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Research Article

# Spatial Determinants of Recurrent Landslides Revealed Through Multi-Source GIS–Remote Sensing Integration in Kindo Didaye, Wolaita Zone, Ethiopia

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## ABSTRACT

Landscape failure and associated landslide occurrence is one of common problem in many parts of the world in hilly and mountain areas. Study in such areas could enhance proper land use management practices. The objective of this study was to assess root causes of landslides occurrence with the use of Remote Sensing (RS) and GIS. In this study analytical hierarchy process (AHP), Spatial Multi-criteria evaluation (SMCE), and weighted linear combination (WLC) were used to produce landscape and landslide susceptibility map. In order to identify major causes of landscape failures and associated landslide problem field observation, Focus Group Discussion, and Key Informant Interview methods were employed. Geology (0.32), Slope steepness (0.24), soil texture (0.19), aspect (0.08) and drainage density (0.05) were found major causes for landslide susceptibility. Five susceptibility zones were identified in the study area. From the total area(308.44km2): very high susceptibility (28.75%), high susceptibility (22.46%), moderate susceptibility (20.97%), low susceptibility (8.01%), and very low susceptibility (19.81%). This shows that about 70.21% of the region in the south and east are prone to moderate to very high levels of landslide susceptibility. Information obtained from FGD and KII revealed that major causes of landslide occurrences besides to physical problems were landscape failures due to removal of indigenous plants around farmland boundaries, stream courses, hill sides and absence of modern landscape based soil and water conservation practices. Therefore, intervention with integrated indigenous and modern farmland management as well as income diversification for the farming communities is highly recommended.

Keywords: Landscape failure; Landslide Susceptibility; Analytical Hierarchy Process; Remote Sensing; GIS

## INTRODUCTION

Destructions caused by catastrophic landslides are a worldwide phenomenon, and the rapid increase in population has augmented the problem due to increased deforestation and the expansion of settlements [1], [2]. As confirmed in [1], [3] the worldwide landslide problems are expected to continue in the 21st century for the following reasons: (a) landscaping failure (b) increased urbanization and development in landslide-prone areas, (c) continued deforestation of landslide-prone areas, and (d) increased precipitation caused by changing climatic conditions. Thousands of people killed or vanished in a matter of minutes or hours as a result of catastrophic landslide events that were reported worldwide [4], [5]. For instance, Venezuela landslide in Vargas in 1999 caused the destruction of substantial human life, farmland losses, and economic crises [6]. Only from 1995 to 2005 over 12,730 causalities have been reported due to landslide worldwide [7]. From 1900 to 2011 a total of 54,020 peoples have been killed, 6,848,109,000 US dollars have been lost by Landslides excluding Subsidence and Avalanches (www.em-dat.net accessed on Feb, 2022).

Natural disasters and their consequences have considerable and destructive effects on human life, properties, infrastructures, and, of course, on environment [8], [9]. Landslide by its nature is accidental which occurs without any prior indication, such unpredictability demands development of tools and techniques to study the landslide [10]. Hence, many countries, particularly the developed ones, invest huge amount of money either in mitigation or in prevention of landslides through landscaping techniques [6].
The first, and probably the most important, stage of mitigation and/or prevention efforts is to assess landslide susceptibility by obtaining data related to landslides, i.e. preparation of landslide inventory and database [9], [11]. Consequently, results of these assessments, i.e. landslide susceptibility maps, will provide useful information and economic benefits for landscaping, land use planning, development planning, and engineering application [9], [12], [13]. Slope failures are generally considered as fairly well predictable hazards and economic losses due to such hazards can be reduced significantly [9], [14]. In spite of such advancements, landslides continue to prevail in both the developed and developing countries, with larger causalities in developing nations but severe economic losses in the industrialized world [14].

Geographic Information Systems (GIS) and remote sensing have developed into essential instruments for assessing landslide susceptibility and hazard events in recent years [8], [11], [15]. Moreover, GIS is an excellent and useful tool for the spatial analysis of a multi- dimensional phenomenon such as landslides [9], [15]. Because of its complex geomorphological, hydrological, and geological setting, the hilly terrains of the Ethiopian landmass has been frequently affected by landslides [9]. With the on-going infrastructural development, urbanization, rural development, and with the present land management system, it is foreseeable that the frequency and magnitude of landslides and losses due to such hazards would continue to increase unless appropriate actions are taken in Ethiopia [14]

In unstable mountainous areas of Wolaita Zone mass movement occurrence has been recorded frequently. The frequency of landslides has increased in recent years. The worst landslide occurred in the study area in 2018 G.C (2011 E.C) and displaced thousands of tons of earth and rock debris, causing much economic and life loss. At study area about 80,000 populations were facing the above mentioned physical and socio-economic problems since the last four decades. For instance 2018 landslide caused 1969 total victims out of this number total loss of life of 49 people, loss of significant amount of livestock and crop land equivalent of 14,215,895.00Birr is the most severe occurrence in the recent history of the study area. Considering the scale of the landslide problems and the socio-economic development in the study area, the on-going research on landslides and landscape is very important [6], [14], [16].

Landslide-generated hazards are becoming serious concerns to the general public and to the planners and decision-makers at various levels of the government. However, so far, little efforts have been made to reduce losses from such hazards [17]. With the on-going infrastructural development, urbanization, rural development, and with the present land management system, it is foreseeable that the frequency and magnitude of landslides and losses due to such hazards would continue to increase unless appropriate landscape development-oriented actions are taken in Ethiopia. It is also unquestionable that landscape development and management in natural and urban planning; for maintaining landscape, in construction design and planning of a variety of projects [6]; [12] .

Thus, the main aim of this study is to determine landslide susceptibility and evaluate landscape failure in the case of Kindo Didaye "Woreda" (District). In view of the objectives, the study was attempted to answer the following basic research questions: What are factors aggravating landslide occurrence in the study area? Which parts of the study areas are more susceptible to landslide? What measures should be taken to restore landscape failure and mitigate landslide in the study area?

## METHODS

### Description of the study area

This study was conducted in wolaita zone which is about 380 km from Addis Ababa. It covers a total area of 4511km2 and is composed of 12 administrative weredas (Districts) and 3 registered towns. According to Central Statistical Agency report of 2017, total number of population of the zone is about 2,091,842. Population density of the area is estimated at 464person per square kilometer [18]. Kindo Didaye is one of 12 Woredas (Districts) in Wolaita Zone which is selected for this study due to previous land slide cases and other landslide susceptibility factors. Kindo Didaye woreda is bounded by Omo river to the West, North West, and North. Its absolute location is $6^0$ 40' 0" N and $6^0$53' 0" N Latitude and $37^0$ 10' 0"E and $37^0$ 30' 0" E Longitude. The centroid latitude and longitudes location of the present landslide occurred area is $6^0$45’57’’ N and $37^0$21’05’’E.

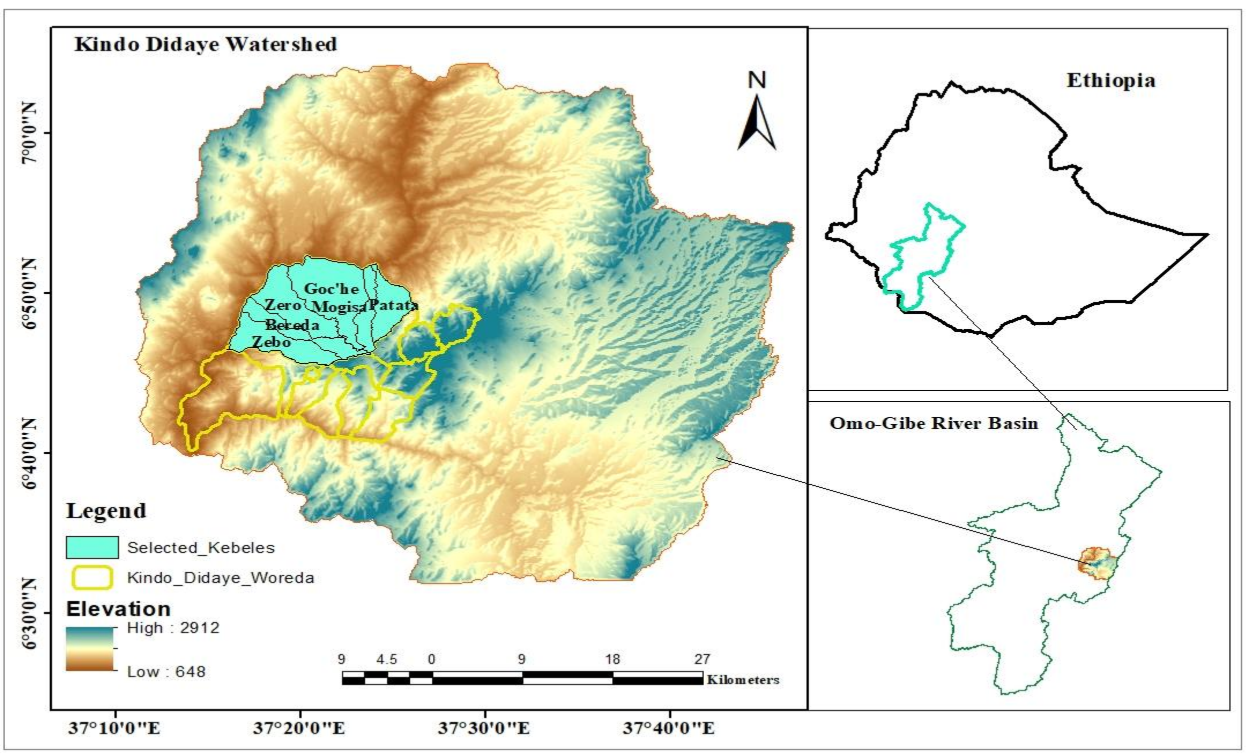



Figure 1. Map of the study area: Portraying six selected Kebeles for the study (Patata, Gocho, Mogisa, Zero, Bereda, and Zebo)

## Research Design

This study incorporates two types of data analysis strategy. These are qualitative and quantitative ones. In terms of qualitative method the researchers used some personal judgments based on existing parameters and interpreting FGD and key interview data on qualitative statements. In case of quantitative method the researchers used some statistical and mathematical techniques through the use of Arc GIS and ERDAS IMAGINE software.

## Data Sources and Soft wares used

Sources of data used in this study include: Topographic maps (large scale 1: 50,000 ), the geological map (Small scale 1: 250000 ) of the study area, Satellite images include Landsat TM and ETM+, Digital Elevation Model with 30m resolution, Ground truth Data from fieldwork using GARMIN GPS72 Receivers. Soft wares chosen to apply in this study include ArcGIS 10.1, ArcGIS 10.3, and ERDAS IMAGINE 9.2. Data were collected from different sources i.e., primary and secondary sources. To collect spatial data from the study area Garmin GPS receiver of the specific channel was used. Spatial data such as Topographic maps of the study area and Satellite image of the same area were purchase from EMA (Ethiopian Mapping Agency) and geo-referenced using both ArcGIS10 and ERDAS IMAGINE 9.2 software. In addition to spatial data collection technique, FGD, personal observation and key informant interview were used as data primary collection techniques.

## RESULTS AND DISCUSSION

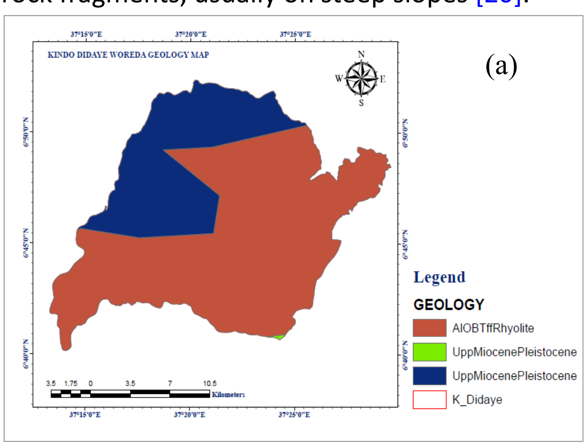
## Factors for Landslide Susceptibility

### Geology

Three geological classes are extracted from geological survey map of Ethiopia with the scale 1:250000 for Kindo Didaye Woreda. These are Alkali Olivine basalt and tuffs rare rhyolite, Magdala Group (Upper Miocene – Pleistocene) and other Upper Miocene Pleistocene. All of these are belongs to volcanic rocks.

### Soil Type

The study area is characterized with two main types of soil: Acrisols, which are soils with acid, low base status (<50% base saturation) and strongly leached [19]. One of the most inherently infertile soils of the tropics, becoming degraded chemically and organically very quickly when utilized. In addition, Acrisols have very low resilience to degradation and moderate sensitivity to yield decline. On the other hand, Lithosols are soils which are limited in depth by continuous coherent and hard rock within 10 cm of the surface. Lithosols are also considered as shallow soils lacking well-defined horizons especially, an entisol consisting of partially weathered rock fragments, usually on steep slopes [20].



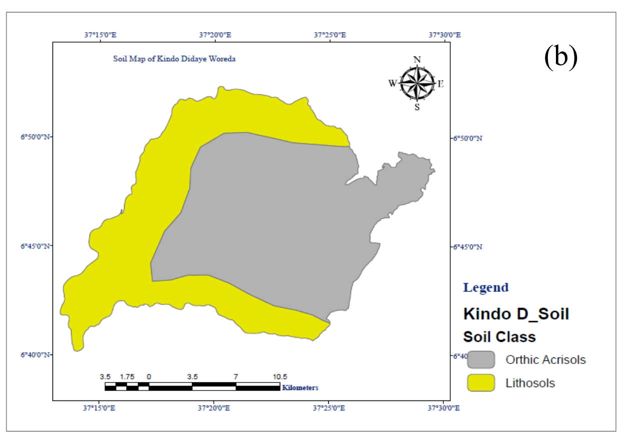




Figure 2. a. Geology b. Soil Type

## Slope Steepness

Slope is an important factor in the analysis of landslide susceptibility. As the slope increases the probability of the occurrence of landslide increases because as the slope angle increases the shear stress of the soil increases. The slope map is derived from the DEM and the topographic map of the study area through the use of ArcGIS10.3 -Spatial Analyst Tool. The slope class was categorized (in Degrees) as 0 – 10.73$^0$ as very gentle slope, 10.73 – 19.14$^0$ as gentle slope, 19.14 - 28.43$^0$ as Moderately steep slope, 28.43$^0$ – 39.74$^0$ as steep slope and 39.74$^0$ – 73.97$^0$ as very steep slope (Table 1).

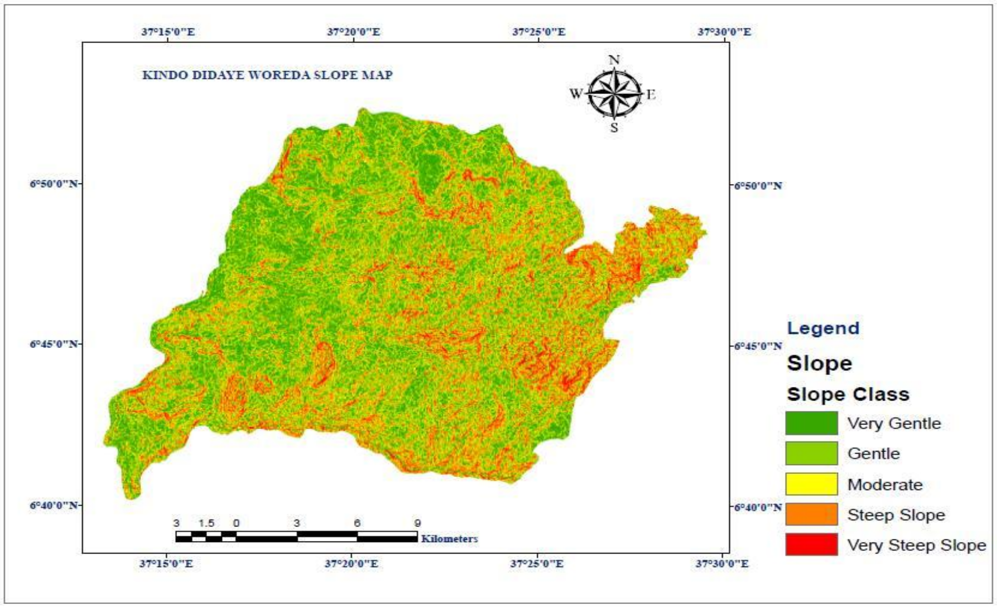



Figure 3. Slope angle map of the study area

Table 1. Slope Steepness of Kindo Didaye Woreda

| FID | Slope Classes | Class Range (in Degree) | Level of Susceptibility |
|---|---|---|---|
| 01 | Very Gentle | 0 – 10.73 | Less Susceptible |
| 02 | Gentle | 10.73 – 19.14 | Susceptible |
| 03 | Moderate | 19.14 – 28.43 | Moderate Susceptible |
| 04 | Steep | 28.43 – 39.74 | Highly Susceptible |
| 05 | Very Steep | 39.74 – 73.97 | Very Highly Susceptible |

## Slope Aspect

The slope aspect of the study area was derived from DEM with 20-m horizontal resolution. The N–NW-facing slopes are favorable for landslides due to their shadier, colder, and more humid conditions [21]. The slope aspect of study area depicted on Figure 3 encompasses that flat (-1), North (0-22.5), North east (22.5-67.5), East (67.5- 112.5), southeast (112.5-157.5), south (157.5-202.5), south west (202.5-247.5), west (247.5-292.5), Northwest (292.5-337.5), North (337.5-360).

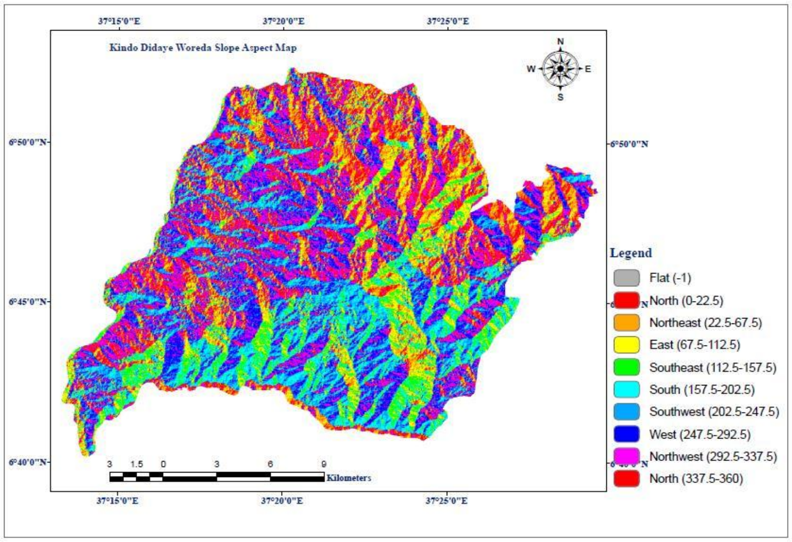



Figure 4. Slope aspect map

## Land use/Land cover

The land cover of the study area categorized as Vegetation, Farmland, water bodies, built-up area, shrub land, grassland and bare land based on field survey data and supervised image classification result. As can be observed in (Figure 5 and Table 4), 1993 to 2023 vegetation cover decreased 66.96 percent to 43.07 percent, respectively. Shrub land and bare-land were decreased from 4.58 percent in 1993 to 3.27 percent in 2023 and 6.99 percent in 1993 to 4.18 percent in 2023, respectively. On the contrary, farmland increased from 18.45 percent in 1993 to 29.2 percent in 2023. Area covered by built-up and water bodies were increased from 1.27 percent in 1993 to 6.11 percent in 2023 and 0.54 percent in 1993 to 4.69 percent in 2023, respectively. The increment of water body was due to Gibe III hydro power plant reservoir. The above land use land cover changes might be major causes for the frequent landslide occurrence recorded in between 2013-2020 in the present study area.

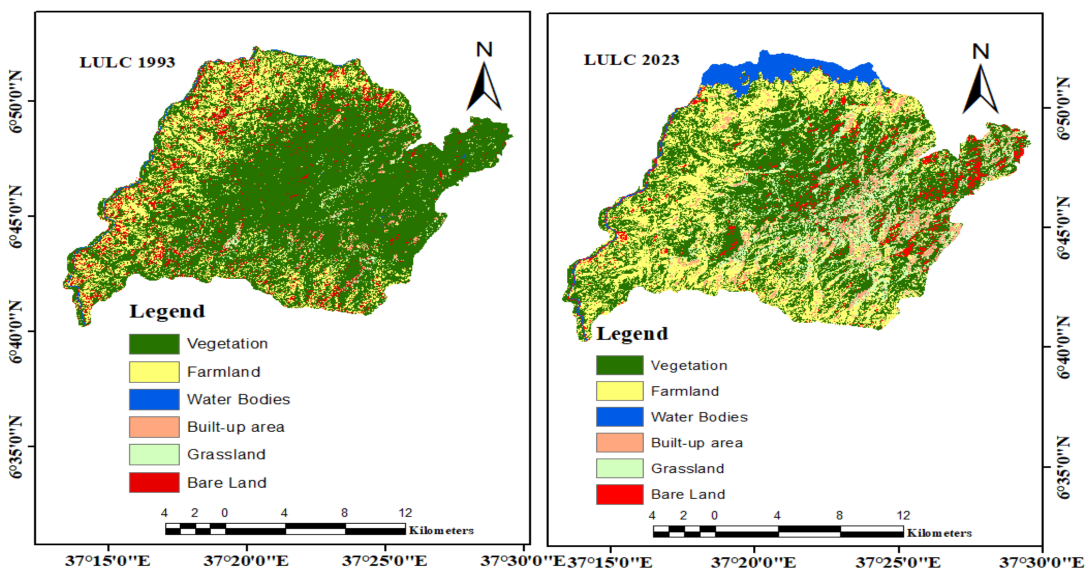



Figure 5. Land use/Land cover map

Table 2. LULC Classification Accuracy Assessment (1993)

| LULC Class | Veg | FrmL | WB | Bu | Grsl | Brnl | RT | Ur_Accr |
|---|---|---|---|---|---|---|---|---|
| Veg | 104 | 0 | 1 | 1 | 1 | 1 | 108 | 96.30 |
| FrmL | 0 | 83 | 0 | 0 | 0 | 1 | 84 | 98.81 |
| WB | 2 | 1 | 64 | 0 | 1 | 0 | 68 | 94.12 |
| Bu | 1 | 0 | 0 | 58 | 1 | 0 | 60 | 96.67 |
| GrsL | 1 | 1 | 0 | 0 | 73 | 0 | 75 | 97.33 |
| BrnL | 0 | 0 | 0 | 1 | 0 | 52 | 53 | 98.11 |
| CT | 108 | 85 | 65 | 60 | 76 | 54 | 448 | |
| Pr_Accur | 96.30 | 97.65 | 98.46 | 96.67 | 96.05 | 96.30 | | |

Over all accuracy = 434/448=96.88 Kappa Coefficient ($\widehat{K}$) = 96.20

**Veg=vegetation, FrmL=Farm Land, WB=Water Bodies, Bu=Built-up area, GrsL=Grassland, BrnL=Barren Land, CT=Column Total, RT=Row Total, Pr_Accur=Producer's Accuracy, and Ur_Accr=User's Accuracy.**

Table 3. LULC Classification Accuracy Assessment (2023)

| LULC Classes | Veg | FrmL | WB | Bu | GrsL | BrrnL | RT | Ur_Accu |
|---|---|---|---|---|---|---|---|---|
| Veg | 97 | 0 | 1 | 0 | 0 | 0 | 98 | 95.83 |
| FrmL | 0 | 85 | 0 | 1 | 1 | 0 | 87 | 96.92 |
| WB | 1 | 0 | 79 | 0 | 0 | 1 | 81 | 95.16 |
| Bu | 0 | 1 | 0 | 81 | 1 | 0 | 83 | 97.14 |
| GrsL | 1 | 0 | 1 | 0 | 72 | 0 | 74 | 98.63 |
| Barel | 0 | 1 | 0 | 0 | 1 | 54 | 56 | 97.37 |
| CT | 99 | 87 | 81 | 82 | 75 | 55 | 479 | |
| Pr_Accu | 97.98 | 97.70 | 97.53 | 98.78 | 96 | 98.18 | | |

Over all accuracy = 97.70 Kappa Coefficient = 97.31

**Veg=Vegetation, FrmL=Farmland, WB=Water Bodies, Bu=Built-up area, GrsL=Grassland, BrnL=Barren Land, CT=Column Total, RT=Row Total, Pr_Accur=Producer's Accuracy, and Ur_Accr=User's Accuracy.**

Table 4. Land use/land cover change analysis of Kindo Didaye Woreda(1993 – 2023)

| | | LULC 1993 | | LULC 2023 | | Change (1993-2023) |
|---|---|---|---|---|---|---|
| OID | LULC_Classes | Area (Ha) | Area (%) | Area (Ha) | Area (%) | Change (hectare) |
| 1 | Vegetation | 27591.66 | 71.54135 | 17622.54 | 46.31754 | -9969.12 |
| 2 | Farmland | 7115.31 | 18.44901 | 11129.58 | 29.25201 | 4014.27 |
| 3 | Water Bodies | 209.43 | 0.543023 | 1801.98 | 4.736166 | 1592.55 |
| 4 | Built-up area | 487.98 | 1.265264 | 2348.55 | 6.172723 | 1860.57 |
| 5 | Grassland | 467.64 | 1.212526 | 3544.47 | 9.315974 | 3076.83 |
| 6 | Bare Land | 2695.41 | 6.988825 | 1600.11 | 4.205589 | -1095.3 |

## Drainage Density

Drainage density calculations consider cells measuring 250 x 250 m, which are then classified into intervals, where drainage channel overlays show a relatively large number and are more densely packed in the high-density class. Areas can have high potential of landslide occurrence when the distance to the rivers or water bodies decrease  Because it generally believed that the geomorphological impact of rivers is directly attributed to the weaknesses of slopes [22], [23].

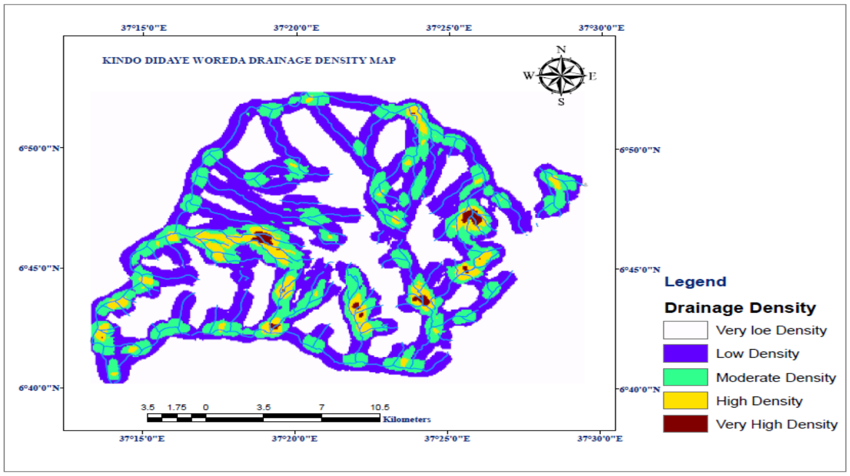



Figure 6. Drainage Density Map

DEM data was extracted to obtain information related to elevation, slope direction, slope angle, and river basin area (Table 5), then used with contour intervals of 10 m and 20 m with the TIN module from Arc View 3D.

Table 5. Ranks and weights for factors and their classes

| No. | Data Layers (Factors) | Factor Rank | Classes | Weights |
|---|---|---|---|---|
| 1. | Geology | | AlOB Tff Rhyo | 5 |
| | | 2 | Upp Mio Ple (i) | 3 |
| | | | UppMio Ple(ii) | 1 |
| 2. | Soil Texture | 3 | Acrisols | |
| | | | Lithosols | |
| 3. | Slope Angle | | 0 – 5 | 0 |
| | | 1 | 5 – 10 | 2 |
| | | | 10 – 15 | 3 |
| | | | 15 – 20 | 4 |
| | | | 20 – 25 | 5 |
| | | | Flat | 0 |
| | | | North | 5 |
| | | | Northeast | 3 |
| | | | East | 1 |

| | | | | |
|---|---|---|---|---|
| 4. | Slope Aspect | 4 | Southeast | 0 |
| | | | South | 2 |
| | | | Southwest | 3 |
| | | | West | 2 |
| | | | Northwest | 4 |
| | | | North | 5 |
| 5. | Drainage Density | | Low | 0 |
| | | 6 | Moderate | 1 |
| | | | High | 3 |
| | | | Very high | 5 |
| | | | Water body | 5 |
| 6. | Land Use/ Land Cover | 5 | Settlement | 4 |
| | | | Farm land | 3 |
| | | | Vegetation | 1 |
| | | | 0 – 500 | 5 |
| 7. | Distance to main road in meter | 7 | 500 – 1000 | 4 |
| | | | 1000 – 1500 | 3 |
| | | | 1500 – 2000 | 2 |
| | | | >2000 | 1 |
| | | | 0 – 500 | 5 |
| 8. | Distance to Fault line | 8 | 500 – 1000 | 4 |
| | | | 1000 – 1500 | 3 |
| | | | 1500 – 2000 | 2 |
| | | | >2000 | 1 |

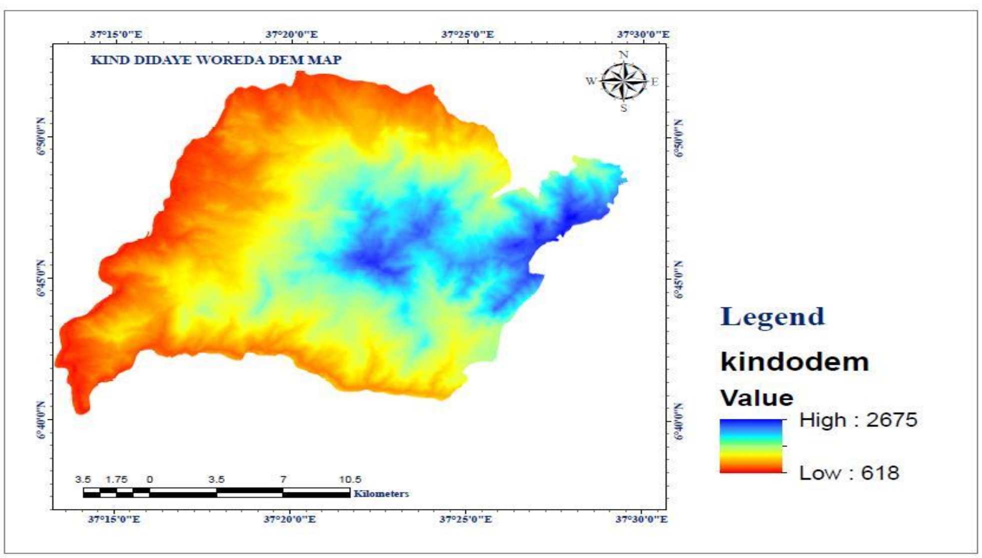



Figure 7. Digital Elevation Model of the study area

## Distance to Roads

The distance to road is an essential factor to map landslide susceptible areas. Frequently used roads by high volume cars are causes for landslide damage. Roads with unstable slopes can intensify the disintegration of rocks around them by strong vibration [24]. Roads around highly unstable slopes also can change the nature of topography and cause weak strength of the slope towards landslide hazard. Particularly during rainy season the road causes infiltrating of water in slopes and enforces extra stresses due to traffic loads. In this study, it was identified (Figure 8 and Table 6) that many landslides have occurred near to main roads and associated to unchecked and unsystematic road construction.

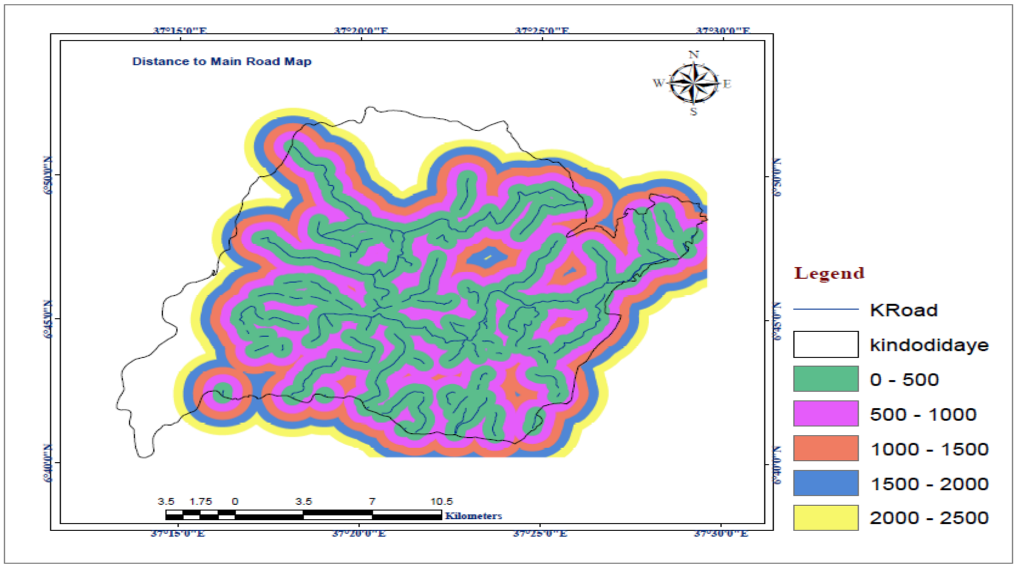



Figure 8. Distance to Road map

Table 6. Distance to Roads

| | Class Range | Area (SqKm) | Area (%) |
|---|---|---|---|
| **1** | 0 - 500 | 175.28 | 40.01 |
| **2** | 500 - 1000 | 112.26 | 25.63 |
| **3** | 1000 - 1500 | 63.95 | 14.60 |
| **4** | 1500 - 2000 | 46.76 | 10.68 |
| **5** | >2000 | 39.79 | 9.08 |

## Distance to Fault line

According to [25] faults are the structural landscapes, which describe a zone of weakness with relative movement, along which landslide susceptibility is higher. The chance for landslide occurrence increases as the distance to the fault line decreases, which can cause slope instability which in turn results in contribution to terrain permeability [25]. As can be observed from Figure 9, present study area is located within close vicinity to major fault lines. Thus distance to fault line was considered as one of the factors for landslide occurrence.

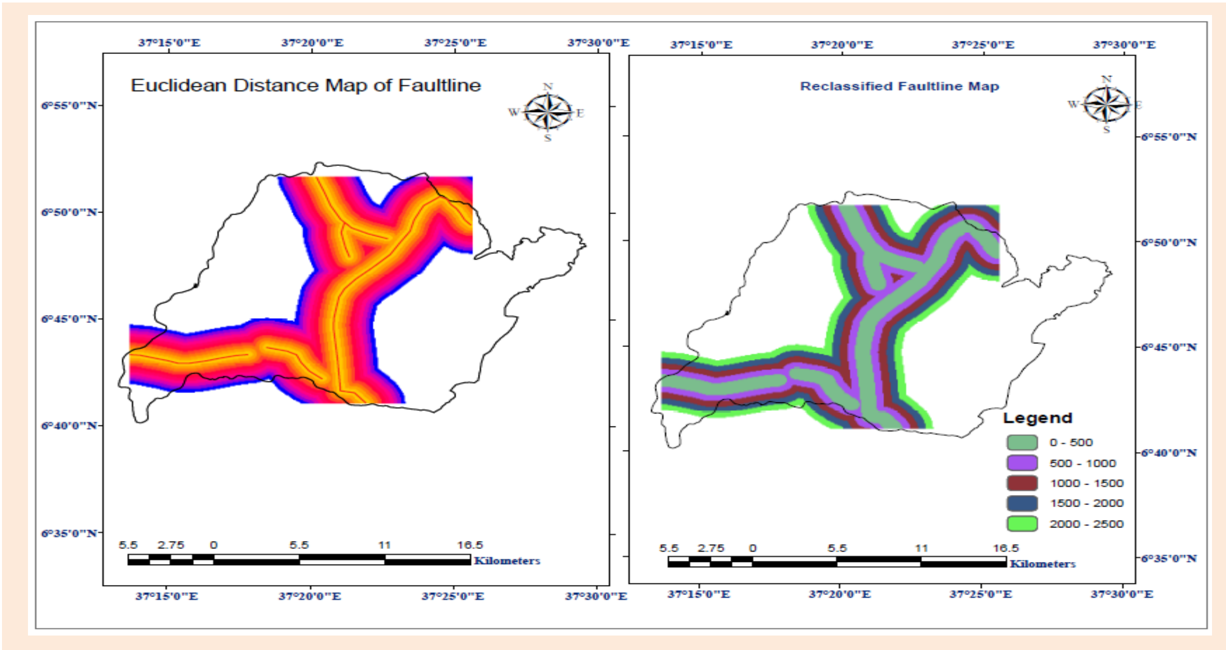



Figure 9. Distance to Fault line Map

### 3.2 Weighted Overlay Analysis and Landslide Susceptibility Mapping

In this weighting, each factor is assigned a numerical label from a scale of 1-5 according to its level of importance. Several iterations are considered for modifying the scheme using different weight combinations. Table 7 explains the assessment scheme given for each factor. This pairwise comparison is analyzed to obtain a weight accumulation with the same amount as AHP (Saaty, 2001).

Table 7. Pairwise Comparison Matrix for Landslide Susceptibility Analysis

| Factors | Slope | Soil | Geol | Aspect | LULC | Drainage | Road | Fault line | Weight |
|---|---|---|---|---|---|---|---|---|---|
| Slope Angle | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 0.316069 |
| Soil Texture | 0.50 | 1 | 2 | 3 | 4 | 3 | 4 | 3 | 0.189773 |
| Geology | 0.33 | 0.50 | 1 | 6 | 7 | 7 | 6 | 7 | 0.238257 |
| Slope Aspect | 0.25 | 0.33 | 0.17 | 1 | 2 | 3 | 4 | 3 | 0.084867 |
| Land Use/Land Cover | 0.20 | 0.25 | 0.14 | 0.50 | 1 | 2 | 2 | 4 | 0.05912 |
| Drainage Density | 0.17 | 0.33 | 0.14 | 0.33 | 0.50 | 1 | 4 | 3 | 0.052942 |
| Distance to Main Road | 0.14 | 0.25 | 0.17 | 0.25 | 0.50 | 0.25 | 1 | 2 | 0.031845 |
| Distance to Fault line | 0.12 | 0.33 | 0.14 | 0.33 | 0.25 | 0.33 | 0.50 | 1 | 0.027127 |
| Consistency Ratio: CR= 0.089 < 0.1 (Acceptable) | | | | | | | | | |

Most landslides are caused by slope angles, so steep slopes are given maximum weight, and then steep slopes are weighted from highest to lowest. Furthermore, geological factors are also taken into consideration because they are related to faults that indicate weak zones. Human activity is also considered because it causes increased erosion compared to areas without human activity. Based on field observations, other aspects of land use are also very influential, because erosion and slope cutting affect slope instability.

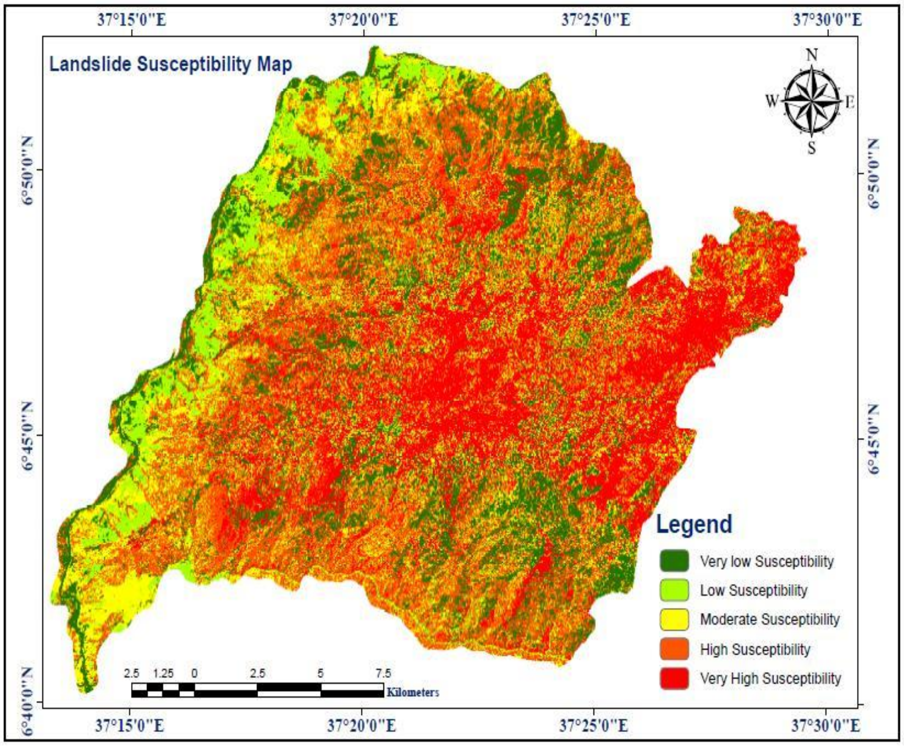



Figure 10. Landslide Susceptibility map

Table 8. Levels of landslide Susceptibility Kindo Didaye Woreda

| | **Level of Susceptibility** | **# Pixels** | **Area (Km)** | **Area (%)** |
|---|---|---|---|---|
| **01** | Very High Susceptibility | 121521 | 109.3689 | 28.75 |
| **02** | High Susceptibility | 94933 | 85.4397 | 22.46 |
| **03** | Moderate Susceptibility | 88622 | 79.7598 | 20.97. |
| **04** | Low Susceptibility | 33910 | 30.519 | 8.01 |
| **05** | Very Low Susceptibility | 83728 | 75.3552 | 19.81 |

According to the landslide susceptibility map and ground verification of study woreda in Figure 10 and Table 8 above 72 percent of the total land area falls under moderate to very high landslide susceptibility. Specifically, kebele's namely Patata, Mogisa, Gocho', Zaro, Bereda, and Zebo, falls under high to very high landslide susceptibility. Debris flows dominated the landslides that occurred in the study area, while rotational and complex landslides were also found. Excessive runoff was a major factor in these landslides, especially during the rainy season with high erosion and steep slopes around the fault.

## Landscape Techniques

As Focus Group Discussion/FGD/ made with local elder peoples in regards of landscaping practice and landslide occurrence in study area, before 30 years our marginal land and nearer to farmland was completely covered with bamboo tree including watersheds.

a.


b.


Figure 11. FGD(a) and KII(b) with Study area Communities

One of FGD discussant called Mr. Mengesha said:

> *“Before 3 decades there were as such no landslide occurrences in our villages. This may be due to farmland expansion by clearing existing bamboo tree and shrubs around farm boundary and marginal land. In addition, we had no skill and experience of landscaping and modern form of soil and water conservation methods”*

As above expression implies there was interruption of indigenous farmland practices and lack of immediate intervention with modern farmland management techniques including landscaping and appropriate soil and water conservation practices.

One of the two key informants from the community said:

> *“For prolonged period there was cereal crop and tillage cultivation practice focus in our village. For this reason and farmland shortage we cleared grazing and shrub lands. Besides we encroached almost all marginal lands including river banks and marsh lands. That might have caused soil erosion, gulley formation on farmlands and landslide occurrence.”*

Based on the above statements the researchers can conclude that farming community have realized root causes for landscape and slope failure and related recurrent landslide occurrences. Thus, the present lack of indigenous or modern form of landscaping on study area farmland like stone bund, soil bund, bench terrace, graded fanaya juu terrace, normal fanaya juu terrace, gabion etc, and also low biological land conservation methods were adopted on that highly land slide susceptible area.

In addition to FGD and KIIs information, the observation done by research team on landslide prone area clearly indicated that there was poor landscaping and inappropriate farmland management practice resulted in frequent landslide occurrence in study area. Furthermore, topographic condition, geology (unconsolidated soil condition), and road construction (deep hill side cutting) aggravated landscape failure and recurrent landslide occurrence.

Figure 12. Landslide picture taken during Field observation at Zebo(Galaza), 2021

Therefore, aforementioned situations in study area demands high level intervention with modern landscaping (stone bund, soil bund, bench terrace, graded fanaya juu terrace, normal fanaya juu terrace, gabion etc) as well as introduction of appropriate farming practice and farming community income diversification.

## CONCLUSION

In the present study landslide susceptibility status was analyzed using analytical hierarchy process (AHP), Spatial multi-criteria evaluation (SMCE), and weighted linear combination (WLC). In order to substantiate analysis by Remote sensing and GIS data for major causes of landscape failures and associated landslide problem field observation, Focus Group Discussion, and Key Informant Interview methods were employed.

Findings indicated that major causes for landslide susceptibility in study area in the order of importance were slope steepness (0.32), geology (0.24), soil texture (0.19), aspect (0.08), and drainage density (0.05). Accordingly five susceptibility zones were identified in the study area. From the total area (308.44 km2): very high susceptibility (28.75%), high susceptibility (22.46%), moderate susceptibility (20.97%), low susceptibility (8.01%), and very low susceptibility (19.81%).

Qualitative data obtained from FGD and KII revealed that major causes of landscape failure and landslide occurrence were removal of indigenous plants around farmland boundaries, stream courses, hill sides and absence of timely intervention of integrated landscape based soil and water conservation practices. As above 72% of the study area is moderate to very high landslide susceptible, concerned bodies such as government lined departments, local level community organizations and NGOs should give attention for intervention with integrated indigenous and modern farmland management as well as income diversification for the farming communities is highly recommended.

## DECLARATIONS

### Conflict of Interest

We declare no conflict of interest, financial, or otherwise.

### Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

**Informed Consent**

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

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