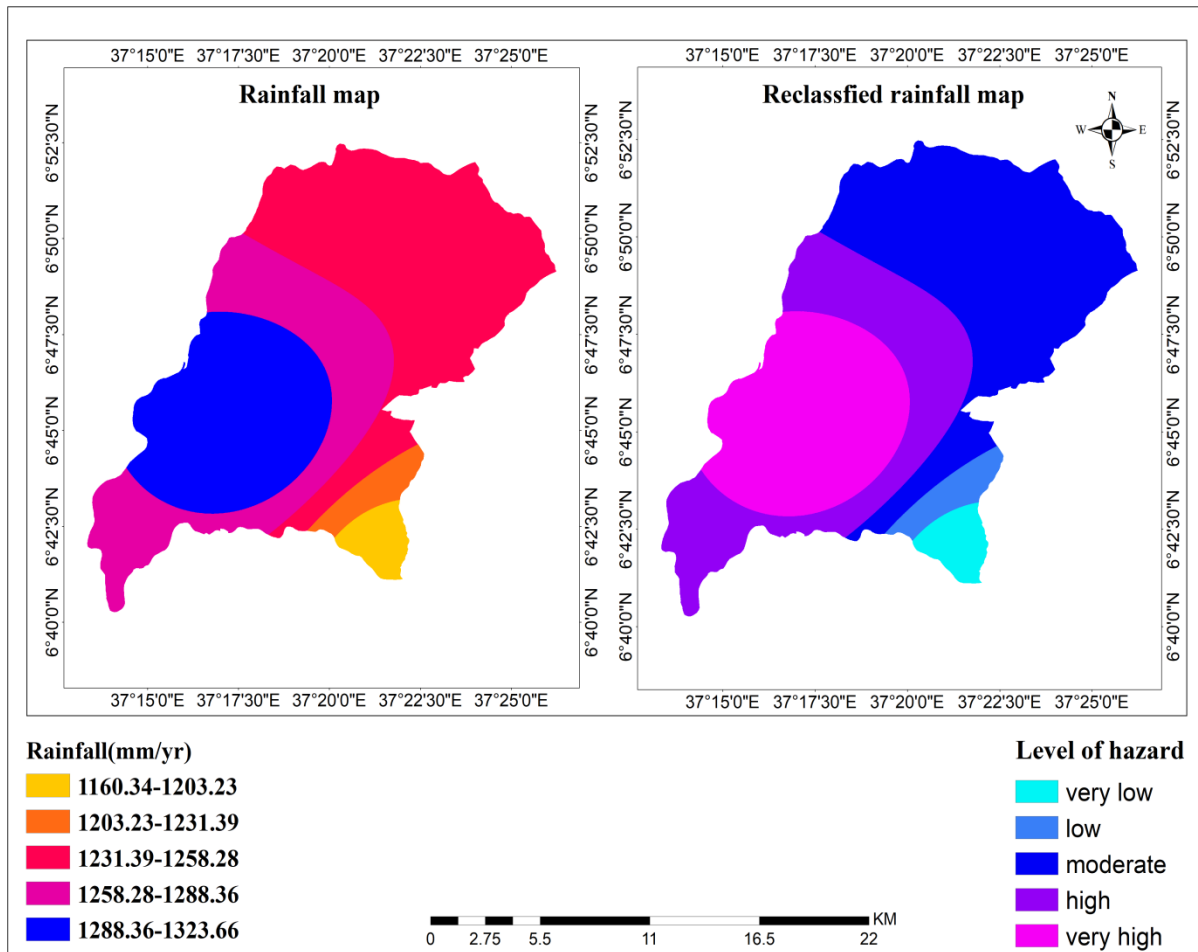


Fig 4.6 Rainfall class with their distribution of Kindo Didaye woreda

4.2.7 Distance to River

The distances from streams play a significant role in the occurrence of landslides. River overflows are essential for the start of a landslide event. Often, the inundation originates in the river and spreads to the surrounding areas. Landslide vulnerability is greatest near river banks and decreases as one moves away from the river, emphasizing the importance of distance from the river in assessing landslide risk (Kazakis et al., 2015). The effect of distance from the river will vary depending on the capacity of the river channel and the amount of rainfall in the area.

Table 4.7 Reclassification of distance from the river of Kindo Didaye Woreda

Distance to river(km)	Ranking	Area in (sq. km)	Percentage of area	Level of landslide
0 - 7.868	5	79.65	29.33	Very high
7.868 - 23.6	4	61.74	22.72	High
23.61 - 47.21	3	61.02	22.44	Moderate
47.21- 62.95	2	45.09	16.60	Low
>62.95	1	24.21	8.89	Very low
Total		271.69	100	

Source: computation from GIS

The distance from the river is further reclassified into five classes. The class up (0 km - 7.868km) was assigned the very highest rank as it is more vulnerable to landslides and is located especially in the northern parts of the study area. The second class with a distance of river ranges between (7.868 km - 23.6 km) was assigned a high rank and covers 61.74 sq. km (22.72%) found in the central and eastern parts of the study area. As shown, in Table 4.7, moderate, low, and very low hazard level covers 22.44 (61.02 sq. km), 16.60(45.09 sq. km), and 8.89(24.21 sq. km) percent of the total area respectively, and are located in central and eastern parts of study area. Landslides tend to occur along the sides of valleys as a result of flowing of the Omo River, which in turn affects undercutting processes. Landslide vulnerability is greatest near river banks and decreases as one moves away from the river, emphasizing the importance of distance from the river in assessing landslide risk (Kazakis et al., 2015). So northern parts of the study area are near the Omo River this indicates the area is more vulnerable to landslides than an area that is far from the Omo River, which is located in the southern parts of the study area. In general, the potential of landslides increases as the distance to the rivers decreases, because water saturates the lower part of the material, resulting in increased water levels, which may adversely affect stability. As water passes through an area, it ruptures the rough material on the surface. Next to the lateral pressure, the water wants to penetrate the fine-grained material. As a result of this penetration, the entire process may cause a crash (Kazakis et al., 2015). According to (Kazakis et al., 2015). The presence of water has an inverse relationship to the shear strength of a substance, because as

the percentage of water increases, the shear force of the material tends to fall by half an exponential behavior. According to this fact, high deposition of drainage channels will result in greater water penetration and consequently a decrease in the shear strength of the formation. Fig (4.7) Shows the distance from river class with their distribution.

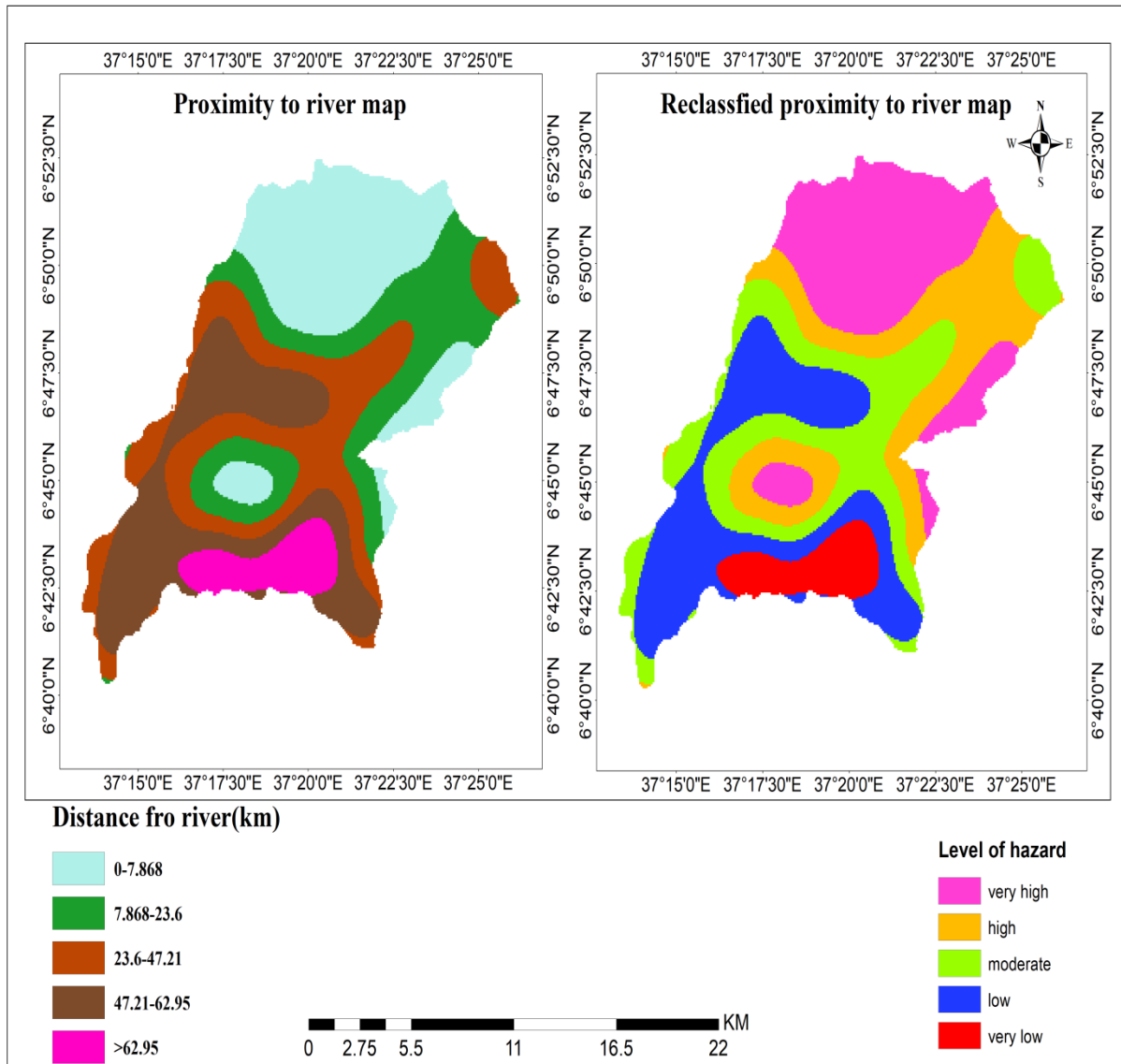


Fig 4.7 Distance from river class with their distribution of Kindo Didaye Woreda

4.2.8 The topographic wetness index (TWI)

The topographic wetness index (TWI) regulates the flow of water overland by describing the spatial distribution of wetness. TWI has a large impact on landslide mapping (Samanta et al., 2018). The TWI is a physically based index or indicator that measures how topography

influences runoff, flow direction, and flow accumulation. A topographic wetness index is based on the idea that a terrain profile influences the distribution of water and the areas where water accumulates (Samanta et al., 2018). TWI was calculated for this study by evaluating the flow direction, flow accumulation, slope, and various geometric functions derived from GIS software. TWI was calculated using the formula provided by (Beven and Kirkby 1979), and a TWI spatial distribution map was created using ArcGIS (Fig. 4.8). $TWI = \ln(a / \tan B)$, where a is the catchment area [$a = A/L$, total basin area (A) divided by length of contour (L)] and B is the slope in degrees. The TWI calculation produced a GIS data layer depicting areas with drainage depressions where water is likely to accumulate. Smaller TWI values indicate less potential for landslide vulnerable and slope instability (Counties & Ballerine, 2017). The TWI layer was reclassified into five classes, with the higher TWI receiving a higher value and the lower TWI receiving a lower value.

Table 4.8 Reclassification of TWI of Kindo Didaye woreda

TWI	Ranking	Area in (sq. km)	Percentage of area	Level of landslide
2.98-8.64	1	33.29	11.88	Very low
8.65-14.34	2	93.04	34.76	Low
14.35-20.29	3	86.61	32.30	Moderate
20.30-28.69	4	43.92	15.96	High
28.70-36.76	5	14.80	4.81	Very high
Total		271.69	100	

Source: computation from GIS

From above table 4.7, the most dominating class of TWI in the present study area is low level its value ranges from (8.65-14.34) and covers 93.04 sq. km (34.76%) of the total area and is located in almost all parts of the study area. The second dominating class of TWI in the present study area is moderate level its value ranges from (14.35-20.29) and covers 86.61 sq. km (32.30%) of the total area. The other rest class of topographic wetness index level in the present study are subjected to a very low, high, and very high level which ranges from (2.98-8.64), (20.30-28.69), (28.70-36.76), covers 33.29(11.88%), 43.92(15.96%), 14.80(4.81%) respectively. Smaller TWI values indicate less potential for landslide vulnerable and slope

instability (Counties & Ballerine, 2017). This indicates that low classes of topographic wetness index value have a low probability of being landslide-prone and vulnerable compared with a high value of TWI. See (figure 4.7).

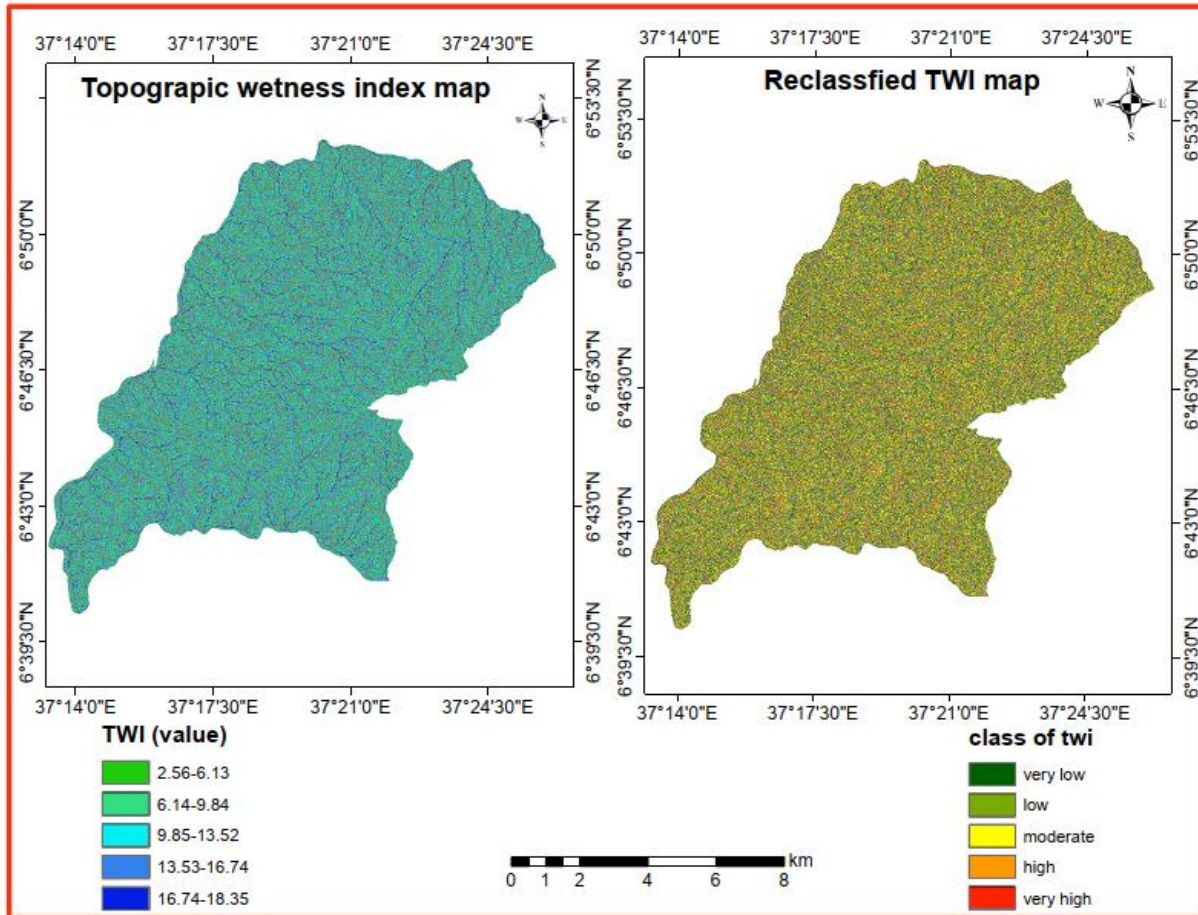


Fig 4.8 TWI class with their distribution of Kindo Didaye woreda

4.2.9 Soil type

Soil type is an important parameter in landslide analysis because soil particle resistance to sliding across each other is determined by the type of soil. The earth materials involved control the movement's nature (Peter. 1970). Sandy soils are the most cohesive, while clayey soils with fine particles are almost as cohesive. The friction force is determined by the load applied to the soil surface. The greater the load, the more likely the force of friction will prevail. This causes soil particle movement within the soil layer and the possibility of slope failure. Sandy soil has less moisture content, is less cohesive, and is more resistant than silt and clay soils but has high drainage potential. But in high rainfall areas, clay soils are more

susceptible to landslides (Ramakrishnan et al. 2002). The soil texture and wetness are the two most crucial aspects of soils. Soil texture has a big impact on landslides since sandy soil absorbs water quickly and has few runoffs. In contrast, clay soils are less porous and retain water for a longer period than sandy soils, making them more prone to landslides (Berhanu et al., 2012). This indicates that landslides are more likely to occur in places with clay soils. The soil's potential to function as a sponge and absorb water will be significantly influenced by its structure and infiltration rate. According to (Ouma and Tateishi 2014), different types of soil have different capabilities. However, the presence of various soil types in the area influences the nature of mass movement and slope failure. The total area coverage and soil type exist in the study area was, presented in the Table below. Three different soil types exist in the study area.

Table 4.9 Reclassification of soil type of Kindo Didaye woreda

Soil	Ranking	Area in (sq. km)	Percentage of area	Level of landslide
Eutric nitosol	1	119.24	44.45	Low
Eutric cambsoil	2	61.95	22.09	Moderate
Haplic xero soil	3	90.5	33.44	High
Total		271.69	100	

Source: computation from GIS

From the table (4.9), the most common soil type in the current study area is Eutric Nitosols covers 119.24sq.km (44.45%) of the total area, which is located in the northern and southern parts of the area and subjected low levels of landslide than haplic zero soil and cambsoils. Nitosols are associated with highlands with high rainfall. They are characterized by soil leaching poor in soluble minerals like potassium, calcium, etc.; and rich in non-soluble minerals like iron and aluminum (Peter. 1970). The second most common soil in the present study area is haplic xerosoil, which accounts for 90.5sq.km (33.44%) of the study area and located in the eastern parts of the study area. They have low organic content. They are extremely subjected to wind erosion and soluble salts. Easily prone to landslide subjected to high levels of landslide (Peter. 1970). The third soil type that dominates the area was eutric cambsoil which accounts for 61.95 sq. km 22.09% of the area. This soil type is located in the

central part of the study area by covering a small area. They are fine textured. They have high water holding capacity and the water content fluctuates, that are prone to easily (Peter. 1970) . Eutric cambsoil subject to moderate levels of landslide compared to both haplic xerosoil and nitosoil in the current study area. Figure (4.9) shows soil class with their distribution.

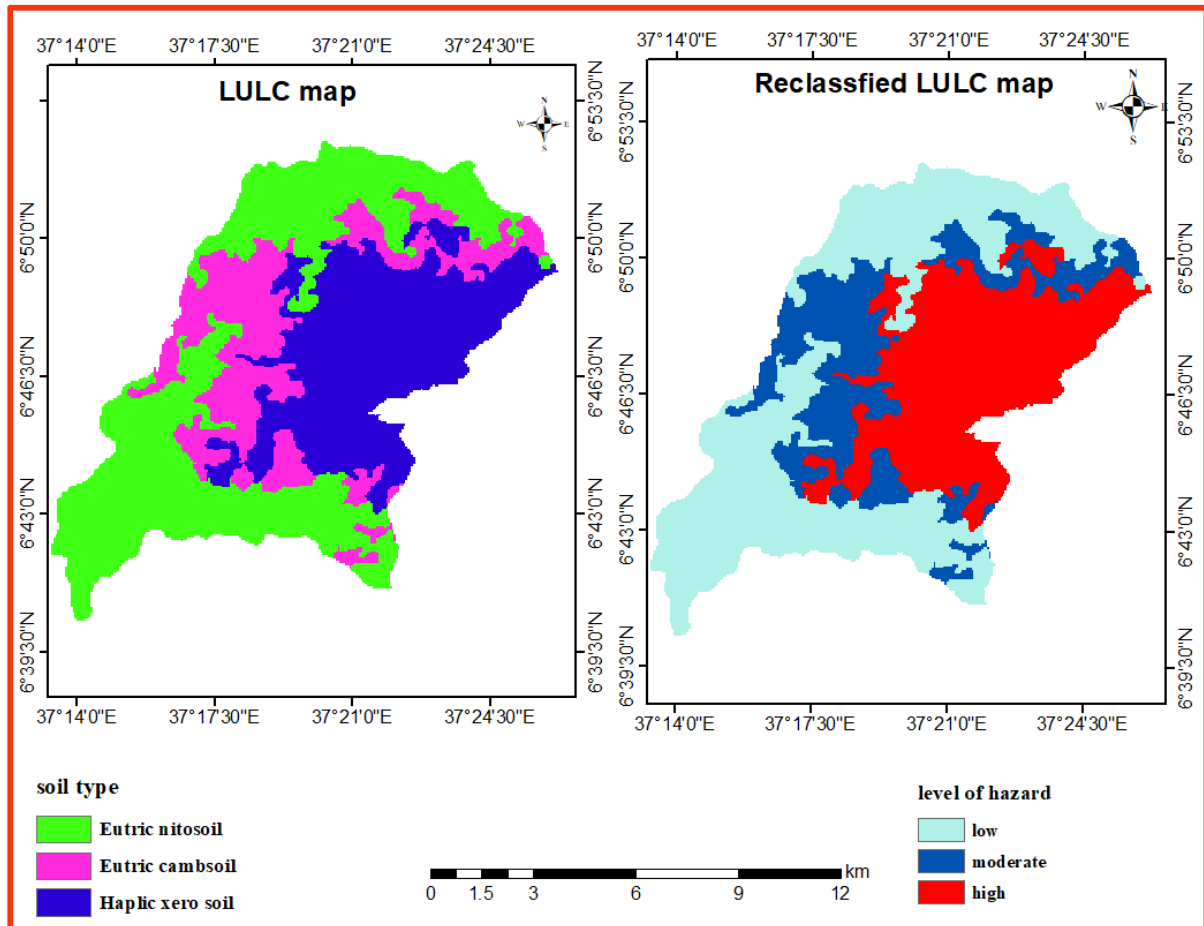


Fig 4.9 Soil class with their distribution of Kindo Didaye woreda

4.2.10 Land use land cover

LULC plays a substantial role in aggravating landslides. Because less vegetated areas are more prone to erosion than densely vegetated areas. Many landslides occur as a result of improper activities such as deforestation and increased urbanization over time. Landslides and mass-wasting events are more likely in areas with little or no vegetation cover and areas degraded by inappropriate logging, pastoral, agricultural, or construction practices (Varnes, 1978). Despite this, rapid changes in land use and land cover, as well as land degradation processes, are precursors to mass migration events (Alcantara et al., 2006). Vegetation roots improve

soil's ability to resist erosion and stabilize slopes and bodies of water. The Sentinel 2A level satellite image with a spatial resolution of 10m that was processed by ENVI software to classify the LULC of the study area. Agriculture, bare land, built-up, forest, and wetland were among the land use land cover types that were reclassified in the present study.

Table 4.10 Reclassification of land use land cover of Kindo Didaye Woreda

LULC	Ranking	Area in (sq. km)	Percentage of area	Level of landslide
Wet land	5	21.38	7.90	Very high
Bare land	4	39.34	14.48	High
Agriculture	3	87.03	32.02	Moderate
Settlement	2	40.34	14.84	Low
Vegetation	1	83.57	30.76	Very low
Total		271.69	100	

Source: computation from GIS

As indicated in above table 4.10, large parts of the study area were dominated mostly by the agricultural land class since it is one of the main sources of agricultural results in Ethiopia, which accounts for 87.03 sq. km (32.07) of the total area and located almost all parts of the study area. The second class of land use land cover that dominates the area is forest, which accounts for 30.76% (83.57sq.km) of the total area. Forest and highly vegetated areas have a low probability of landslides vulnerable than other classes of land use, the reason is vegetation roots improve soil's ability to resist erosion and stabilize slopes and bodies of water. The third land use class in the current study area is a settlement that covers 14.84% (40.34sq.km) of the total area. The area is also characterized by a Wet land, which accounts for 7.90% (21.38 sq. km) of the total area and is located in the northern parts of the present study area around the Omo River. Wet land are highly vulnerable to landslides because they increase pore pressure and loss in shear strength of soil resulting in sliding of soil mass. The bare land area covers 14.48% (39.34 sq. km) of the total area. Most bare land in the area is located in the southeastern and northern parts of the study area. Barren lands are more vulnerable to landslides because less vegetated areas are more prone to erosion than densely vegetated areas.

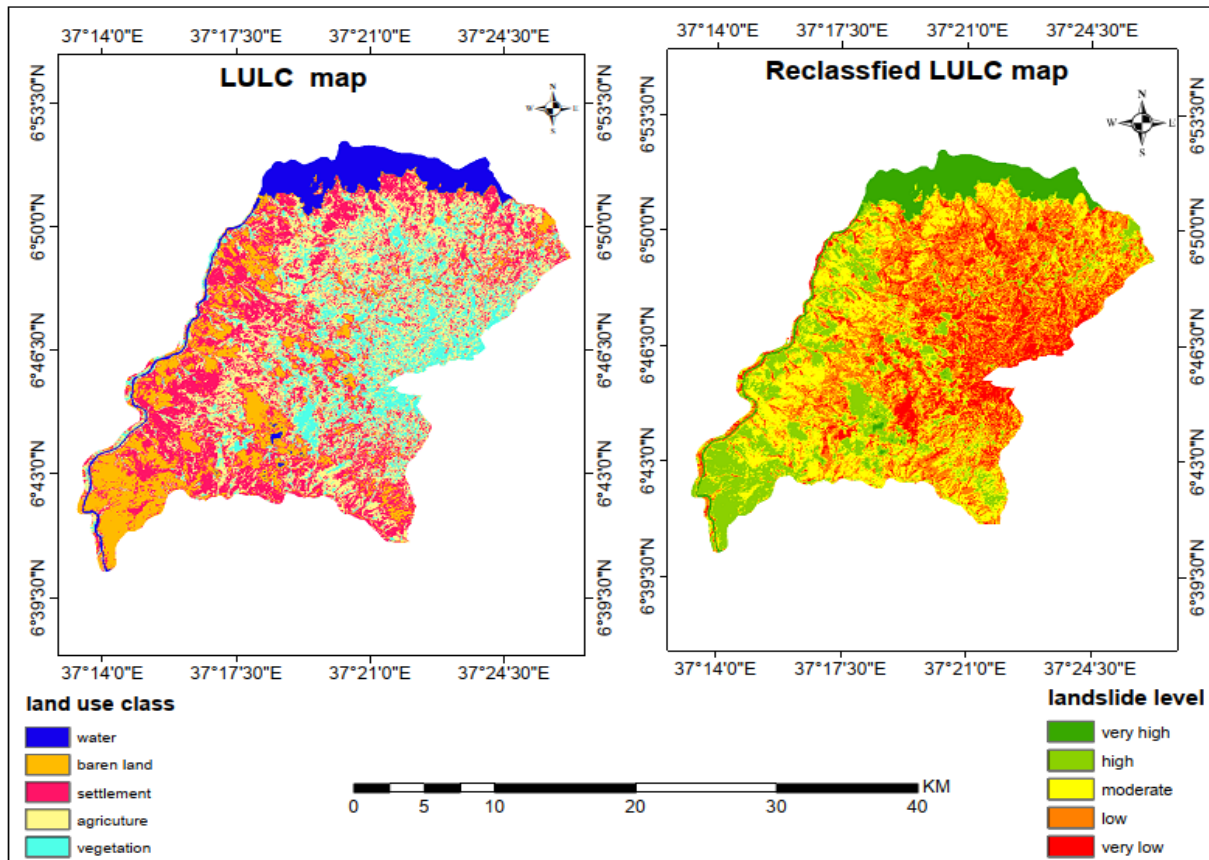


Fig 4.10 Soil class with their distribution of Kindo Didaye woreda

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, an 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 100 randomly selected pixels for the land use /land cover map, which were also checked with reference data (ground data 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 93.33% and a kappa index of agreement of 0.91. The kappa coefficient implies that the classification process is avoiding 91% of the errors that a completely random classification generates. This study's LULC accuracy assessment was summarized in (the appendix IV).

4.3 Landslide Risk Causative Factor Development

The landslide hazard layer and the three elements at risk; population, roads and land use land cover factors were considered as the four important factors in analyzing landslide risk in the study area. These four factors were used to overlay in Arc Map software to determine the degree of landslide risk in the study area or to identify areas with the highest landslide risk. In the weighted overlay analysis, these four factors were considered equally important (rating process)

4.3.1 Population density factor

One of the landslide risk factors was the population density. The landslide's impact will be manipulated by the population as well as the man-made infrastructures of the urban and rural areas (Ogato et al., 2020). A population is a group of individuals within the same species that are living and breeding within a geographic area. The number of individuals living within that specific location determines the population density or the number of individuals divided by the size of the area. Population density is the concentration of individuals within a species in a specific geographic location. Population density data can be used to quantify demographic information and assess relationships with ecosystems, human health, and infrastructure. The population data of the study area was gathered from the Kindo Didaye Woreda administration office; refer to Appendix III. The population density layer was further subdivided into five subgroups using standard classification schemes, namely equal interval, and new values were assigned in ascending order of landslide hazard vulnerability. The population density was reclassified based on the assumption that the denser the population, the more vulnerable to landslides (Ogato et al., 2020). As a result, the highest population density category is assigned a value of 5 because it is extremely vulnerable to landslides. The lowest population density category, on the other hand, was assigned a value of 1 because its susceptibility to landslide risk is very low.

Table 4.11 Reclassification of the population density of the study area

Population density	Ranking	Area in (sq. km)	Percentage of area	Level of landslide
187-244	1	137.55	50.76	Very Low
245-388	2	65.72	24.19	High
389-488	3	30.51	11.23	Moderate
489-725	4	22.55	8.30	High
726-824	5	13.55	5.50	Very High
Total		271.69	100	

Source: computation from GIS

From Table 4.11, the population density value from 187 to 244 subjects with a very low level of landslide risk occupies an area of 50.76% (137.55sq.km). Most of the area falls within a very low landslide level and is almost located in the northern and southwestern parts of the study area around Shele Mekira and Goche Kebele. Population density values ranging from 245- 388 cover an area of approximately 65.72sq.km (24.19 percent) with low-level landslide risk levels and distributed in central parts of the study area around Zeneba and Kindo Halale kebele. About 11.23% of areas cover a moderate population density; its value ranges between (389 – 488) populations per square kilometer and is located in northeastern and southwestern parts of the study area around zero, bosa manara, and Patata kebele. Population density values ranging from (489-725) cover an area of approximately 22.55sq.km (8.30%) and 726-824 cover an area of 13.55sq.km (5.50%) with high and very high-level landslide risk respectively. This area is located in the northwestern, eastern, and southeastern parts of the study area around Dolaye and Mogisa kebele. Generally, the densely populated area is more vulnerable to landslides when compared to sparsely populated areas. Rapid increments in population number and urbanization activities, such as building roads and houses, significantly reorganize the surface which alters slope stability. The increment in population number exacerbates the removal and cutting of trees for different purposes such as for fuel, charcoals, and shelter. This deforestation results in landslides because the roots of trees and plants hold the soil. On clearing the vegetation, the mountain slope loses its protective layer due to which the rain

water flows at a very high speed on the slopes which results in landslides. Figure 4.12 below shows the reclassification of population density based on the landslide risk zone.

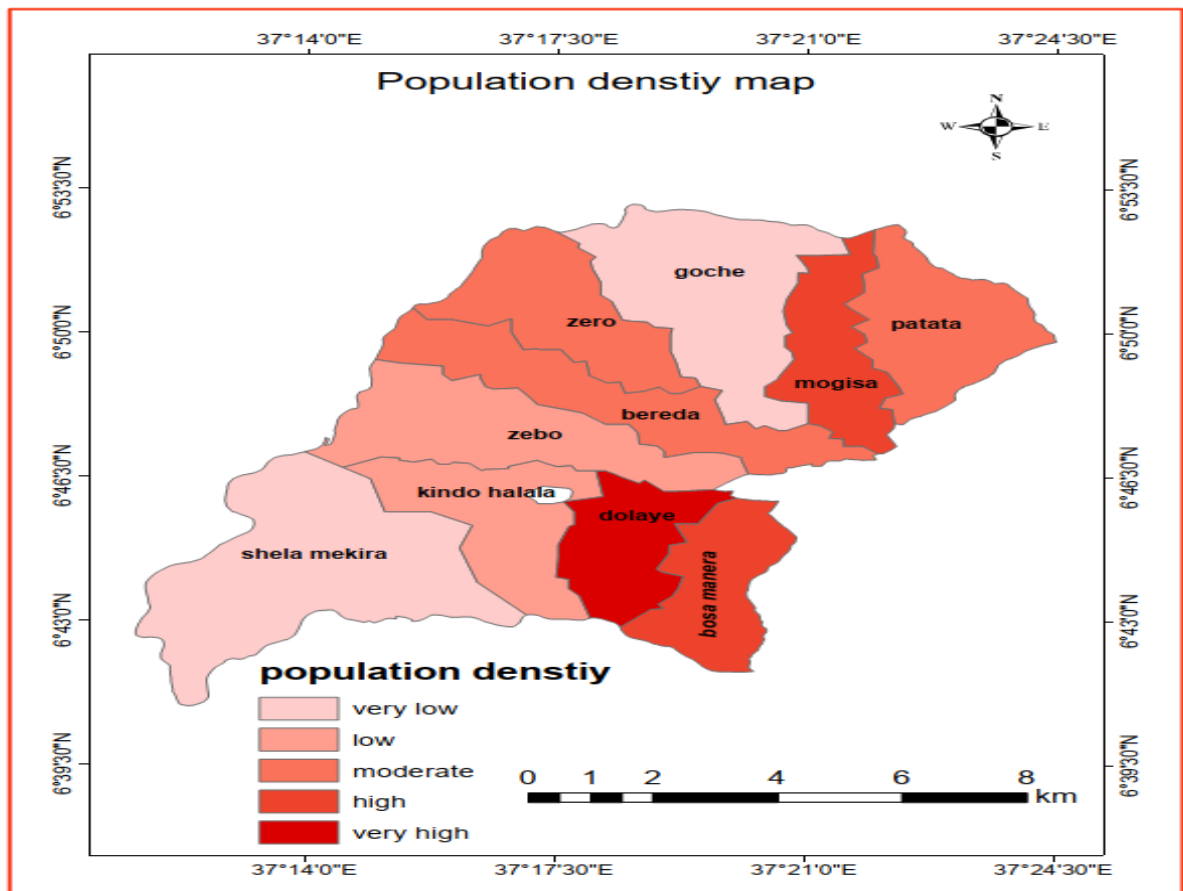


Figure 4.11 Reclassification of the population density map of the study area

4.3.2 Proximity to Road

Due to the topography and infrastructure characteristics that are used to assess the risk of landslides in the research region, proximity to road elements is taken into consideration. Initial road cuts reduce the slopes' overall stability and amplify according to the lithological units' dip orientations (Samanta, 2016). Natural landslides may also be present and may cause instability of the road itself, road cuts, and embankments. Consequences of instable road cuts and embankments may be a failure of the road, be dangerous, and may make the road unusable. According to (Michael and Samanta 2016), During the rainy season, water may run over the natural slope, road cuts, and also over the road. The water around the road makes the road slippery and erodes the pavement. More important, water on the pavement or directly below

the pavement creates excess pore water pressures in the basement and pavement, causing rapid degradation of the road and cracks and potholes in the pavement. The materials on a natural slope in mountainous terrain are normally weathered under the influence of the hydrosphere, e.g. rainfall, groundwater, and day-night temperature changes. According to (Michael and Samanta 2016), induced vibrations and surcharge along slope cuts can cause or exacerbate instabilities. The probability of landslides decreases as you move farther away from the road corridor.

Table 4.12 Reclassification of the proximity to the road map of the study area

Proximity to road	Ranking	Area in (Sq. Km)	Percentage of Area	Level of Landslide
0-1km	1	105.01	38.36	Very High
1-3km	2	65.14	23.80	High
3-5km	3	50.28	18.39	Moderate
5-7km	4	35.06	12.83	Low
>7km	5	18.02	6.59	Very Low
Total		271.69	100	

Source: computation from GIS

From above table(4.12) the road proximity class between (0 - 1 km), is located especially in the eastern and southern parts of the research area. This area was more prone to landslides and subject to a very high-risk level. The second dominating class was given to high-level risk and encompasses 50.28sq.km (18.39%) located in central parts of the research area, its road distance ranging from 3 km to 5 km. As can be seen in figure 4.12 below, the study area's central and eastern regions have moderate, low, and very low-risk levels, which cover 50.28sq.km (18.39%), 35.06sq.km (12.83%), and 18.02sq.km (6.59%) respectively. The relevance of distance from the road in determining landslide risk is emphasized by the fact that landslide vulnerability is highest near road cuts and reduces as one gets away from the road (Kazakis et al., 2015). Therefore, the fact that the northwestern and southern parts of the study area are near to the road indicates that, these areas are more prone to landslides than the central parts of the study area, which are farther away from the road cuts. The road map is shown in the figure below (figure 4.12).

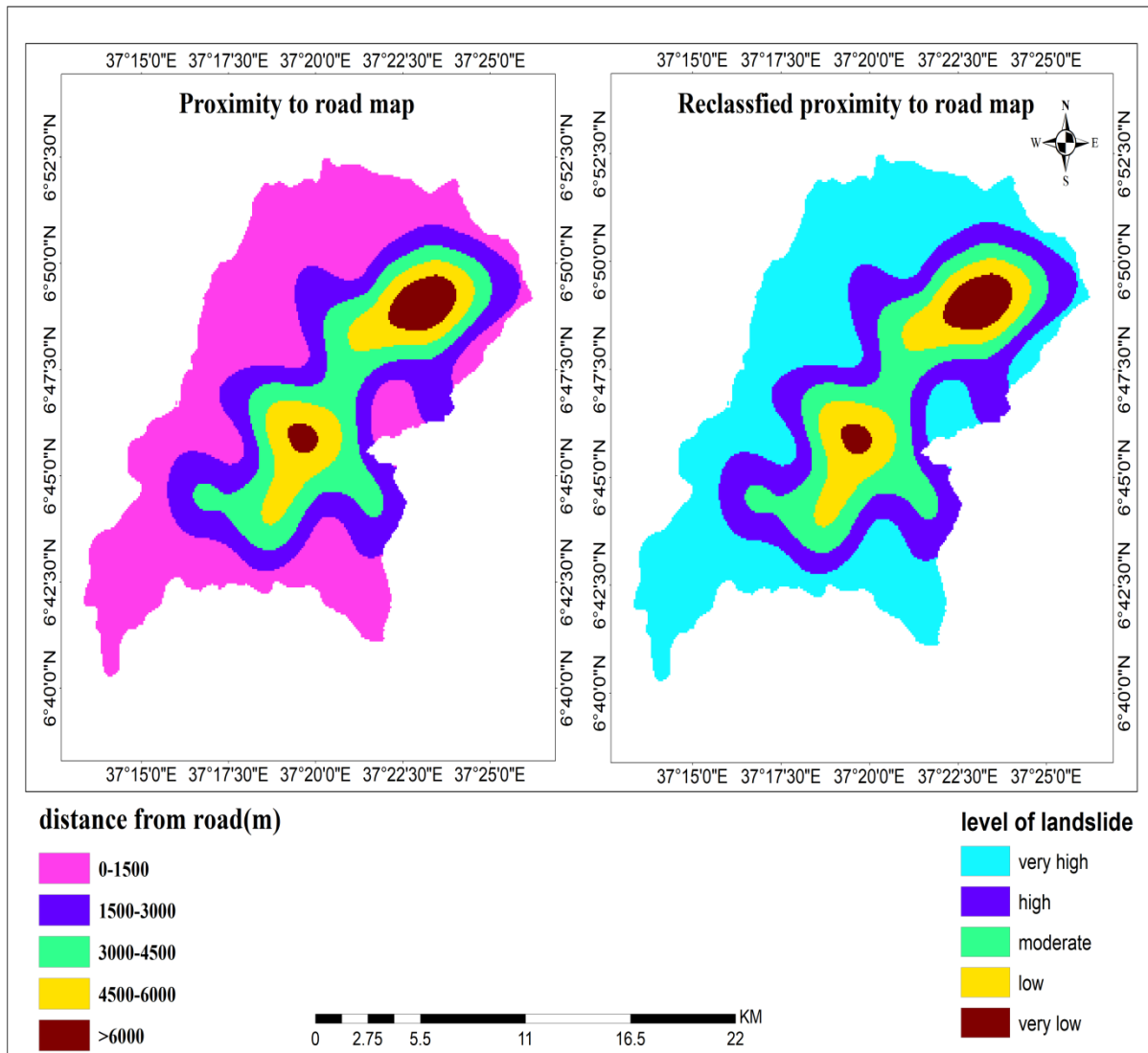


Figure 4.12 Reclassification of the proximity to the road map of the study area

4.3.3 Land use land cover factor

Land use change is influenced by population needs, such as converting agricultural and forest land to urban areas, converting forest to farmland, and lowering the involuntary or unethical slope for infrastructure development. Land use is an important factor in determining landslide susceptibility (Ayalew, 2015). The study area's existing land use classes (wetland, built-up, farmland, barren land, and forest) were reclassified into five groups based on their susceptibility to landslide risk. The study area's land use land cover was reclassified into a common scale of sensitivity for landslide risk mapping. Wetlands are the most vulnerable areas because they are immersed in water.

4.3.4. Landslide Hazard Layer

One of the landslide risk contributing factors in the study area was the landslide hazard layer. The landslide hazard classes of very low, low, moderate, high, and very high were reclassified based on their susceptibility to landslide risk. A very high landslide hazard layer was assigned a value of 5 because it is the most vulnerable to landslide risk. The very low landslide hazard layer, on the other hand, was assigned a value of 1 because it has the lowest susceptibility to landslide risk.

4.4 Analytical Hierarchy (AHP)

The analytical hierarchy process was used for factor weighting in this study, with the Nine Points Pairwise comparison scale (Saaty, 1977). AHP has received praise from researchers, practitioners, and policymakers for its use in assessing various geo-hazard problems such as floods and landslides. Landslide risk assessment is an inherently complex multidimensional process that includes both quantitative and qualitative factors that are susceptible to ambiguity (Gigovi et al., 2017). The primary goal of AHP-based multi-criteria decision-making is to rank and prioritize factors. The quantity of priority setting has a direct influence on the effectiveness of the available resources, which is, in most cases, the primary judgment of the decision-maker. Saaty's analytical hierarchy process is a method for prioritizing multiple-criteria decision problems. A pairwise comparison in AHP provides the weight of each causative factor as well as a consistency ratio that indicates the level of subjectivity in the factor comparison. The pairwise decision is based on the best available information as well as the decision-knowledge maker's experience (Gigovi et al., 2017; Ouma & Tateishi, 2014). AHP consists of four major steps: problem definition, pairwise comparison, calculating the maximum eigenvalues and eigenvectors, calculating the consistency ratio to ensure that the matrix is consistent, and aggregating the relative importance weights for decision alternatives to determine the final weight for decision alternatives (Blistanova et al., 2016; Ogato et al., 2020; Ouma & Tateishi, 2014). The analytical hierarchy process is the most widely used comparison method in the multi-criteria evaluation method. All landslide causative factors were compared based on their potential to cause additional landslides. AHP was used for this study because it provides a flexible, step-by-step, and transparent method of analyzing based on experts and end-users. See Table 4.13 below for detail.

Table 4.13 Pairwise comparison scale importance, definition, and explanation

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Preferences, knowledge, and judgments. Experience and judgment slightly favor one parameter over another
5	Strong importance	Experience and judgment strongly favor one parameter over another
7	Very strong	One parameter is favored very strongly and is considered superior to another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one parameter as superior to another is of the highest possible order of affirmation
2, 4, 6, 8 reciprocals		Intermediate values between adjacent scale values For inverse comparison

Source: (Satty,1977)

The requirement to use expert knowledge in weight determination is one of the most significant problems with the AHP method and can be viewed as a source of bias (Rahmati et al., 2016). The final weight of the factors is significantly influenced by the expert's decision. Determining each variable's weight influence before modeling was necessary for this study because not all variables had equal weight in determining landslide hazard and risk.

The criteria for the AHP process were then compared pairwise using the IDRIS 32 software, using a 9-point scaling method. The AHP method took the pairwise comparisons of each parameter as inputs and produced the relative weights of the parameters as outputs. It is asserted that the consistency of the pairwise comparison judgments directly relates to the output quality of the AHP. The consistency of the pairwise comparison was evaluated using the consistency ratio (CR) value

Table 4.14 The pairwise comparison matrix of the factors affecting landslide hazard

	LULC	Slope	Soil	D.river	Rain	Lithology	NDVI	LD	Elev	TWI
LULC	1									
Slope	3	1								
Soil	2	5	1							
D.river	1/2	2	1/3	1						
Rain	4	2	2	5	1					
Litho	2	1/2	1/2	2	1/3	1				
NDVI	1/4	1/7	1/6	1/3	1/8	1/5	1			
LD	1/2	1/5	1/4	1/2	1/6	1/3	2	1		
Elevation	1/3	1/6	1/5	1/2	1/7	1/4	2	1/2	1	
TWI	1/5	1/8	1/7	1/4	1/9	1/6	1/2	1/3	1/2	1

Source: computation from IDRSI

Where, ELV=elevation, LD=lineament density, LULC=land use cover, TWI=topographic wetness index, NDVI=normalized vegetation index and litho=lithology.

From the per-wise comparison, the highest weight was given for rainfall (26.71%) followed by the slope (20.28%), soil type (15.31%), lithology (11.32%), LULC (8.23%), and distance to a river (5.41%). Lineament density, elevation, NDVI, and TWI obtained 4.4%, 3.98%, 2.48%, and 1.87% percent of the total weight, respectively. From the derived weight, it is evident that the elevation factor is the most influential in landslide generation. This means that the areas with high elevation are more vulnerable than the plain and flat lands.

Table 4.15 The Eigenvector of Weights.

Factors	Weight	Weight in percent
Lithology	0.1132	11.32%
slope	0.2028	20.28%
Rainfall	0.2671	26.71%
lineament	0.0440	4.44%
ndvi	0.0248	2.48%
TWI	0.0187	1.87%

elevation	0.0398	3.98%
LULC	0.0823	8.23%
Distance from river	0.0541	5.41%
Soil	0.1541	15.41%

Source: computation from GIS

The eigenvector is used to weigh the standardized raster layers to illustrate the importance of each factor in comparison to the other criteria in the resulting landslide hazard. The eigenvector of weight for each factor map was determined and the consistency ratio is calculated in IDRISI software. Refer to Figure 4.13 below for more detail.

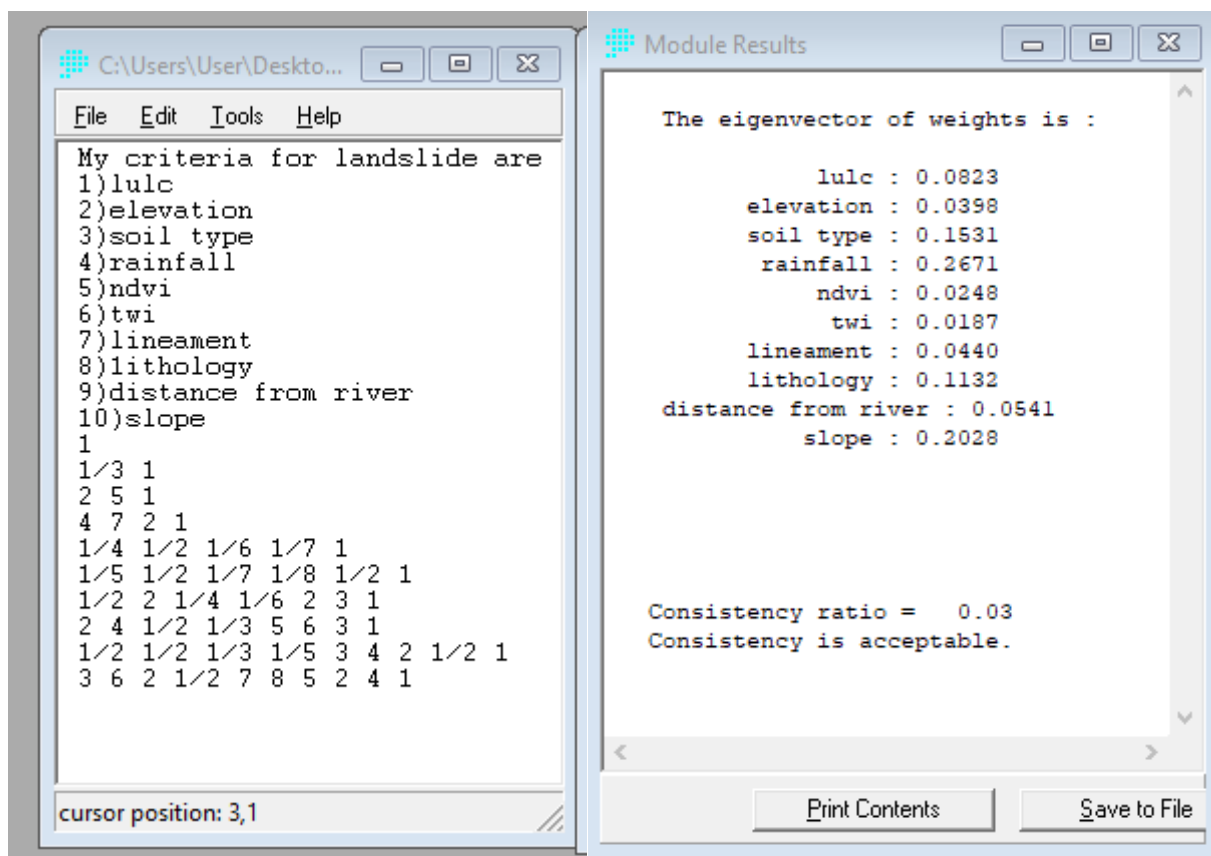


Figure 4.13 Derivation of eigenvector factor on IDRISI

The calculated Eigenvector's critical ratio in this study is 0.03, which is acceptable. As a result, these weights can be used to assign each of the parameters. To create a landslide hazard map using a GIS environment, a multi-criteria analysis was carried out after each factor's weight was determined and the consistency ratio was checked. To put it another way, the

process of criteria map aggregation uses the weighted linear combination method. The fundamental justification for using WLC is that, when the criteria are aggregated, low scores in one criterion are made up for by high scores in another. Landslide risk chart which means the weighted linear combination method, which differs from the AHP method, multiplies each standardized criteria map with criteria weights before summing the outcome (Gigovi et al., 2017). Consequently, a landslide hazard index was created to calculate the landslide hazard map for the study area as shown in Eq.(4.1).

$$\text{Landslide hazard Index} = 0.0823 \times \text{land use/land cover} + 0.2028 \times \text{slope} + 0.1531 \times \text{soil type} + 0.2671 \times \text{rainfall} + 0.0440 \times \text{lineament density} + 0.0398 \times \text{elevation} + 0.0187 \times \text{TWI} + 0.0541 \times \text{distance from river} + 0.0248 \times \text{ndvi} + 0.1132 \times \text{lithology} \dots \text{Eq. (4.1)}$$

Raking, or scaling (from 1 to 5), of each subclass of each factor was carried out in weighted overlay analysis to ascertain their importance in landslide generation.

Table 4.16 Weighted landslide hazard ranking for the study area

Factors	Class	Level of hazard	Rates	Weight
TWI(class)	2.56-6.13	Very low	1	1.87%
	6.14-9.84	Low	2	
	9.85-13.52	Moderate	3	
	13.53-16.74	High	4	
	16.74-18.35	Very high	5	
Elevation(m)	650-1100	Very low	1	3.98%
	1200-1400	Low	2	
	1500-1900	Moderate	3	
	2000-2300	High	4	
	2300-2500	Very high	5	
Slope (%)	0-8.58	Very low	1	20.28%
	8.58-22.65	Low	2	
	22.65-31.24	Moderate	3	

	31.24-47.77	High	4	
	>47.77%	Very high	5	
Precipitation (Mm/yr.)	1160.34-1203.23	Very low	1	26.71%
	1203.23-1231.39	Low	2	
	1231.39-1258.28	Moderate	3	
	1258.28-1288.36	High	4	
	1288.36-1323.66	Very high	5	
LULC(class)	Wet lands	Very high	5	8.23%
	Bare land	High	4	
	Agriculture	Moderate	3	
	Settlement	Low	4	
	Vegetation	Very low	1	
Distance from river(m)	0-1300	Very high	5	5.41%
	1400-2900	High	4	
	300-4500	Moderate	3	
	4600-6200	Low	4	
	6300-8900	Very low	1	
NDVI(class)	-0.28-0.015	Very high	5	2.48%
	0.015-0.14	High	4	
	0.14-0.27	Moderate	3	
	0.27-0.36	Low	2	
	0.36-0.74	Very low	1	
Lineament density (km/km2)	0-54.57	Very low	1	4.40%
	54.57-109.15	Low	2	
	109.15-159.18	Moderate	3	
	159.18-216.78	High	4	
	216.78-386.58	Very high	5	
Lithology (class)	Tertiary intrusive rock (Ti)	low	1	11.32%
	Quaternary volcanic rock(Qv)	High	2	

Soil type (class)	Eutric nitosol	Low	1	15.31%
	Eutric cambisol	Moderate	3	
	Haplic xero soil	High	5	

Source: computation from GIS

For calculating landslide risks, different researchers have used various formulas. Hazard and consequence were combined to produce a risk value (Jamaludin and Hussein, 2006). The standard formula for determining landslide risk (R) is $R = H \times (E \times V)$, where H stands for landslide hazard, E is for the element at risk, and V is for vulnerability. Kouli et al. (2009) stated that landslide risk was determined by the product of hazard and exposure. Data layers on population density, land use, proximity to roads, and landslide hazard were combined to estimate the exposure factor. On the other hand, qualitative risk assessment is primarily based on combining a vulnerability index and a hazard index using spatial multi-criteria evaluation (Corominas and Mavrouli, 2011). The risk of landslides is frequently expressed by the product of landslide hazard and landslide vulnerability (Akgun et al., 2012). By superimposing the landslide hazard layer, and the three elements at risk population density, proximity to road and land use land cover, landslide risk mapping for the study area was completed. The vulnerability is assumed, with the degree of loss being total for the study area. The weighted linear combination process considered the four landslide risk factors to be equally significant (Ogato et al., 2020). As shown in the methodological flow chart in chapter three figure (3.3), these four factors were combined to create the landslide risk map using the weighted overlay analysis technique in the spatial analyst tool of Arc-GIS 10.5 environment. Landslide risks of the Kindo Kidaye area were produced from the following general risk equation.

Risk= landslide hazard* landslide vulnerability.....Equation 4.2

A landslide risk index was created and used in a weighted linear combination process in the ArcGIS environment to generate the study areas landslide risk map as shown in Eq (4.3)

Landslide risk index = $0.25 \times \text{landslide hazard} + 0.25 \times \text{Population Density} + 0.25 \times \text{Land use/Land cover} + 0.25 \times \text{proximity to road}$ Eq. (4.3)

Table 4.17 Weighted landslides Risk ranking for the study area

Factors	Weight (%)	Class	Ranking
Landslide hazard layer	25%	Very low	1
		Low	2
		Moderate	3
		High	4
		Very high	5
Land use land cover	25%	Wet lands	5
		Barren land	4
		Agriculture	3
		Settlement	2
		Dense vegetation	1
Population density (population number/area)	25%	187-244	1
		245-388	2
		389-488	3
		489-725	4
		726-824	5
Proximity to road	25%	0-1km	5
		1km-3km	4
		3km-5km	3
		5km-7km	2
		>7km	1

Source: computation from GIS

In this study, the four elements at risk (hazard layer, proximity to road, population and land use, and land cover) were taken into account for weighted overlay analysis for landslide risk mapping. But different aspects of vulnerability need to be taken into account for a more thorough assessment of landslide risk (economical, ecological, and social). Without taking into account the coping abilities of the people and the structural integrity of the buildings, the vulnerability was assumed to be one, which means an equal degree of loss to the landslide risk of element a risk. These three variables land use and land cover, population density, proximity

to the road, and landslide hazard map layer were still equally significant in the Weighted Overlay technique (25 percent for each). Based on their ability to generate landslides, each subclass was rated. Table 4.17 includes a list of the targeted factors, their weights, and ratings. The data in the table above was used to create a map of the study area's landslide risk. The map that the landslide risk index produced, which was divided into five risk categories very low, low, moderate, high, and very high shows the various levels of landslide risk in the study area.

4.5 Landslide Hazard Mapping and Analysis

Disasters caused by landslides are among the most common and harmful natural hazards in the world. Delineation of the landslide-prone areas is the most crucial task in landslide hazard management and mitigation to identify the areas most susceptible to landslide hazards. In this study, the ten landslide causative factors distance from the river, topographic wetness index, slope, elevation, lineament density, rainfall, land use land cover, soil type, aspect, and normalized vegetation index were weighted together to calculate the landslide hazard mapping. In a GIS environment, each of these variables was created, reclassified, weighted, and stored. As shown in (Fig. 4.14) below landslide hazard zonation was produced from identified environmental factors using GIS-based AHP model. AHP was developed by Professor Thomas Saaty of the Wharton Business School in 1977. It was based primarily on the pair-wise comparison matrices that decision makers use to establish preferences between alternatives for different criteria and the rating methods (Saaty, 1994). Since its introduction the AHP has been applied widely in various fields. It has been utilized in a lot of specific applications and areas such as natural hazards like landslides, floods, earthquakes, energy, health, conflict resolution and arms control, material handling and purchasing, manufacturing system, manpower selection and performance measurements, project and portfolio selection, marketing, budget allocation, education, politics, sociology and the environment (Saaty, 1980; Saaty & Vargas, 1982; Zabedi, 1986).



Model

Figure 4.14 Landslide hazard analysis model builder dialogue box

The weights for each factor were determined after discussions with relevant organizations (experts) and research in the literature, and IDRIS software was used to calculate the eigenvectors. To combine the factor maps in a weighted overlay analysis for mapping

landslide risk and hazard in the Arc GIS environment, the computed eigenvector was used as a coefficient.

According to the detailed results of the landslide hazard map of the study area (Fig. 4.15), the study area's 98.55, 48.69, 55.67, 41.96, and 26.99sq.km were subjected to very low, low, moderate, high, and very high landslide hazard zones respectively as shown in (Table 4.15).

Table 4.18 Area's coverage of landslide hazard analysis of the study area

Rank	Area in sq. km	Percentage of the area	Level of hazard
1	98.55	36.24	Very low
2	48.69	17.90	Low
3	55.67	20.48	Moderate
4	41.96	15.43	High
5	26.99	9.93	Very high
Total	271.69	100	

Source: computation from GIS

Table 4.18 reveals that out of the total 271.69 sq. km that covers Kindo Didaye woreda, the very high landslide hazard zone covers an area of 26.99sq.km, while the high landslide hazard zone is 41.96sq.km. The very high landslide hazard zone falls around, areas that receive the maximum amount of rainfall, areas near the river, and areas with steep slope found. The values for the very high landslide hazard zone seem small compared to the other hazard area coverage. However, because landslides happened mostly in high steep slope, an area with undulating terrain and viable water bodies, people tend to settle at high lands, especially closer to the river. These kinds of human activities are needed to be managed and no construction around the river basin are to be allowed. The landslide hazard map of the study area also confirms that the most landslide-vulnerable areas are those steep slope, those areas nearer to the omo river, and areas around bare lands.

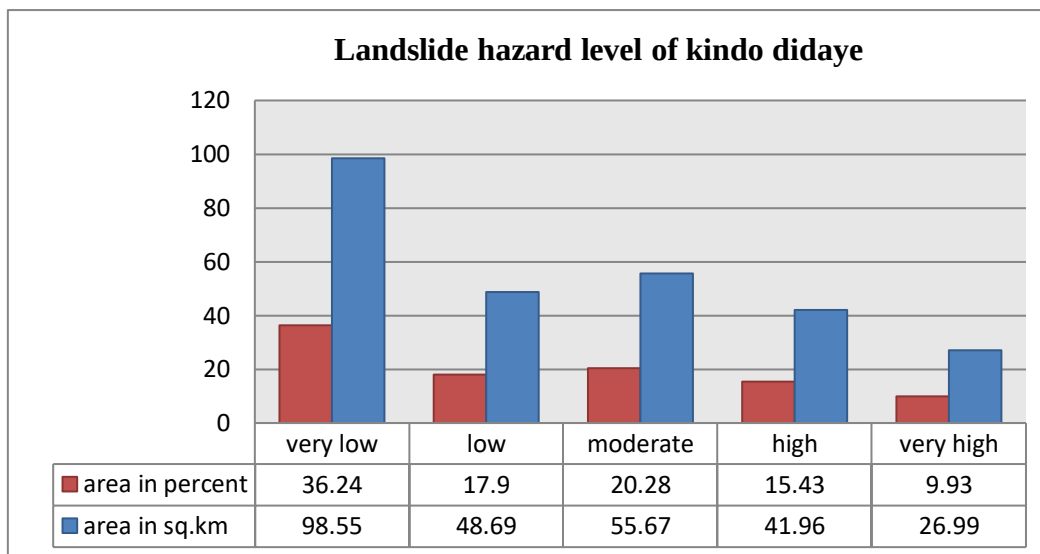


Figure 4.15 Level of landslide hazard analysis by charts

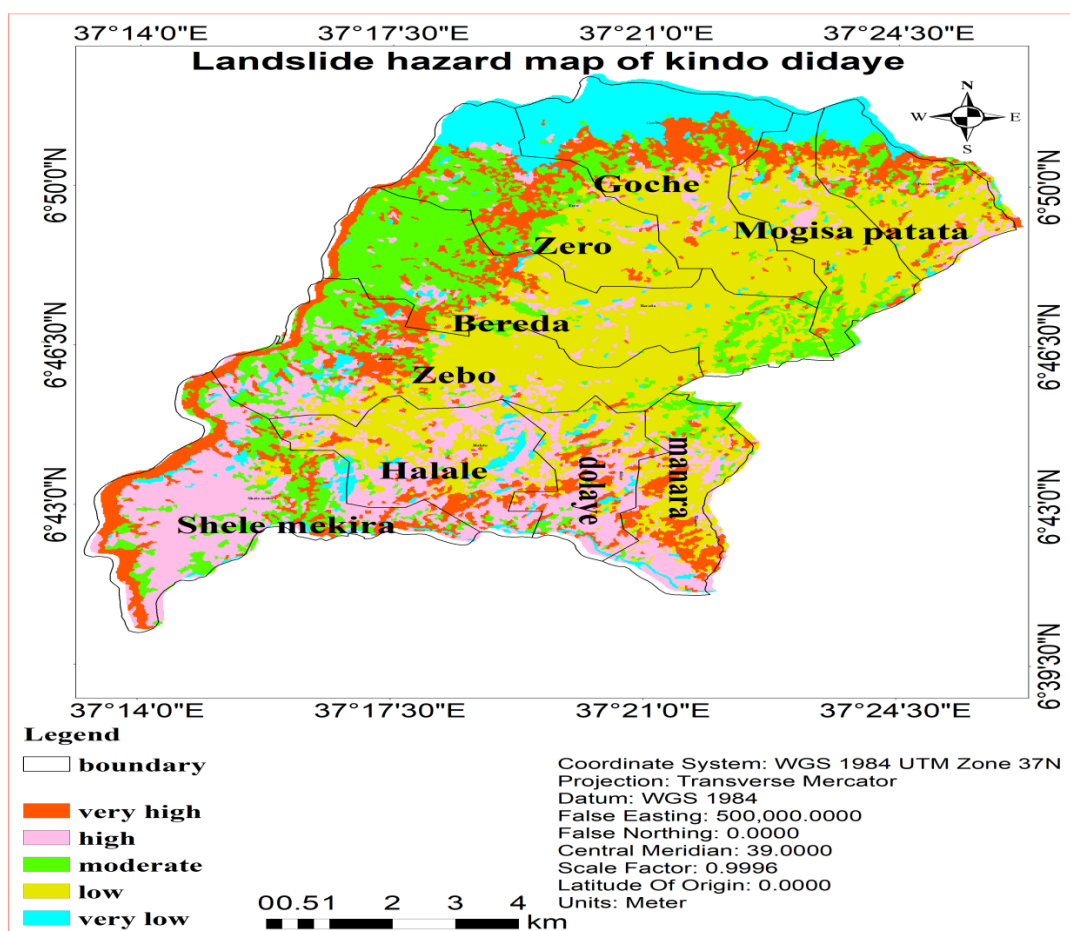


Figure 4.16 Landslide hazard map of Kindo Didaye

4.6 Landslide Risk Mapping

Landslide risk mapping was done for Kindo Didaye Woreda by taking population density, roads and land use land cover elements that are at risk of landslide combined with the degree of landslide hazards of the study area. Figure (4.16) shows the landslide risk analysis model builder dialogue box.

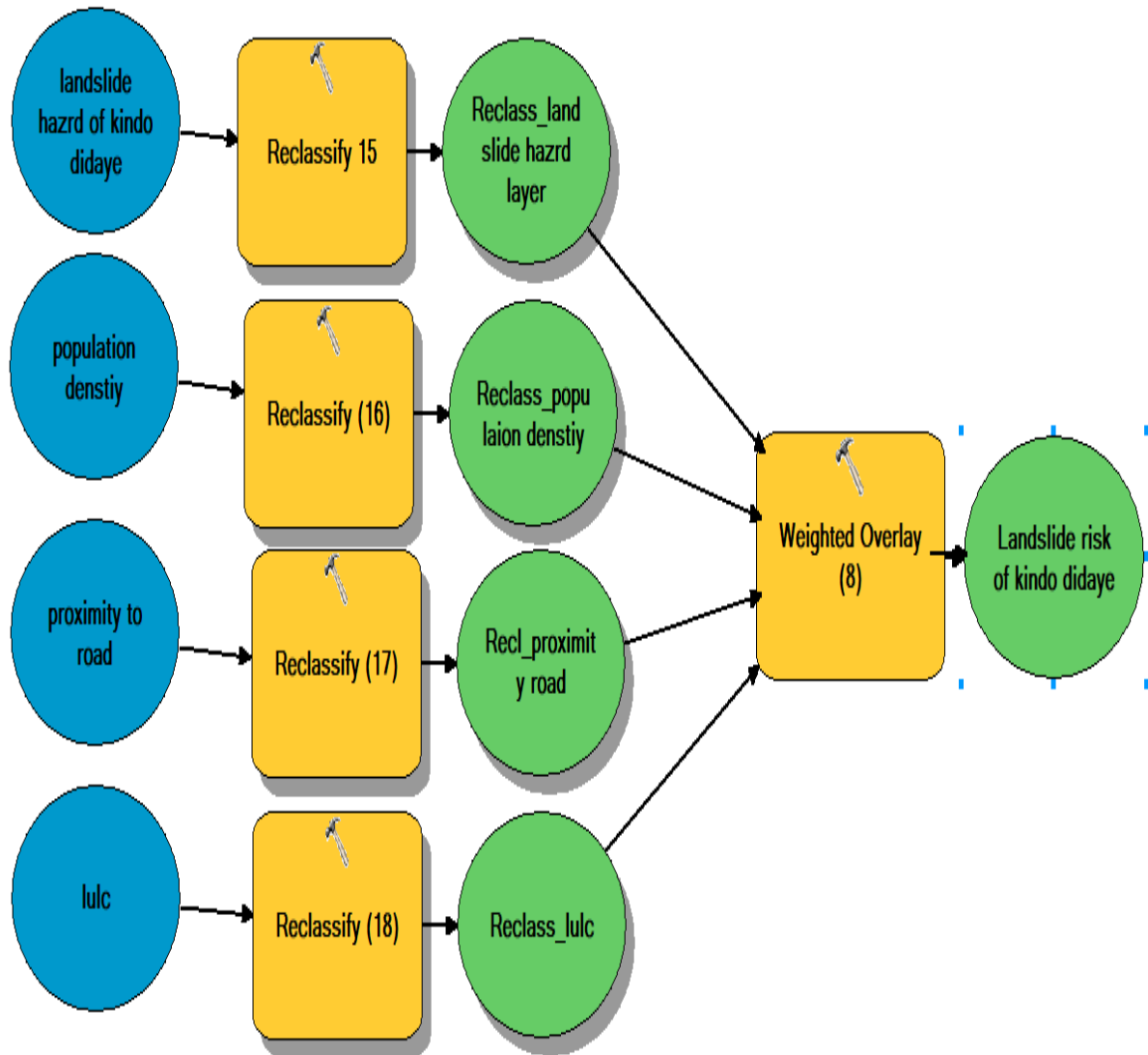


Figure 4.17 Landslide risk analysis model builder dialogue box

It was determined from the study area's landslide risk map that 37.04 (7.62%), 41.59 (15.30%), 50.50(20.57%), 47.67 (19.52%), and 95.12 (36.98%) sq. km of the study area were,

respectively subject to very high, high, moderate, low, and very low landslide risk levels (fig.4.11). The risk factors taken into account in this study demonstrate varying degrees of risk. The area subjected to a high and very high landslide risk is in the eastern and northern part of the study area near Omo River.

4.19 Area's coverage of landslide Risk analysis of the study area

Rank	Area in (sq. Km)	Percentage of the total area	Level of hazard
1	95.12	36.98	Very low
2	47.67	19.52	Low
3	50.51	20.57	Moderate
4	41.59	15.30	High
5	37.02	7.62	Very high
Total	271.69	100	

Source: computation from GIS

According to Table 4.19, there is a very high and high landslide risk zone covering 41.59 and 37.02sq.km of the total area, respectively. An area of about 20.57 percent (50.50 km) of the total area is at moderate risk for landslides. An area of 19.52 percent (47.67sq.km) and 36.98percent (95.12sq.km) of the land is covered by low and very low landslide levels, respectively. The study area reveals that there is a very high and high landslide risk area almost distributed in the central, northern, and eastern parts of the study area. The areas closer to the Omo River in the study area are the areas with very high and high landslide risks. In addition to this, the area near Omo River, the area with the highest population density, and those that fall under the category of barren lands are subject to very high risk. The study area landslide risk map also confirms that the most landslide-affected areas are those with high the area with steep slope (greater than 47.77%), those areas closer to the Omo River, and areas with higher population density, and the areas that are not covered by artificial or impervious surface (settlement or built-up areas) such as barren lands were exposed to landslide disaster.

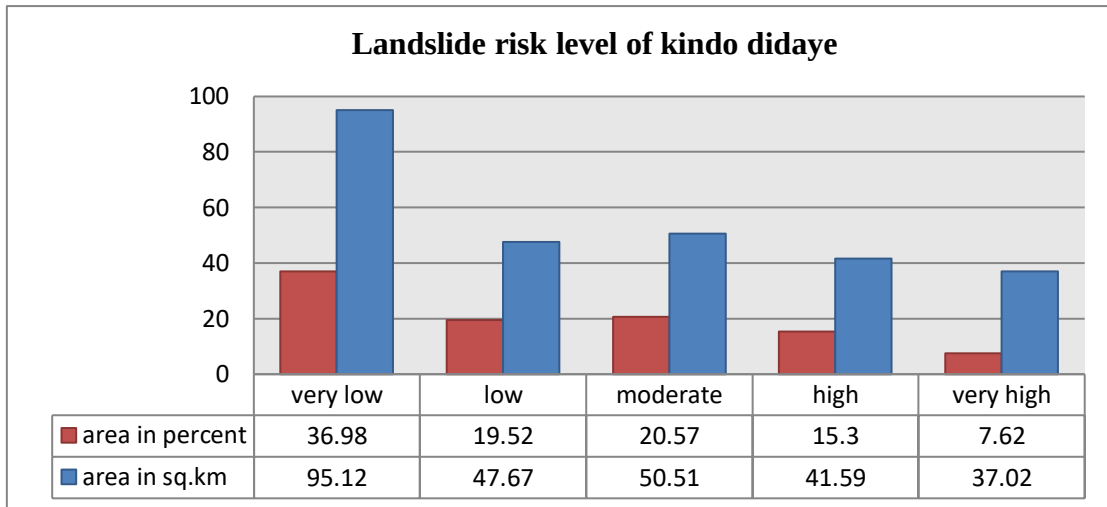


Figure 4.18 Landslide risk level analysis of Kindo Didaye

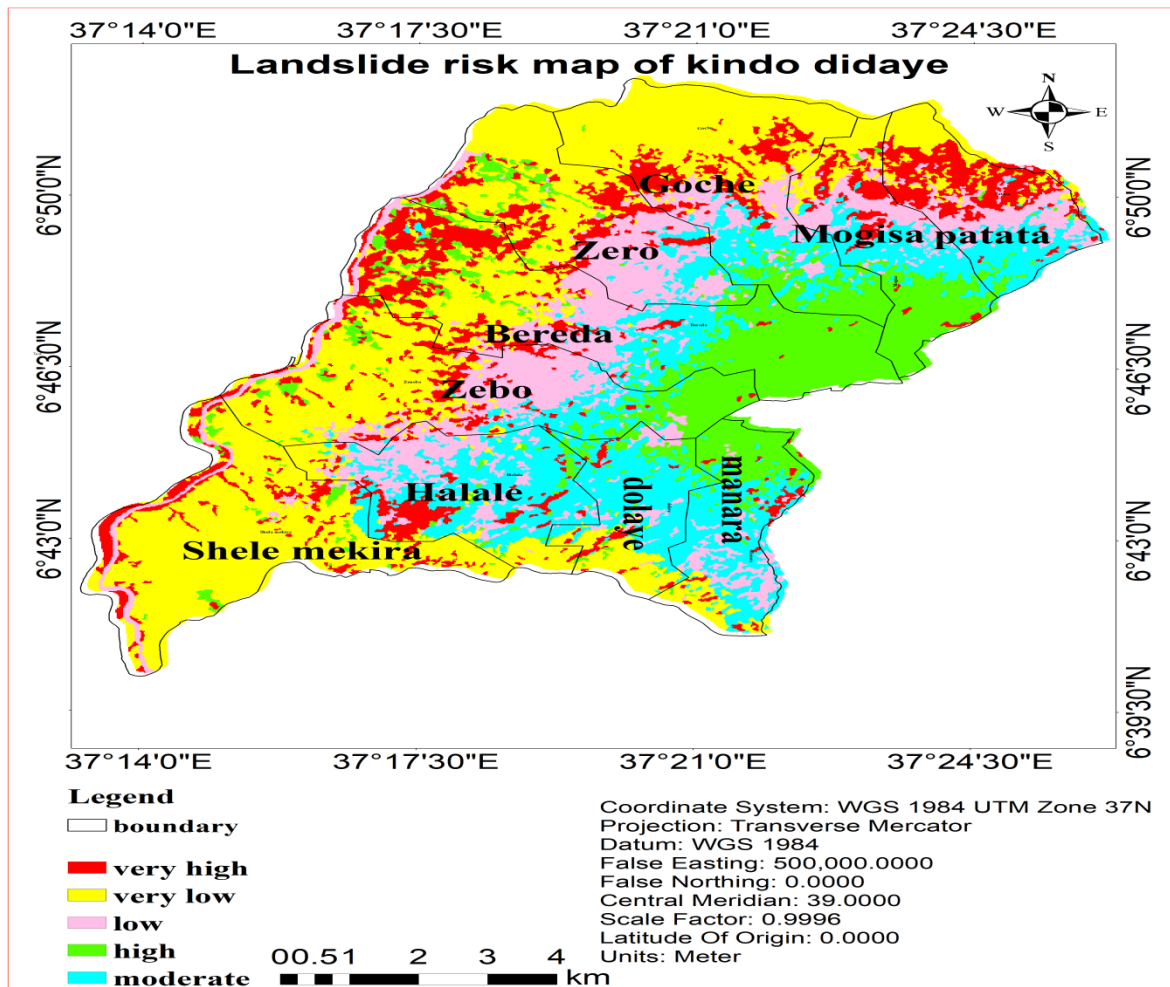


Figure 4.19 Landslide risk map of Kindo Didaye

4.7 Landslide inventory

The land slide inventory map was created by combining several techniques as follows. A total of 119 landslide locations were determined via field investigation and Google earth from the current study area, and they were randomly divided into training and validation landslides while maintaining their spatial distributions. 84 (70%) and 35 (30%) of the area were used for the training landslides and the validation landslides to validate the predicted image, respectively (Figure 4.20).

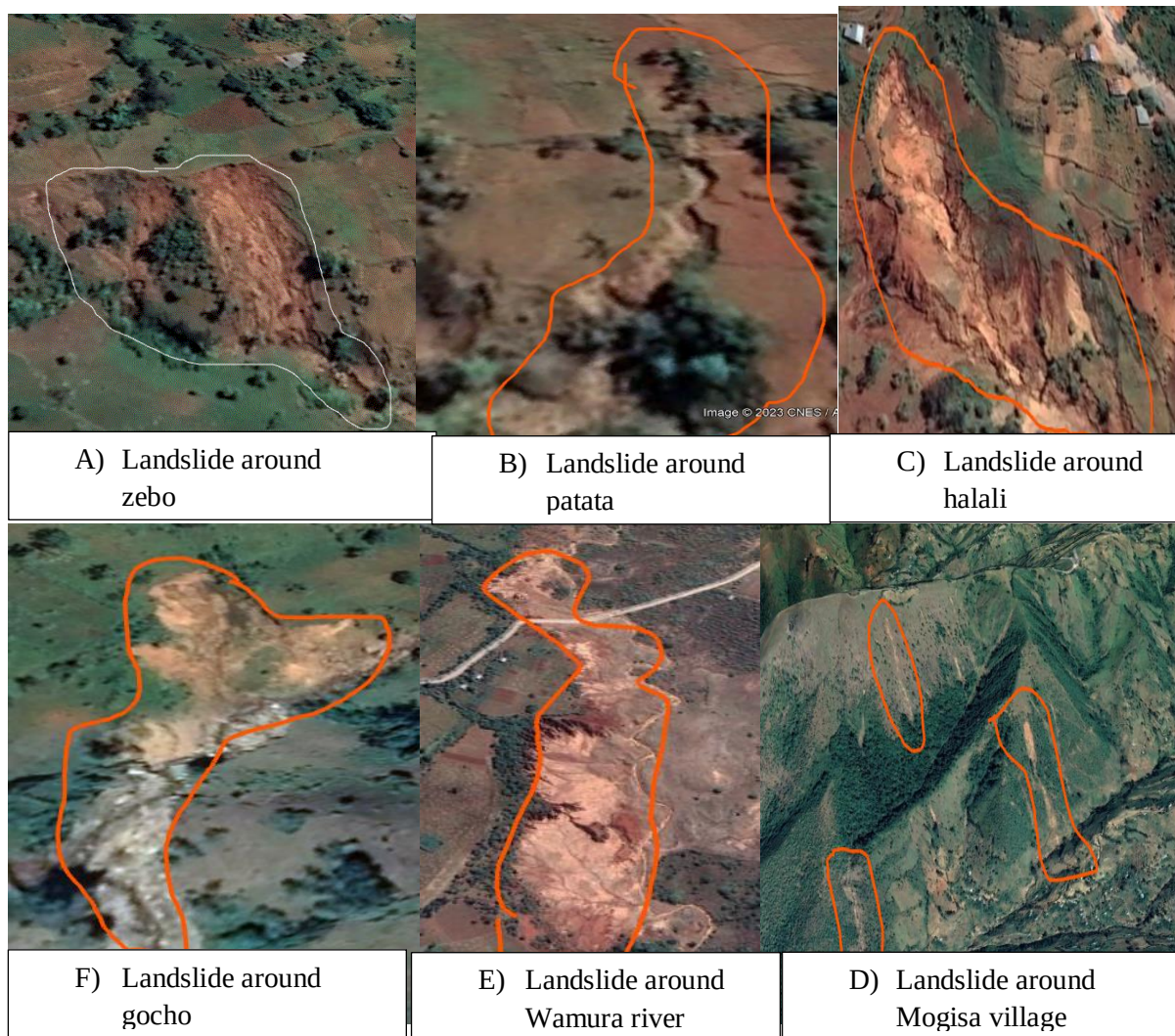


Figure 4.20 (A-F) landslide-prone areas of the different villages of the study area by Google earth. The remaining landslide-prone areas were discovered during field investigations. See figure 4.21(G-L) below



Figure 4.21 (G-L) landslide-prone of the study area by field observation

Vegetation, forest, crop, and grassland damage in the study area are mainly distributed in the northwest-southeast, south, and central regions of the study area. This region consists of rocky, mountainous terrains with high stream network areas, fractured rocks, and weathered rocks with high relative relief. Earth slides, debris slides, and flow, rotational, and translational soil slides are among the frequent landslide occurrences in the study area.

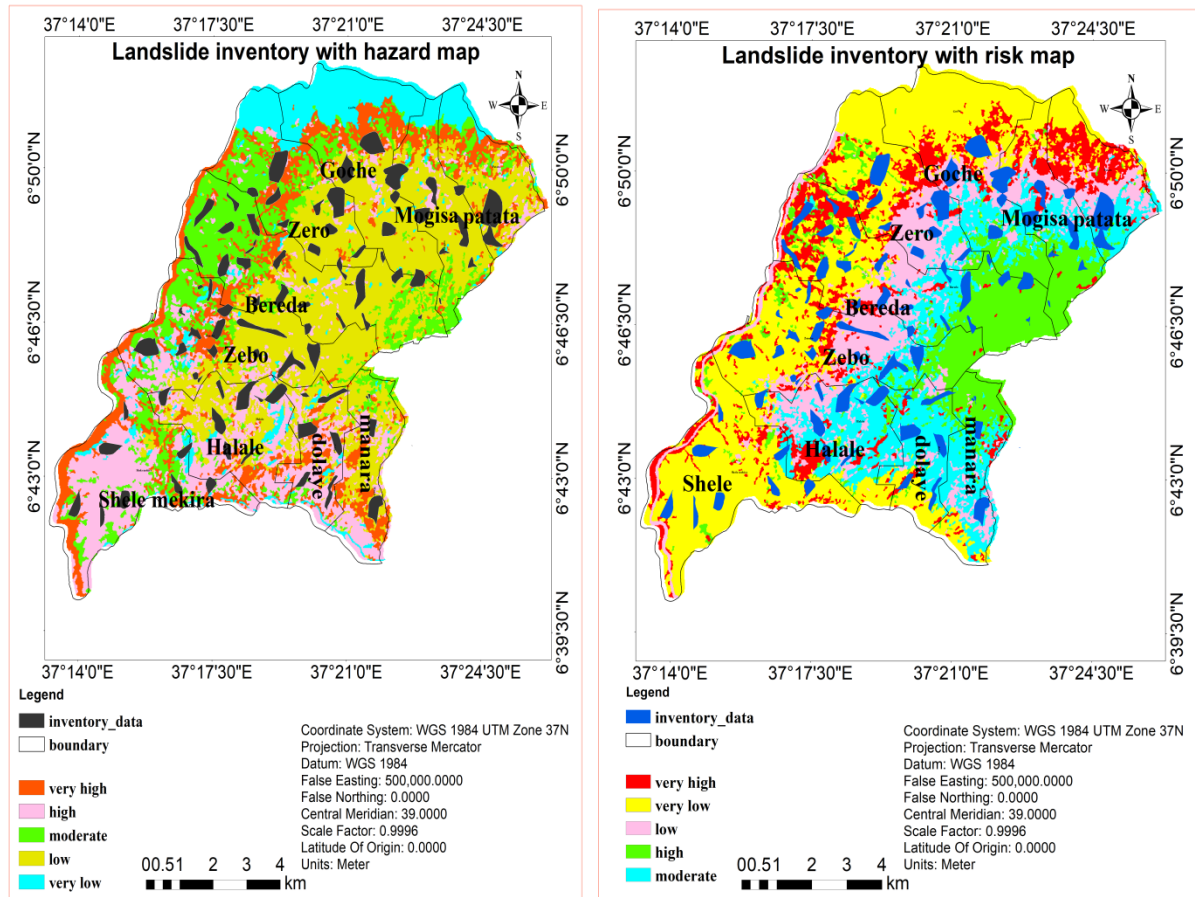


Figure 4.19 Landslide inventory map of Kindo Didaye

4.8 Validation

Landslide hazard maps are useless without validation. Therefore, a crucial step in the process of landslide hazard mapping is the validation of predictive landslides (Bui et al., 2012). The 30% of the validation landslide dataset was used to validate a training map created using the 70% of landslides with the causative factors. Utilizing receiver operating characteristics (ROC) and the area under the curve, the performance of the landslide hazard map created by weighted overlay approaches was assessed in the current study (AUC).

4.8.1 Area under the Curve (AUC)

To calculate the area-under-curvature (AUC) method, success rate and prediction rate curves are created (Lee, 2005). By contrasting the hazard map with both the training landslide (70%) and validation landslide (30%), it is possible to validate the landslide hazard map. For both

methods, rate curves can be produced. The comparison between the training landslide and the prediction map forms the basis of the success rate curve. Additionally, the validation landslide and predicted map comparisons form the basis of the prediction rate curve. The model's ability to accurately categorize the occurrence of existing landslides is shown by the Area under the Curve (AUC) of the success rate, whereas the proposed landslide model's ability to predict landslide hazard is demonstrated by the AUC of the prediction rate (Pamela et al., 2018). In this study, AUC was created using a landslide inventory along with result maps (landslide hazard map). Most of the researchers use ROC and AUC for model validation for bivariate static methods like frequency ratio (Padmani and RA, 2017; Roy and Saha, 2019; Meten, 2020; Li, 2020, 2017). The study used the AUC for model validation. The ROC curve is drawn by the X and Y-axis. The X-axis represents the false positive rate (1-specificity) and the Y _ axis represents the true positive rate (sensitivity). The model validates the range of the AUC based on the input value. The area under the curve ranges between (0_1). To create AUC for the currents study, ArcSDM is downloaded from <https://github.com/gtkfi/ArcSDM> and plugged into GIS arc tool box for further processing. As a result, it is acceptable because both the training and validation (testing) results showed above 0.5. Table .4.20 shows that whether the performance of the model used was good or not if the AUC value is less than 0.5 calculations must be done again. Refer (Figure 4.20) below for more detail.

Table 4.20 Characteristics of AUC of ROC curve

AUC value character	Character
0.9-1.0	Perfect
0.8-0.9	Excellent
0.7-0.8	Very good
0.6-0.7	Good
0.5-0.6	Average
0.4-0.5	Satisfactory

Source: (Yesilnacar, 2005)

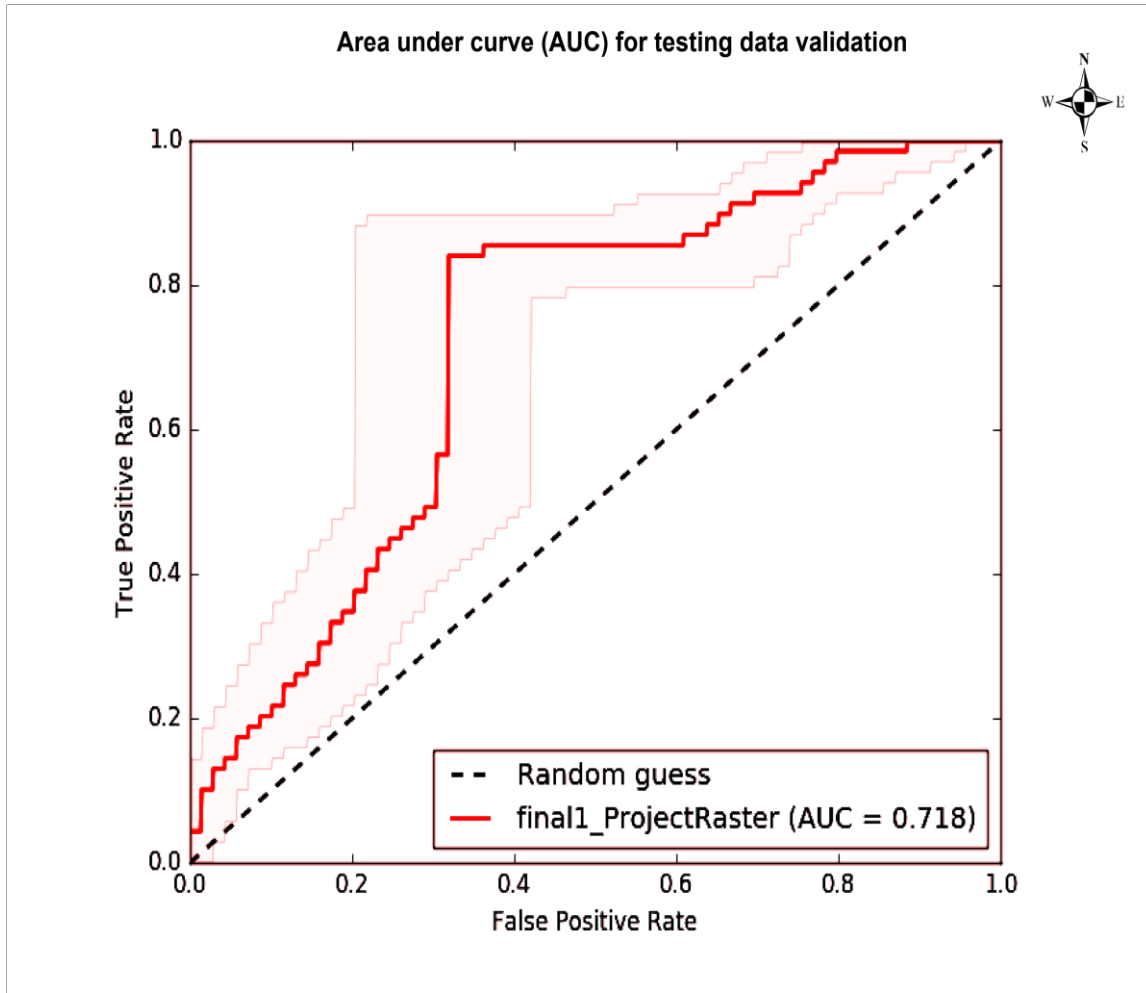


Figure 4.22 AUC for testing data

4.9. Mitigation Measures

Mitigation is the process of preventing or reducing the risk that natural hazards will negatively impact life, property, social and economic activities, and natural resources. When precise information about the frequency, magnitude, and character of slope failure within a specific area is known, mitigation of the landslide hazard can be successfully implemented (Vijith et al., 2009; Liu et al., 2006). For these reasons, locating landslide-prone areas is a quick and inexpensive way to comprehend this risk and make sure that the proper mitigation measures are put in place (Bai et al., 2009). Physical countermeasures like slope stabilization, reforestation, and water management can reduce the risk of landslides. However, each class has some unique characteristics and mechanisms for failure; as a result, mitigation measures

are proposed to counteract each class's impact on slope stability (Bhim et al., 2017). The most prevalent factors causing landslide hazards and risk in the study area were used to generate a map showing the likelihood of landslides. The slope, elevation, lineament density, aspect, soil, normalized vegetation index, topographic wetness index, distance from the river, rainfall, and land use of the land cover of the area corresponding to the hazard class were taken into consideration when analyzing the landslide hazard class. Local government planners will be able to mitigate landslide hazards and support the development of sustainable, hazard-resilient communities in the study area with the help of the landslide hazard information provided by this study's work. Therefore, when choosing the most effective mitigation strategies to implement in hazard zones, it is important to consider the factors that may affect the risk of movement or landslides, such as the local topography and any current or potential causes of geo-system changes that may have an impact on these events. By taking into account the topography of the area concerning the hazard zone, mitigation measures were suggested based on various predominating factors and overlapped in every cell unit of the landslide hazard map. The landslide hazard class was observed in a different class of causative factors when the landslide hazard map overlapped with those factors. According to the causative factor class and landslide hazard class, the study area's concise mitigation representation of the hazard zone was presented. In this study, mitigation strategies are used to prevent erosion, strengthen the soil by building retaining wall, improve drainage, reduce soil and rock from the tip of highly affected areas, reforestation, plant trees, and protect the area's hillside foot. Stopping cultivation on top of hilly area.

4.9.1 Mitigation method for very high hazard zones

Very high hazard zones indicate the most affected landslide-prone area and this area is mostly located in central, northwestern parts of the current study area near Zebo village and southern parts of the study area near Dolaye and Manara village. Settlement (construction) and other activities need to be limited in this area. Mitigation methods for very high-hazard zone include:

- A) *Stopping cultivation on extremely steep slopes:*** cultivating crops on steep slopes can weaken the slope via undercutting, which destabilizes the earth farther upslope and

may potentially cause a worse slide than is being prevented. If the forest cover in those areas is cleared for cultivation, the hill slopes are more likely to have landslides (Lee 2004).

- B) ***Removing the soil and rock at the head of the landslide:*** A landslide can be slowed down or stopped by clearing away the soil and rock near the top of the slide. To stop another landslide from occurring upslope, more rock and soil will need to be removed from above the slide. Landslides can be stabilized by reducing the angle of the slope at the top of the hill and making it inclined to slopes (Wischmeier, 2013).
- C) ***Building retaining walls:*** Slopes that have been severely eroded will keep collapsing downward unless they are stabilized. A retaining wall at the slope's bottom will contain the soil and delay the collapse. As a result, grass or other plants have more time to develop and strengthen the soil. These structures are built from concrete blocks, rock, or wood (Lee 2004).

4.9.2 Mitigation Measures for high hazard zones

The high-hazard zone is mostly located around Shele Mekira, Dolaye, Manara, Zero Village, and the northern parts of the study area. Construction and other activity should be restricted and consulting with a professional is better before significantly altering existing slopes uphill or downslope. Mitigation measures high hazard zone include:

- A) ***Preventing Soil Erosion:*** When the forces keeping rock or soil together are weaker than the forces of gravity drawing them downward, landslides can occur. The soil is kept in place in part by the tree and brush roots. The soil and rocks tumble down the hill once they are gone. In tropical locations, soil erosion is a frequent geological hazard that has significant detrimental effects on the places where it occurs (Muslim 2015). For land use planning techniques and agricultural management, determining the spatial distribution of regions vulnerable to erosion risk by improving drainage is crucial (Mati et al. 2000).
- B) ***Improving surface and drainage:*** Because water is a major contributor to landslides, the site's surface and subsurface drainage can be improved to boost the slope's stability. Surface water should be redirected away from the landslide-prone area by running it

down the slope in a sewage pipe or lined drainage ditch. To prevent causing a landslide close to the location, the water should be diverted. The landslide-prone slope shouldn't be permitted to accumulate surface water (Smith, 1978).

C) *Planting Vegetation:* Planting trees and tiny bushes on the slope is another easy approach to stop landslides. The roots of these trees and bushes hold the soil together as they enlarge, preventing soil erosion that could eventually cause the slope to become unstable. In reality, there are some types of plants with shallow roots that are utilized specifically in mountainous areas to safeguard the top layer of soil. You may find out more about these plants at a local nursery and plant them along the hill (Koesmono, 2016).

4.9.3 Mitigation Method for moderate hazard zones

The moderate hazard zone is located in all parts of the study area, especially in the central and southeastern parts of the study area. Existing property owners in this zone should be notified and educated about the hazard. Mitigation method for moderate hazard zone include:

A) *Changing weak crops with strip cropping:* This technique is used to lessen and prevent landslides on agricultural land. More susceptible to landslides are crops that require sparse planting or have weak roots. Plant alternate strips with a crop that resists erosion (Alfan, 207).

B) *Protecting grazing around landslide area:* If cattle are allowed to graze year-round, grazing land cannot be maintained in a healthy and landslide-resistant condition. (Triandanu, 2014).

C) *Keeping the soil covered year-round:* Compared to soil with ground cover, bare soil is much more susceptible to landslides (Renard et al. 1991).

D) *Terracing in steep slopes:* Terracing is a technique that involves cutting into steep slopes to create contour ridges and cultivable areas that are supported by stone walls. The terraces' perpendicular placement to the water's flow prevents erosion, holds onto soil moisture, and creates a microclimate that is favorable to crop growth. While their primary goal is to enhance cropland, they also lessen the slope of the hillsides to minimize landslides that could harm upstream buildings, homes, and crop regions.

Traditional terracing construction and restoration methods need significant manpower input, which must come from the community (Suwarna, 2016).

4.9.4 Mitigation method for very low and low hazard zones

The very low and low hazard zones are located in all parts of the study area, especially in the northern parts of the study area. Construction and other activities in this area need only consider landslides as a minor threat. Mitigation method for very low and low zone include:

A) Public Awareness and Education Program: Although the general public and communities at risk were the program's primary target audiences, there were additional target audiences that included state and local governments, private property owners, the media, universities, and schools. The public was to receive two important messages from the awareness campaign. The first was to notify the public that there is a body of relevant knowledge on the phenomena of landslides as well as advice on monitoring and maintenance that is available to the public. The second is that a government organization is in charge of defending the interests of public safety. All of the awareness program's activities were focused on the "Learn, and Report" marketing theme, which encompassed these messages. The slogan "Safe Slopes Save Lives" served as the unifying theme for all of these events" (Rashid Ahmad, 2017).

1) Learn: Residents and the broader public are required to have some understanding of the slope safety concepts before any community action could be conducted. The general public received training on slopes and landslides through seminars and open forums. The definition of a slope, different types of landslides, factors that cause landslides, triggers for landslides, and key ideas in slope water control, slope cover, retaining walls, and geological elements were all taught to the residents (Zainal Arsad, 2015).

2) Report: If the observations are not reported to the appropriate authorities for remedial or mitigation action, the main message of monitoring for landslide signals will not be effective. Residents are therefore advised to report any indications that they believe warrant taking action (Siti Zarina Ngajam, 2016).

4.10 Discussions

One of the most destructive forms of natural hazard in the world is the landslide. It destroys property worth hundreds of billions of dollars annually; wrecks public works projects, agricultural areas, and transportation networks, and kills and hurts tens of thousands of people annually (Chimindi et al., 2017). Due to this, determining landslide hazard areas is necessary to development of ones countries (Meten, 2016). So, in order to achieve the objectives, this study used different primary and secondary data. The study used GPS field data as primary data. The secondary data, like a satellite image, DEM, the boundary of the study area, metrology data, topographic map, and soil data were collected from the relevant sources. After that, the major criteria for landslide hazard and landslide risk were identified based on, literature review, nature of study area, and researcher knowledge. Based on this ten (10) major landslide triggering factors were identified for current study. These are: rainfall, slope, elevation, land use land cover, lineament density, soil type, lithology, normalized vegetation index, topographic wetness index, and proximity to rivers (streams) were used create landslide hazard maps. In this study, all datasets were converted into the same projection system, and the Universal Transverse Mercator (UTM) projection was used for all the data sets before the factor datasets were created from the raw data. The datasets were stored in a personal geo-database with UTM zone 37 as the common grid zones. In a GIS environment, each of the above landslide-generating factors was created, reclassified, weighted, and stored. The weights for each factor were determined after discussions with relevant organizations (experts) and research in the literature, and IDRIS software was used to calculate the eigenvectors. Then, weighted overlay analysis for each variable using Satty's Analytic Hierarchy Technique, which generates a pair-wise comparison matrix for each map based on a nine-point relevance scale. Engine vectors, which were produced by pair-wise comparisons, were used to calculate the weights for each factor. To calculate the weight, IDRIS Selva 32 was used to calculate engine vectors. Each factor's weight indicates how much of an impact it has on the likelihood of a landslide. An easy-to-use program called IDRIS can quickly determine weights. Additionally, it determines whether the supplied pair-wise weights are appropriate or whether a different configuration is needed by calculating a consistency ratio. By analyzing and utilizing a multi-criteria approach and geospatial-based technologies, landslide hazard and risk maps were produced in the GIS environment. Each of selected factor has its own significance, from the

per-wise comparison, the highest weight was given for rainfall (26.71%) followed by the slope (20.28%), soil type (15.31%), lithology (11.32%), LULC (8.23%), and distance to a river (5.41%). Lineament density, elevation, NDVI, and TWI obtained 4.4%, 3.98%, 2.48%, and 1.87% percent of the total weight, respectively. GIS technology has emerged as a key contemporary tool for identifying regions at risk of disaster (Varnes, 1984). Landslide hazard map was then created using the weighted linear combination (WLC) approach, and the risk map was made by combining the vulnerability and hazard maps. To combine the factor maps in a weighted overlay analysis for mapping landslide risk and hazard in the Arc GIS environment, the computed eigenvector was used as a coefficient. According to the results of the landslide hazard map study area's, shows 98.55 (36.24%), 48.69 (17.90%), 55.67 (20.48%), 41.96 (15.43%), and 9.93% (26.99) sq.km were subjected to very low, low, moderate, high, and very high landslide hazard zones respectively. In this study, three elements at risk (population, road and land use and land cover) were taken into account for weighted overlay analysis for landslide risk mapping. Population density, land use land cover were considered to be equally significant in the weighted overlay analysis, were used in the current study to mapping landslide risk. The map that the landslide risk index produced was divided into five risk categories very low, low, moderate, high, and very high. The results of the landslide risk map of the study area, show that 37.04 (7.62%), 41.59 (15.30%), 50.50(20.57%), 47.67 (19.52%), and 36.98% (95.12) sq. km of the study area were, respectively subject to very high, high, moderate, low, and very low landslide risk levels. Lowland landscapes have a moderate landslide risk class in this study, while the high and very high landslide risk classes are found in western and northern parts of the study area closer to the Omo River, on steep slopes with humic nitisol soil types, Low and very low landslide risk was found in low plain landscapes. The areas near the Omo River, those with a higher population density, and areas without any vegetation or forest coverage including bare lands are subject to the very high and high landslide risk zones. The landslide risk map for Kindo Didaye also confirms that the most landslide-prone areas are those with high elevations (2100-2447m) (Rahmati et al., 2016), those with steep slopes (greater than 35 percent) (Kumar & Sonam, 2020), those with clay soil, those that are closer to Omo river, on agricultural land and those area covered with bare lands (Ogato et al., 2020). According to the causative factor class and landslide hazard class, the study area's concise mitigation representation of the hazard

zone was presented. In this study, mitigation strategies include preventing erosion; strengthen the soil, reforestation, afforestation and stopping construction in risk area. Planners and decision-makers can use the developed landslide hazard and landslide risk maps to implement suitable strategies to reduce the threat of landslides in Kendo Didaye woreda.

CHAPTER V: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

The purpose of this study was to analyze the landslide hazards and risk of Kindo Didaye woreda. Landslide hazard and risk was created using a Geographic Information System (GIS) based on Multi-Criteria Decision Analysis (MCDA) techniques using identified environmental factors. Taking into account the nature of current study area, a total of ten landslide causative factors were taken into account in this study. Landslide hazard and risk analysis was based on multi-criteria decision-making with the integration of AHP because it provides a flexible, step-by-step, and transparent method of analysis based on the opinions of experts, end users, and their preferences, knowledge, and judgments. To determine the relative weights for each causal factor, the eigenvector matrix calculation was performed using the IDRIS Selva software. Using Arc Map 10.8 software, a landslide hazard map of the study area was created after assigning the derived weights and landslide risk map was created by superimposing the developed landslide hazard map, population density, and land use/land cover data using the weighted sum method in GIS overlay analysis. The results of the landslide hazard and risk map of the study area shows that 98.55 (36.24%), 48.69 (17.90%), 55.67 (20.48%), 41.96 (15.43%), and 9.93% (26.99) sq.km were subjected to very low, low, moderate, high, and very high landslide hazard zones respectively, as well as 37.04 (7.62%), 41.59 (15.30%), 50.50 (20.57%), 47.67 (19.52%), and 36.98% (95.12) sq. km of the study area were, respectively subject to very high, high, moderate, low, and very low landslide risk levels respectively. The created landslide hazard and risk map will be used to plan, manage, and develop future disasters in the study area. Any future development and habitation could be dangerous in the very high and high-hazard zones. Therefore, it is urgent to put into practice mitigation strategies like improving drainage, reforestation, and water management to protect people and property in the area and minimize the adverse effects of landslides. As a result, the best technique for hazard and disaster studies is the MCE technique in a GIS environment. The advancements in RS and GIS technologies make it possible to implement this concept of hazard and risk of landslides in Kindo Didaye woreda.

5.2 Recommendation

The relevant decision-makers could use the information on landslide hazard, and risk provided by this research to make changes to the current land use policy for lowering threat to landslide hazards in Kindo Didaye woreda. Therefore, as one of the short-term interventions in the study area, the responsible bodies of Kindo Didaye woreda Administrative Council and land use planners should use the landslide hazard and landslide risk maps of this study in the currently ongoing activities related to landslide disaster. Based on the recent study, the following suggestions are made;

- Activity in hazard zones must be limited, prohibited, and creating awareness among community should be developed.
- It is necessary to prepare a landslide Atlas map for current study area, to use it in landslide hazard preparedness.
- Landslide forecasting and preparedness measures should be implemented as soon as possible to reduce the likely negative effects of landslides on people's lives and livelihoods.
- To evaluate the risk of landslides in terms of ecological, social, and economic factors, more research is necessary.
- Governmental organizations should offer preventive measures for future land use because landslides in the study area destroy residential and agricultural areas of the living community.
- To reduce potential risks to the human population, the environment, and engineering structures like road, a risk management program must be planned.

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APPENDIX

Appendix-I Landslide inventory area gathered by researcher

No	X	Y	Z(m)	Landslide on LULC type
1	322887	748102	2436	Agricultural land
2	322308	748105	2154	Grass land
3	328247	748018	2065	Forest land
4	323137	747668	2029	Agricultural land
5	322721	747575	1995	Wet land
6	321098	747449	2021	Barren land
7	322590	747360	2378	Agricultural land
8	328404	747254	2274	Forest land
9	322426	747182	2314	Barren land
10	322848	747157	2147	Wet land
11	324441	747103	1958	Agricultural land
12	322459	747028	2019	Agricultural land
13	323621	747051	2130	Forest land
14	328399	746981	2212	Forest land
15	317988	746897	2421	Agricultural land
16	323646	746839	2414	Around road
17	324311	746885	2408	Forest land
18	318019	746733	2307	Agricultural land
19	328252	746710	2216	Barren land
20	317709	746665	2036	Wet land
21	323621	746651	2422	Agricultural land
22	323738	746552	2388	Forest land
23	324586	746495	2277	Settlement
24	317489	746493	2115	Agricultural land
25	322329	746464.	2237	Settlement
26	317676	746395	2196	Road
27	326201	746290	2289	Forest
28	324356	746214	2066	Settlement
29	324586	746495	2433	Forest land

Appendix-II Accuracy assessment for land use land cover done by researcher

Classified data	Water	Bare land	Settlement	Forest	Agriculture	Total	User Accuracy	Kappa
Water	17	0	0	0	0	17	1	0
Bare land	0	18	0	0	3	21	0.857	0
Settlement	0	0	14	0	0	14	1	0
Forest	0	2	1	28	1	32	0.875	0
Agriculture	0	0	0	0	16	16	1	0
Total	17	20	15	28	20	100	0	0
Producer Accuracy	1	0.9	0.93	1	0.8	0	0.93	0.91

Appendix-III Population data of current study area: Source kindo didaye woreda administration

Kebele	Female	Male	Total	Ratio
Bereda	7643	7586	15229	11.14%
Mogisa	6648	5479	12127	8.87%
Patata	5157	4963	10120	7.40%
Shele mekira	8120	6109	14229	10.41%
Halale	6148	5902	12050	8.81%
Zebo	6595	6125	12720	9.30%
Sima dolaye	7096	6819	13915	10.18%
Zeero	7549	6679	14228	10.87
Bosa mamura	6985	6478	13463	9.85%
Gocho	6854	6371	13225	9.67%
Total	68795	62511	136631	100%

Appendix-IV Rainfall data: source national metrology agency

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ann	belg	kiremt
1991	33.4	87.4	145.3	78.3	223.6	166.1	125.1	136.7	142.8	6.3	5.7	83.4	1234.1	447.2	427.9
1992	25.4	145.6	108	105.2	145.2	105.8	150.6	231.1	133.1	133.7	86.8	54.6	1425.1	358.4	487.5
1993	63	86.6	64.5	228.7	294	109.6	141.4	132.4	112.9	53.1	11.8	3.1	1301.1	587.2	383.4
1994	1.5	28.3	125.4	154.9	158.4	179.4	213.1	187.8	72	27.7	33.7	8.4	1190.6	438.7	580.3
1995	0	63.4	106.8	264.1	105.6	122.8	107.1	115	111.3	52	4	26.9	1079	476.5	344.9
1996	26.9	72	27.5	101.9	196.7	121.3	245.1	168.4	218.8	149.2	15.7	20.5	1364	326.1	534.8
1997	3.5	10	85.5	247.6	206.4	101.8	126.8	128.3	67.9	232.3	265.3	14.7	1490.1	539.5	356.9
1998	79.3	109.8	136.1	230.3	290.4	160.9	150.9	155.8	67.5	132.4	20.2	6	1539.6	656.8	467.6
1999	32.3	0	39.7	105.9	98.5	94.3	200.7	167.5	40.1	174.4	18.9	15.2	987.5	244.1	462.5
2000	0	0	26.4	92.6	204.8	97.1	83.7	142.5	70.3	130.1	81.7	22.5	951.7	323.8	323.3
2001	10.1	67.2	100.2	122	245.72	140.2	212.4	200.8	126.1	106.4	33.1	28.6	1392.82	467.92	553.4
2002	6.7	10.9	165.3	113.6	119.8	59.6	138.1	160.6	130.5	52.2	1.5	113.6	1072.4	398.7	358.3
2003	59.1	20.3	81.1	182.4	64.3	143.1	200.9	159.6	129.1	76.4	29.6	34.1	1180	327.8	503.6
2004	78.3	41.1	43	154.5	85.2	71.3	217.4	76.1	173.1	69.3	24.1	50.7	1084.1	282.7	364.8
2005	22.3	22.5	115.3	279.9	212.9	123.8	139.5	94.1	190	48.4	90.8	7.4	1346.9	608.1	357.4
2006	12	57.2	130.9	226.4	124.2	85	202.1	150.1	52.2	118.8	41.7	135.3	1335.9	481.5	437.2
2007	36.7	66.1	91.9	158.1	213.7	198.8	207.5	229	269.3	21.1	10.7	0	1502.9	463.7	635.3
2008	9.1	3.5	13.5	74.1	108.8	100.1	146.1	183.9	129.7	159.9	82.6	1.1	1012.4	196.4	430.1
2009	28.7	31.3	47.8	64.7	124.7	57.3	98.5	189.5	107	83.3	28.2	110.9	971.9	237.2	345.3
2010	18.3	91.1	71.2	233.7	280.5	121.4	91.3	118.1	97.6	30.1	19.5	25.9	1198.7	585.4	330.8
2011	13.1	20.4	43	63.3	371.9	170.6	157.9	172.8	60.8	18.4	112	3.4	1207.6	478.2	501.3
2012	0	0	44.6	180.8	71.6	171.8	196.6	169.7	135.3	13	32.9	16.8	1033.1	297	538.1
2013	25.3	25.2	105.9	254.4	95.3	110.8	194.7	232.8	210.2	149.7	82.3	0	1486.6	455.6	538.3
2014	11.1	38.6	153.3	140.5	189.5	169.1	158.8	163	190.6	0	0	0	1214.5	483.3	490.9
2015	22.2	14.3	26	75.1	126.4	109.2	93.4	58.9	103.4	17	103.4	26.2	775.5	227.5	261.5
2016	55.8	5.4	101	275.1	166.5	136.2	89.9	80.8	140.2	78.7	73	25	1227.6	542.6	306.9
2017	0	44.5	16.2	0	199.7	38.6	146.9	116.2	183.1	84.1	64.8	0	894.1	215.9	301.7
2018	0	58.5	73	324.5	0	197.1	113.8	276.6	22.8	46.6	143.7	23.6	1280.2	397.5	587.5
2019	0	0	50.4	84.23	123.7	251.7	150.1	137.6	127.6	91.1	144.1	34.5	1195.03	258.33	539.4
2020	33.3	38.7	130.6	174.6	230.1	117.9	161.5	168	162.6	83.7	6.4	14.6	1322	535.3	447.4

Appendix-V: The landslide-prone area in the current study area gathered by researcher

