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Landslide Susceptibility Assessment Using GIS on Rock-Soil Slope along Zabidar Mountain Road Corridors, Ethiopia

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Abstract
Landslides are deceitful natural disasters, resulting in the loss of human life, collapse of engineering structures, and the natural environment on the earth. Therefore, the aims of this study to assess, predict and mapping of susceptible landslide hazard map using GIS based software. Six landslide causative factors including aspect, distance from stream, lithology, plan curvature, slope and elevation selected as influencing factor for landslide occurrences. The landslide frequency ratio calculated using the probability technique. The controlling elements graded using a statistical and frequency ratio methodology based on GIS. The landslide hazard map shows 27% (4.8 km^2) is no-danger zone, with 588 (41%) families living there. A medium to landslide danger zone covers 29% (5.2 km^2), with 555 families (38.7%) living. A low-risk landslide zone covers 23% (4.1 km^2), with 228 (16%) families living. A high-risk landslide zone covers 21% (3.8 km^2), with 61 (4.3%) families living. The prediction rate of all factors revealed that, the highest landslide occurrence associated with Lithology and plan curvature. When these are added with high rainfall intensity, the magnitude of the landslide increases. The highest prediction accuracy of 89.58% found from combination of all causative factors which depicts how well the model and factors accurately forecast landslides.

Keywords: Causative Factors, Hazard Map, Landslide, Slope.

Introduction

Landslides are a downward movements of the earth and/or rocks that occur on the earth crust as a form rotational or translational rupture, and in which most of the materials moves as a comprehensible or semi comprehensible mass with little internal deformation. It is also important to note that landslides will also cause other forms of motions, either at the beginning of collapse or thereafter, when the properties of the displaced material shift when it travels downhill (Abeebe et al., 2020). Landslides in mountainous terrain often occur during and after heavy rains, causing death and disruption to the natural and built environment (or both). Landslide-prone areas should also be known ahead of time to minimize risk (Woldearegay, 2013).

Risk of Natural and man-made landslides and associated disasters have been observed in every all regions of Ethiopia, resulting in the loss of human life, the collapse of engineering

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systems and disruption to agricultural lands and the natural environment. Major infrastructural development (including roads and railroads), urbanization and comprehensive natural resource management are currently underway in the country (Woldearegay et al., 2005)

Landslides are one of the most dangerous natural phenomena, causing great damage to construction systems such as highways, railways, bridges, dams, bioengineering structures, and homes, as well as death. Therefore, landslide vulnerability mapping is required to identify potential landslide areas (Hungr et al., 2014). Over the last 50 years, Ethiopia has caused in the deaths of humans and animals, as the destruction of infrastructure and property. Between 1960 and 2010, 388 people died, 24 people were hospitalized, and a large area of cultivated and non-cultivated soil, buildings, and homes were all impacted. Rainfall-induced landslides killed 62 people, wounded 30 others, displaced 5091 families, damaged homes, and damaged both cultivated and non-cultivated land across the country in 2018. Despite the fact that Ethiopia's landslide issue is severe, there is still no comprehensive landslide susceptibility mapping in the country's various regions (Abay & Barbieri, 2012). Rainfall-induced landslides of various forms and sizes often occur in Ethiopia's hilly and mountainous terrains. With careful project preparation and execution, landslide susceptibility mapping will provide most of the critical knowledge needed for hazard mitigation (Hong et al., 2015). Therefore, creating landslide susceptibility map is an efficient and cost-effective way to minimize minimizing the negative effect of landslides.

Natural disasters are a major obstacle to economic development, especially in developing countries (Crosta et al., 2003). The landslide hazards is one of the world's most deadly natural disasters. Through taking effective steps, landslide threat mapping assists in reducing the danger of a landslide. Monitoring landslides in a vast region with a sparse population, on the other hand, can be a costly, labor-intensive, and physically exhausting activity. Landslides are often characterized as local issues, but their consequences and costs often exceed local governments, becoming State, Provincial, or national problems (Eberhardt et al., 2004)

It is difficult to reliably predict the time and location of landslide over wide area. In landslide studies, the quality of the data is important, and when the data is sufficient and relevant and extracted from various parameters, more reliable results can be obtained. A field survey or visual analyses of stereoscopic aerial photography are two of the most popular techniques for landslide mapping. These processes, on the other hand, are not only time-consuming but also resource consuming.

The use of geographical information system is one of the most important approaches for estimating the frequency of landslides and identifying landslide risk zones. This allows for rapid analysis of cartographic material and selection of the method that are appropriate for the target, size, and data available (Yalcin et al., 2011). In recent years, many countries have minimized loss of life, property destruction, and infrastructure failure caused by landslide-related hazards by detecting and providing appropriate landslide safety systems using GIS-based landslide hazard zone maps. Concerns about the causes of landslides and their estimation of their occurrence vary widely from region to country this especially in developed countries, where landslides and associated hazards are seen as growing rather than decreasing in severity and danger.

Fresh bedrock's susceptibility to rock falls, rockslides, and block glides is determined by a variety of factors, including seepage forces during rainstorms. The weathered zone grows outward from the joint, isolating rock and fresh rock blocks or boulders to form core stones. Core stones can become remnants on the ground surface in some areas and can roll down hills during rainy seasons, causing severe damage. The rock fall landslide is the most common form of slide in this weathering stage. The danger of falling materials is real. Property under the fall-line of big rocks may be damaged by falls. Boulders have the ability to bounce or roll long distances, causing structural damage or death. Rock falls can cause deaths in cars struck by rocks which can obstruct highways and railroads, causing significant damage to roads and railroads. (Lee & Min, 2001).

As shear stress exceeds the shear strength of slope material, landslides/slope collapses occur. The factors that lead to a rise in shear stress and factors that contribute to a decrease in shear strength can be categorized as landslide causative factors. However, water is another factor that contributes to both increasing and decreasing shear stress and shear strength of slope material, respectively (Zhou et al., 2016).

Understanding the geological setting (lithological and structural), terrain characteristics, hydrological condition (surface and groundwater), land use/vegetation status, and other geomorphological processes is essential for understanding failure mechanisms and designing effective landslide mitigation measures (Mersha and Meten, 2020) The lithology, elevation, slope, aspect, plan curvature, and distance from the river all have a role in the spatial distribution and intensity of landslides. Therefore, assessing the effects of these causal parameters on the spatial distribution of landslides is important for understanding their working mechanism of action and developing a landslide susceptibility maps (Felicisimo et al., 2012)

In order to prepare the landslide susceptibility map quantitatively, the frequency ratio method was implemented using GIS techniques. Frequency ratio methods are based on the observed associations between the distribution of landslides and each landslide-related factor, to expose the correlation between landslide locations and the factors in the study area. Landslide Susceptibility Mapping Index (LSMI) provides very fundamental knowledge of the effective factors and causes of landslide occurrence. In addition, it can be an effective method in hazard management and mitigation measures. The preparation of the LSI map is important through which one can detect susceptible areas for the future landslides and use these maps for the future planning Preparing a landslide susceptibility map of a certain area is a useful tool in landslide hazard management. The landslide susceptibility map thus produced can be used to reduce hazards associated with landslides and to land cover planning (Abebe et al., 2020; Abay & Barbieri, 2012; Meten M et al., 2020).

The Frequency Ratio (FR) model is one of the important probability methods in landslide susceptibility mapping based on the observed relationship between distribution of landslides and each landslide-related factor. The FR method follows the principle of conditional probability, in which if the ratio is greater, the stronger the relationship between landslides and factor classes and vice versa. The frequency ratio was then summed to produce the final landslide susceptibility index (LSI) ((Meten et al., 2020; Abay & Barbieri, 2012; Baharin et al., 2014; Bai et al 2010).

Landslide susceptibility mapping can be done by integrating Relative Frequency (RF) and Predictor Rate (PR). PR was applied to the RF to quantify the prediction ability of the conditioning factors while producing Landslide Susceptibility Index (LSI) (Baharin et al., 2014; Bai et al., 2010).

Modification between landslide areas and related factors that cause landslide can be assigned from the relationship between area without considering past landslide and landslide related factors. To prepare landslide susceptibility map, the frequency ratio implemented using GIS techniques. The frequency ratio method is based on the observed association between distribution and landslide-related factors, showing the correlation between landslide location factors in the study area

Not only does the country lack a competent organization capable of leading the way in landslide hazard assessment and prevention, but it still lacks realistic policies for landslide risk management. This is due to a lack of landslide assessment, a knowledge deficit on various causative factors, internal and external triggering factors, method of counting, measuring, analysis, landslide susceptibility mapping practices, and the lack of appropriate landslide protection mechanisms. As a result, Zabidar Mountain is one of the most prone to landslides of various forms in the Northern South Nations Nationalities and Peoples' Region of Ethiopia. In this area, flooding and landslides are the most serious issues affecting human and animal life, agricultural fields, infrastructure, and the social and economic elements of rural communities as a whole.

The work presented here contributes to the use of a spatial analyst tool cut/fill in GIS software to forecast landslides on Zabidar Mountain rather than manually counting landslides or measuring slide surface area. As a result, a susceptible landslide hazard map of the research area was created using the frequency ration (FR) approach. The FR method follows the principle of conditional probability (calculates importance of contributing factors), in which case if the ratio is greater, the stronger the relationship between landslides and factor classes and vice versa. And vulnerable settlements and potential slope failure spots along the research area road corridor were found. This study's findings may be useful to decision-makers in forecasting the likelihood of a landslide occurrence zones as well as in future land management and hazard reduction programs.2. Materials and methods

Study area

The study was conducted in the Northern South Nations Nationalities and Peoples' Region (SNNPR) on Zabidar Mountain, approximately 120Km from Addis Ababa (Figure 1). Zabidar Mountain is located in central Ethiopia. It is the highest point in the Gurage zone and the entire Southern Nations, Nationalities and Peoples' Region. This mountain has an elevation of 3,719m above sea level. The proposed study area has a perimeter of 17.5km, an area of 17.9Km^2 and a 13.9km highway road through it. The study area is located in between six kebeles (Adeyo, Gugiso and Ageta) from Silt'e zone and (Mirab meskan, Aborat and Wurib) from the Gurage zone. Geographically found between latitude of 8^{O} 05'00"N-8^{O} 06'08"N and longitude of 38^{O}14'46"E- 38^{O}17'26"E with an elevation of 2,221 to 3,364.9m above sea level.

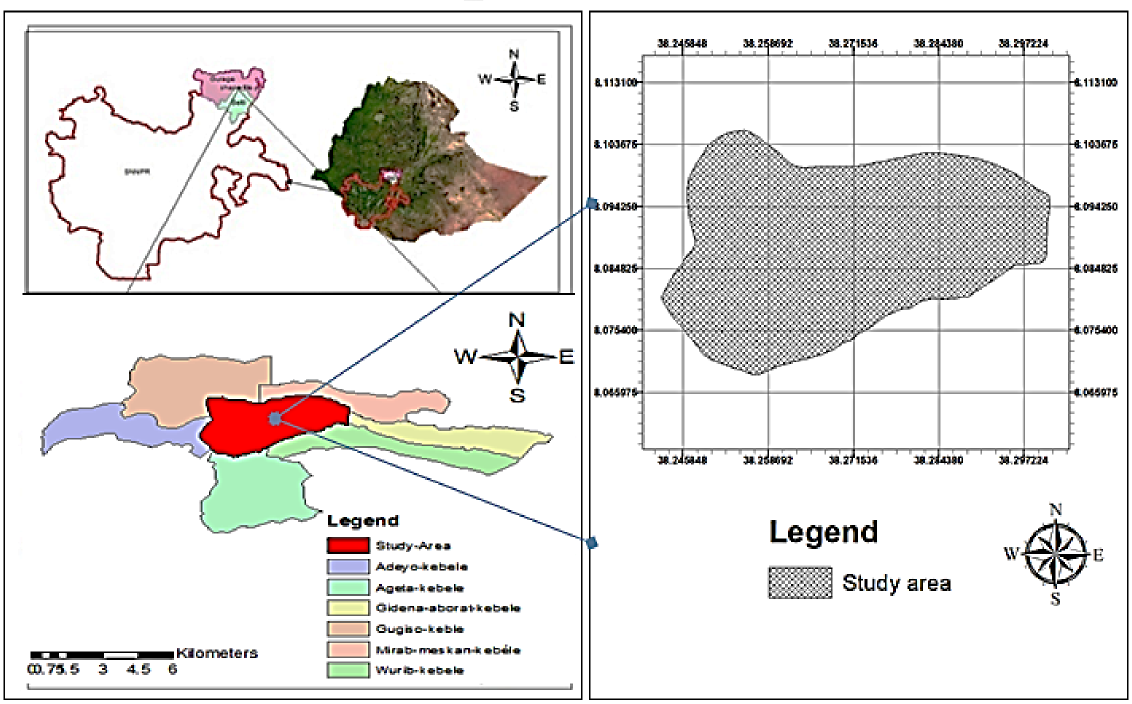


Figure 1. Geographical location of the study area

Field work

Using GIS (Geographical Information System) or downloading from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), GDEM (Global Digital Elevation Model), and USGS (United States Geological Survey), lithology, elevation, slope, aspect, curvature, and distance from stream/river maps of the study area were developed for the last 6 years. Finally, use GIS cut/fill raster surface tool, either from digital elevation models (DEM) or Slope map; loosed, gained and unchanged surface in each causative factors class for each year were developed. Since the study is targeted at landslides, only lost surface was considered and extracted for each of the last 6 years. In each causative factor class in the excel sheet that shows the number of lossed/eroded pixel numbers for each of the last 6 years (2015, 2016, 2017, 2018, 2019 and 2020) were tabulated.

At the site, the ground verification of potential landslides, general layout of the study area (Figure 3), identification of mode and condition of landslides, measurement have been performed for verification. To determine some of the visible geological outcrops and the topographical conditions, of the state of geotechnical work, photographs of key features of the area, and visual identification of rock-soil profiles along the road corridor throughout the study area, location of samples to be taken and sampling were made for determination of the geotechnical properties.

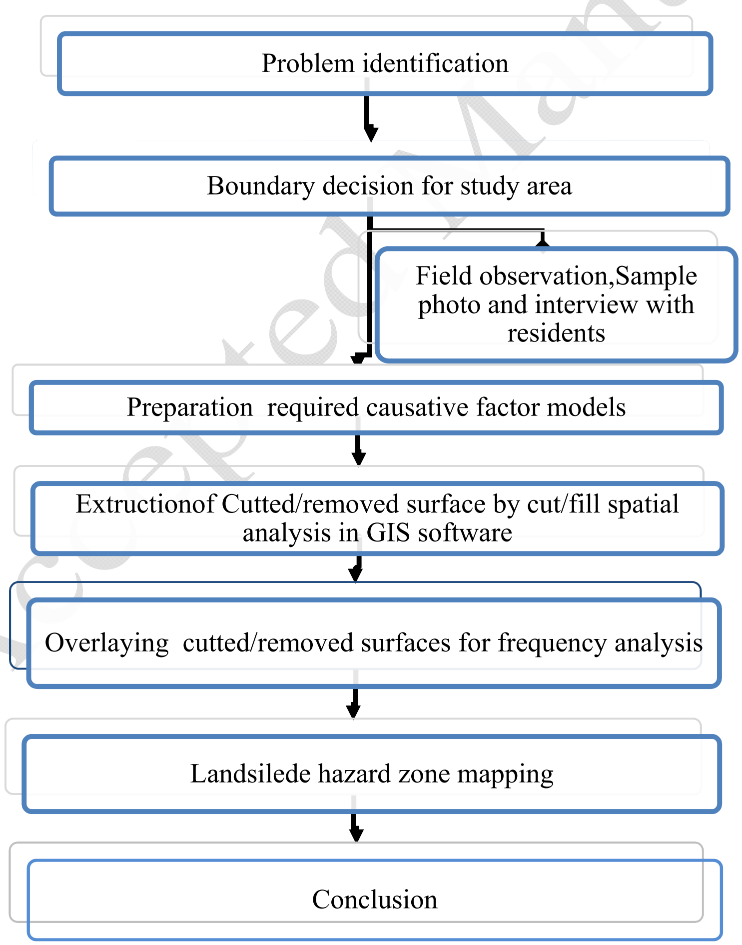
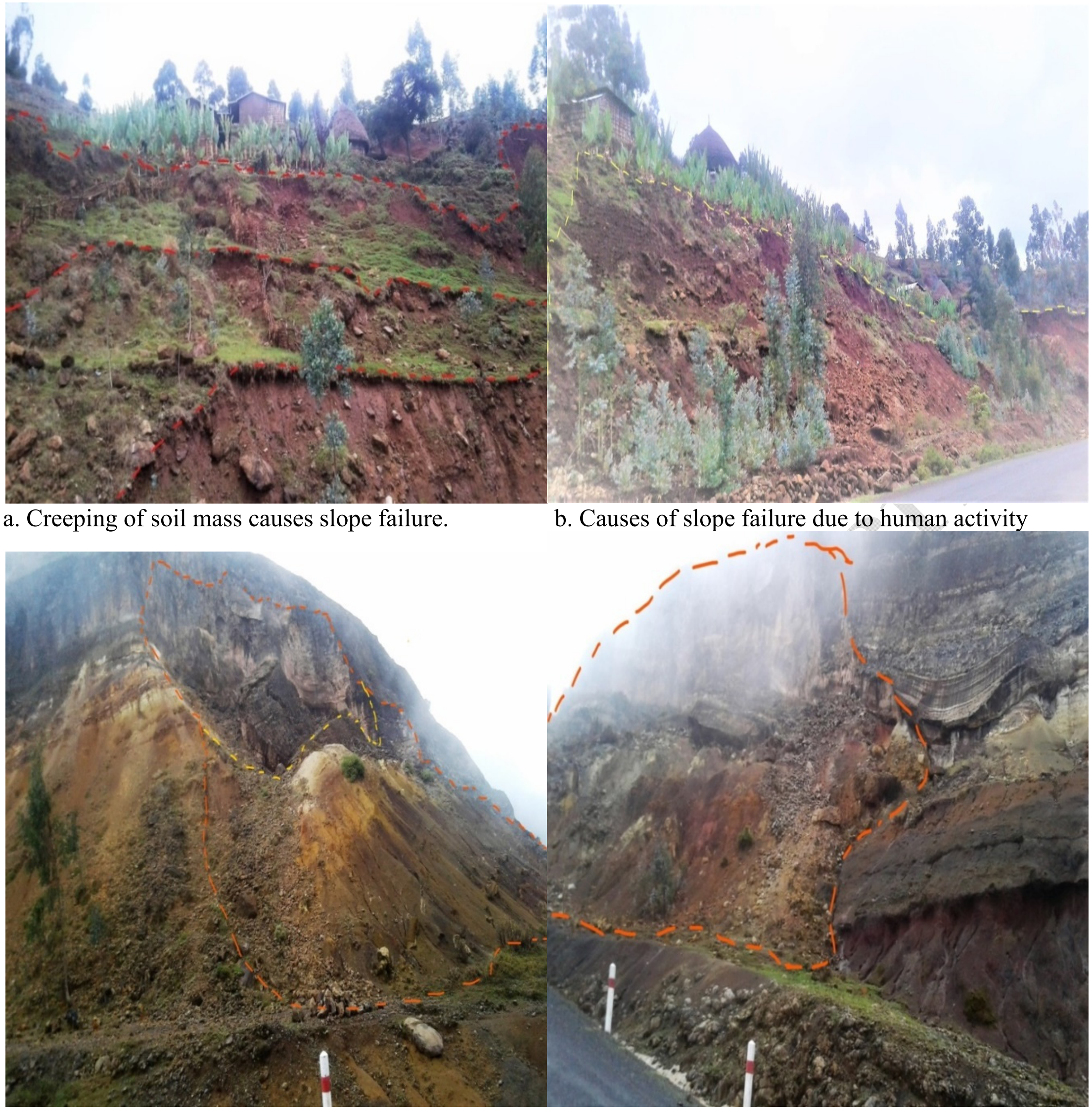


Figure 2. Schematic research design



a. Creeping of soil mass causes slope failure. b. Causes of slope failure due to human activity

c. Weathered rock along with slope failure d. A block of bedrock that breaks off and falls

Figure 3. Sample photo that shows failure Rock-soil slope along road corridor

Geology of study area

Geology is the study of the occurrence and change of rock on the Earth's surface over time. Since various rock types have differing resistance to weathering and soil erosion, geology has a big impact on the occurrence of landslides. The geological map of the study area has been updated from the Ethiopian Geological Survey's 1973 Geological Map. As shown in the Figure 4, the geological composition of the study area is alkaline, Trachyte, tractry basalt, and per alkaline rhyolite with subordinate alkaline basalt.

Landslide causative factors

Factors that causes landslides, in this study, used a frequency ratio (FR) model, a landslide susceptibility index (LSI) map, and Probability ratio (PR) to investigate the relationship between six causative factors and the occurrence of landslides. In order to know where landslides are likely to occur and to create a landslide vulnerability map.

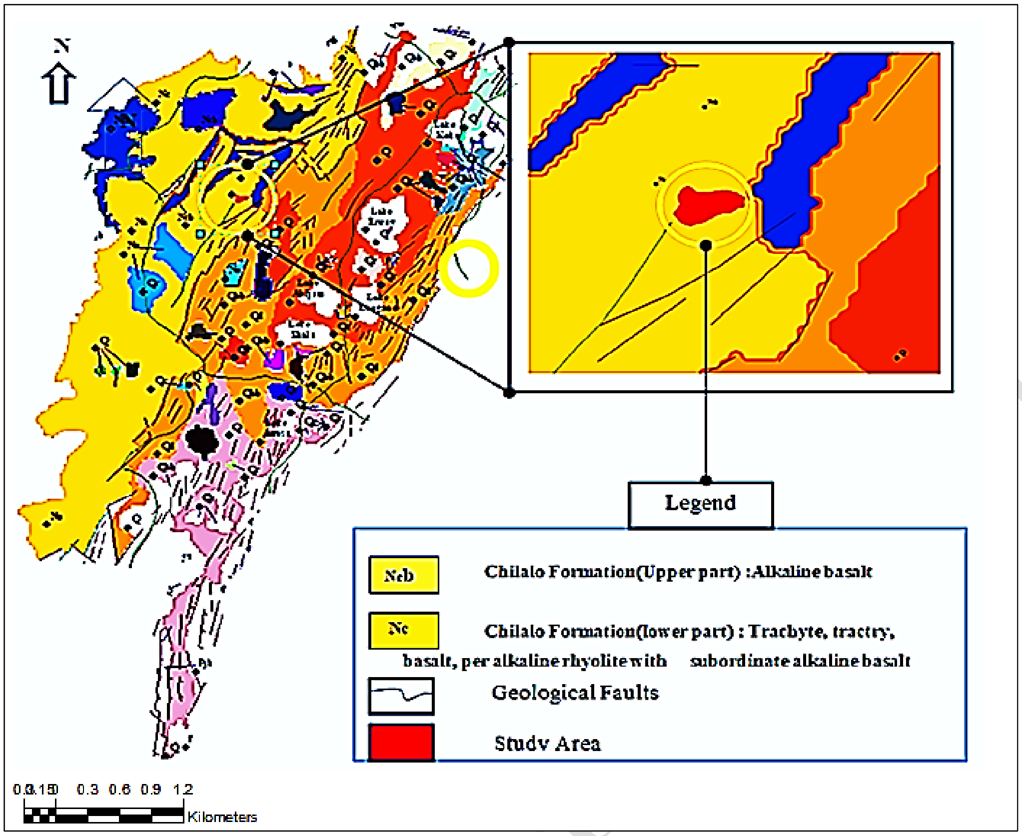


Figure 4. Geological map of the study area

It is important to evaluate the impact of factors that cause land slide spatial distribution. The value of frequency ratio was determined after the causative factors prepared with the help of ArcGIS. The lithology/soil mass, elevation, slope, aspect, curvature, and distance to stream are the six causative factors that have been used in this study to prepare landslide vulnerability maps. In the following sections, it was seen the roles that each of these causative variables played. After all of the eroded or removed surfaces' pixel number in each causative factor class was counted for each six past consecutive years of the study area, based on the ideology of "soil erosion initiates landslides" (Baharin et al., 2014; Bai et al., 2010); the frequency ratio of each causative factors class found by dividing the percentage of landslide pixels to the percentage of area pixels in each factor class.

$$\mathrm{Fri,j}'' = \frac{\boldsymbol{ni,j/Ni,j}}{\boldsymbol{nT/NT}} \qquad (1)$$

Where, ni, j =The number pixels of losses/eroded land surface in jth subclass of the factor i during rainy season, Ni, j = The number of pixels of the corresponding subclass, nT =The total number pixels of losses/eroded land surface and NT =The total number of pixel number under investigation. Calculated frequency ratio (FR) value represents the degree of correlation between causative factors and landslide. A value of 1 is an average value for the landslide occurrence of specific landslide causative factor class. A value of more than one indicates strong and positive correlation and highly probability of landslide occurrence, while value less than one indicates a negative relationship and low probability of landslide occurrences in certain class of landslide causative factor. The frequency map of each causative factor is prepared with the help of ArcGIS by assigning the calculated FR values. Then the FR value of all causative factor maps were overlaid and numerically added using the raster calculator and numerically added using raster calculator of special analyst tool in ArcGIS to prepare the landslide susceptibility index (LSI) map. LSI is computed by summing the FR values of all landslide causative factor maps. And then the resulting LSI map further reclassified in to very low, low moderate, high and very high landslide susceptibility classes.

$$LSI = FRli + FRel + FRsl + FRas + FRcu + FRd \tag{2}$$

Where, LSI = landslide Susceptibility index, FRli = frequency ratio value of lithology, FR_{el} = frequency ratio value of elevation, FR_{sl} = frequency ratio value of slope, FR_{as} = frequency ratio value of aspect, FRcu = frequency ratio value of curvature, FR_{dr} = frequency ratio value of distance from stream/ river. Determined values of frequency ratio for each pixel in the LSI show the relative vulnerability to landslide occurrences. The higher values of LSI pixel have high vulnerability to landslide occurrences and vice versa.

Landslide susceptibility mapping analyses

Landslides are complicated interactions involving a variety of terrain features and are caused by a variety of reasons. There are numerous factors that can cause a landslide. Even if they are not all equally essential in terms of landslide occurrences, it is critical to decide which type of the causative elements shall be appropriate and easily applied in order to construct an effective landslide susceptibility map (LSM) for the desired research region. For instance in this study, distance from geological fault was not applied because of it out of the boundary of study area. In addition land use/cover causative factor was not applied because of very complicated study area and variation of land usage by local residents. Therefore, this research examines the relative contributions of commonly known six landslide causative elements in order to develop an effective landslide susceptibility model. Lithology, elevation, slope, aspect, curvature, and distance from the river are the six criteria employed in this study.

The frequency ratio approach was used in this work to conduct landslide susceptibility studies. After the frequency ratio for all considered causative factor subclasses for all the past six consecutive years were calculated, further analysis between all six causative factors and landslides was made to deduce correlation ratings. The governing parameters were rated using a GIS-based statistical and likelihood approach, and then a customized raster calculation was used to develop the landslide hazard zone maps for each of the past six years.

During the present study six causative factors namely; lithology/soil mass, Elevation, slope, aspect, Plan curvature, and distance from river were considered. It assumed that these causative factors probably responsible for landslide in the area. The probability method attempt was made to establish a spatial relationship between these factors and the landslides/erosion occurred in the study area for all the past consecutive six years. By using statistical approach, in addition to frequency ratio (FR) different parameters such as frequency rate (RF), frequency rate in percentage (RF %) and Probability ratio (PR) was tabulated by excel sheet.

$$(RF) = \frac{frequency\ ratio\ (FR)}{\sum_{n=1}^{\infty} frequency\ ratio\ (FR)} \tag{3}$$

$$(RF\%) = \frac{frequency\ ratio\ (FR)}{\sum_{n=1}^{\infty} frequency\ ratio\ (FR)} * 100 \tag{4}$$

INT(RF)= Integer value of rate of frequency(RF) Without including any decimal value of rate of frequency(RF)

$$(PR) = \frac{Max\ RF - Min\ RF}{MININUM\ OF(Max\ RF - Min\ RF)} \tag{5}$$

Where, Min RF= Minimum frequency rate and Max RF=Maximum frequency rate

After all, required parameters for each causative factor's subclasses for each of the past six years, by using the raster calculator in ArcGIS landslide susceptibility maps for each of the past six years were established.

$$landslide\ hazard\ map(LHM)\ for\ year(ij) = \sum_{n=1}^{\infty} (\text{Causative factor map(ij)} * \text{PR(ij)}) \tag{6}$$

Where, PR(li)=Probability ratio for Lithology map, PR(el)= Probability ratio for Elevation map, PR(sl)= Probability ratio for Slope map, PR(as)= Probability ratio for Aspect map, PR(cu)= Probability ratio for Plan curvature map, PR(dr)= Probability ratio for Distance from river/stream map. Applying this statistical approach, landslide hazard maps for each year under consideration were prepared. Susceptibility to landslides is observed in the areas near rivers/streams, directional slopes to the north and south, and highly steep slope areas, as shown in each of the maps.

Lithology/ Soil mass Map

Lithology describes the characteristics of a rock units. The lithological phase diagram of the current research area lithological map was also collected from the Ethiopian Geological Survey 1973 report (GSE, 2011). The study area has three types of soil mass. According to the map,, Pelitic vertisols, Stone crust, and chromic luvisols are the three types of lithology/soil masses that cover the study area. Figure 5 shows the lost/eroded surfaces on lithological map for the past six years.

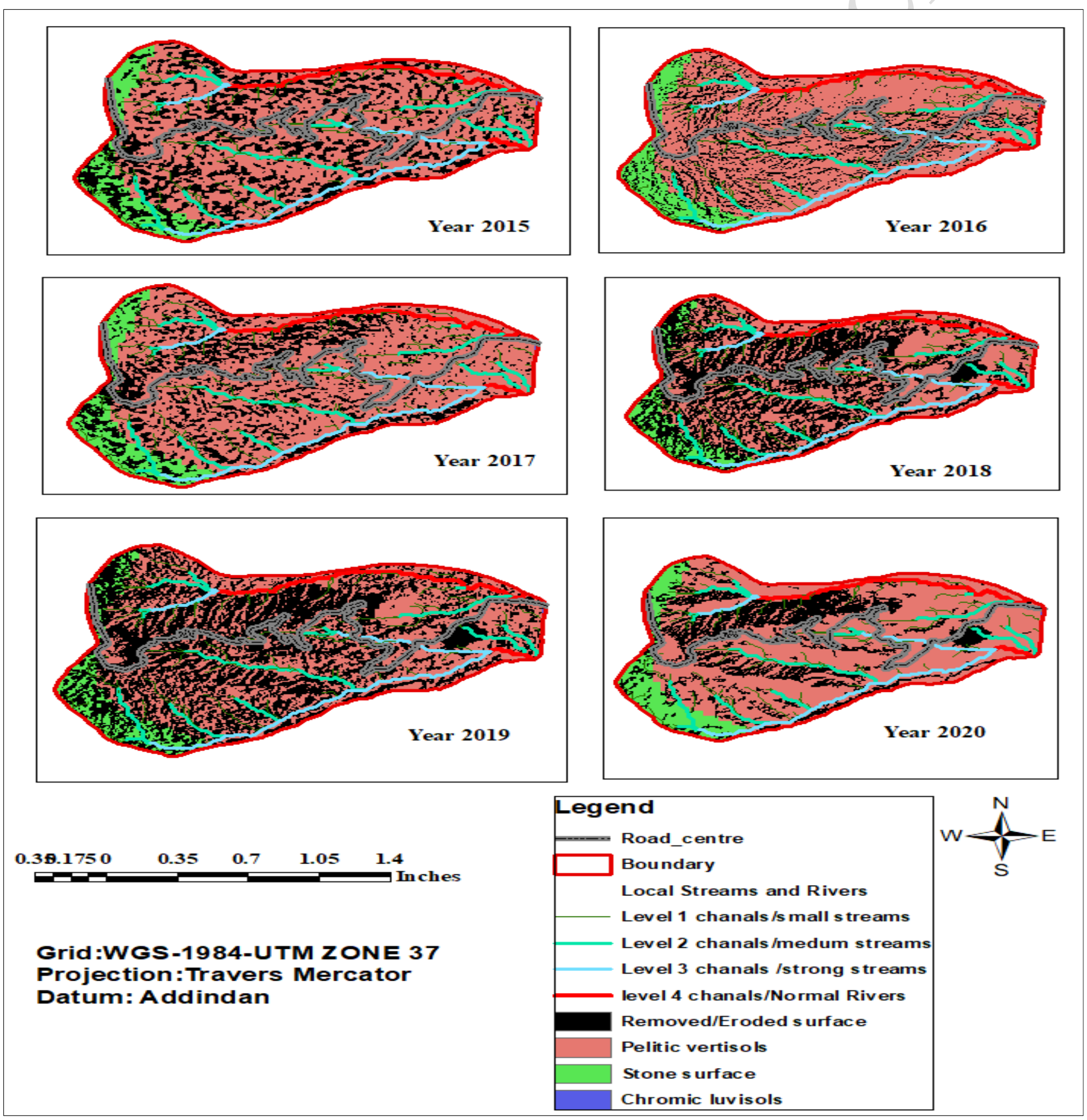


Figure 5. Mapping the lost/eroded surfaces on lithological map for the past six years

Elevation map

Figure 6 shows the lost/eroded surface on the elevation map for the last 6 years. Elevation refers to the height above sea level. It is one of the factors that contribute to erosion and landslides. A digital elevation model (DEM) has been created for this study over the last six years (2015-2020). The elevation maps for all years were classified into five subclasses: 2221-2450 meters, 2450–2670 meters, 2670-2900 meters, 2900-3100 meters, and 3100-3370 meters above sea level.

Slope Map

Figure 7 shows the lost/eroded surfaces on the slope map for the past six years. A slope is the upsurge or drop of the ground surface. Slope angle is the most important relief characteristic that affects the mechanism and the intensity of the landslides. In general, if the slope is steeper it will be more vulnerable to instability as compared to gentle slope. The gravity pull, which is the main activating force for instability, is directly proportional to slope gradient. The slope for the present study area for each of the past six years was extracted from the digital elevation model (DEM). A slope category (subclass) map was created for four categories for the current study: (i) 0–5%, (ii) 5–25%, (iii) 25–50%, and (iv) 50–100%.

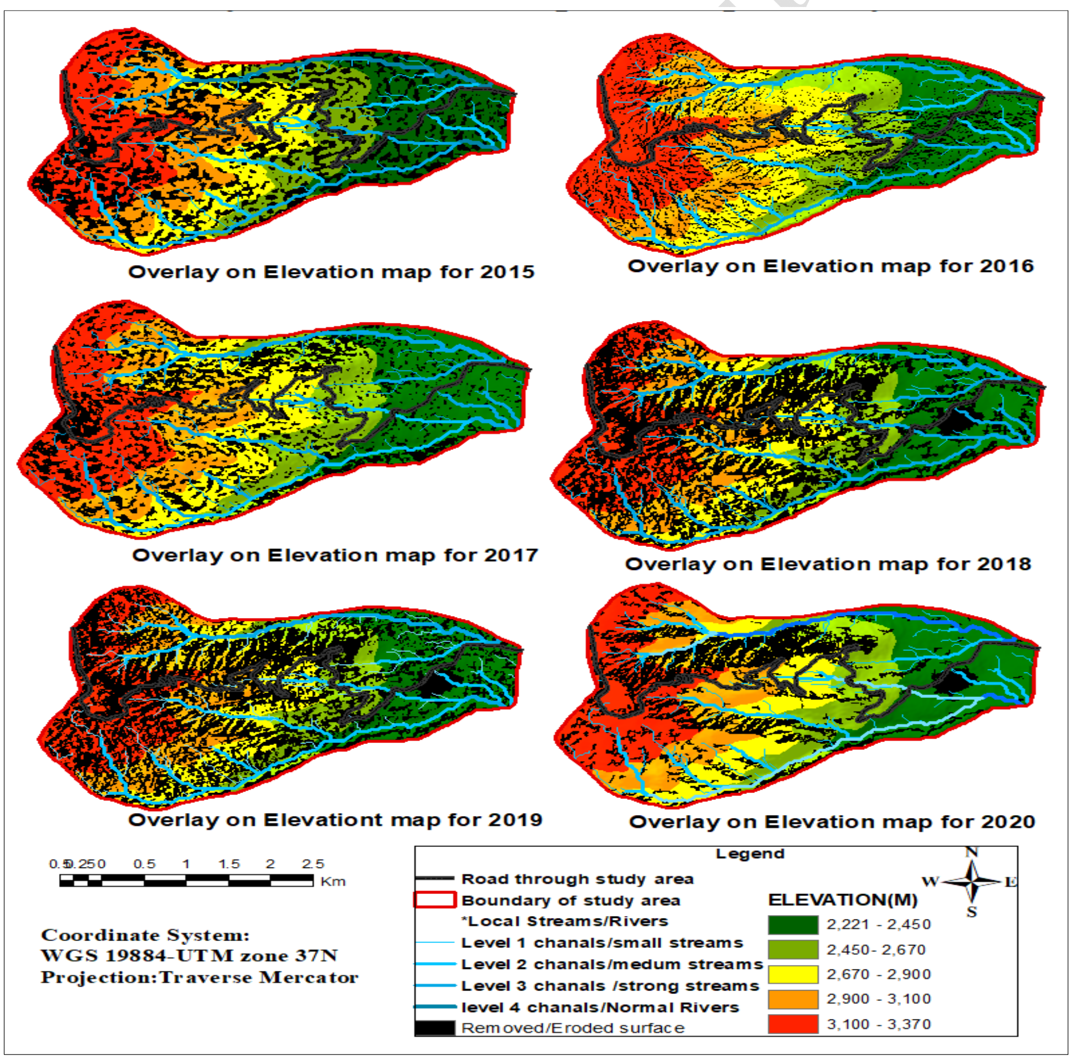


Figure 6. Mapping the lost/eroded surfaces on elevation map for the past six years

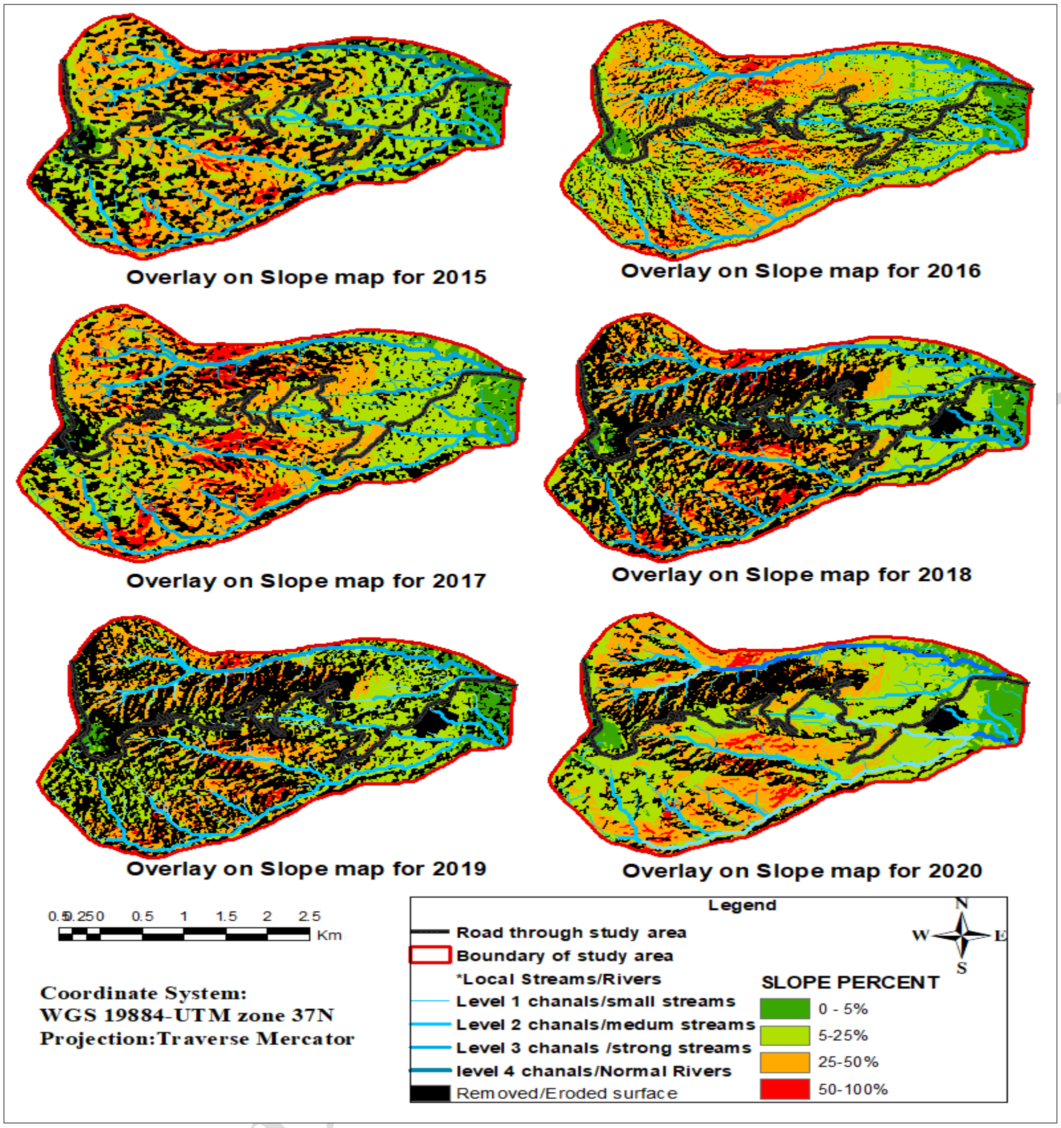


Figure 7. Mapping the lost/eroded surfaces on slope map for the past six years

Aspect Map

Figure 8 shows the lost/eroded surface on the aspect map for the last 6 years. Aspect is the directional slope of the ground surface. It refers to the slope orientation, which is measured in degrees from 0 to 360 degrees. It is a significant factor in landslide studies because it regulates the slope's exposure to sunshine, wind direction, rainfall (degree of saturation), and discontinuity conditions. For this study, the slope aspect was derived from the DEM data and it was divided into nine categories: flat (1), northeast (22.5–67.5), east (67.5–112.5), southeast (112.5–157.5), south (157.5–202.5), southwest (202.5–247.5), west (247.5–292.5) and northwest (292.5–337.5).

Plane Curvature Map

Figure 9 shows the lost/eroded surface on the plane curvature map for the past six years. The curvature of topographic contours or the curvature of a line created by the intersection of an imaginary horizontal plane with the ground surface is known as plan curvature.

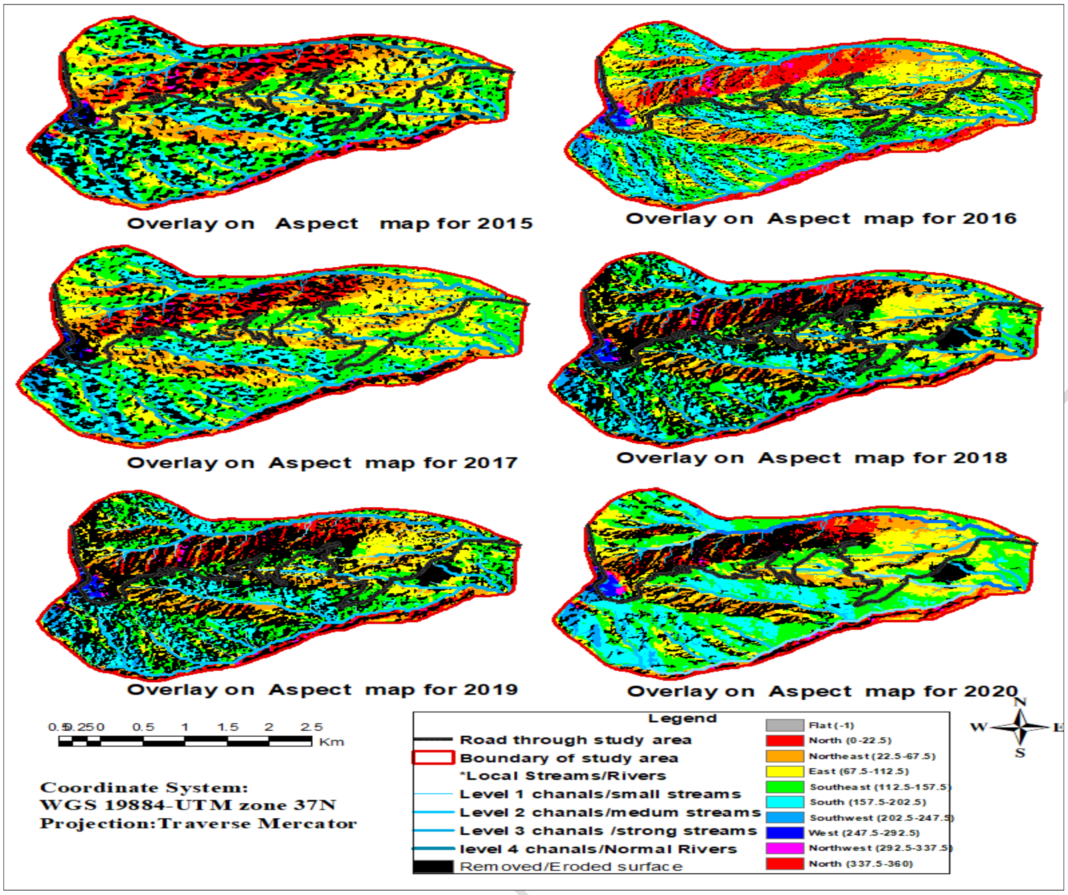


Figure 8. Mapping the lost/eroded surfaces on aspect map for the past six years

Positive plan curvature (convex) indicates flow divergence, while negative plan curvature (concave) indicates flow concentration. Concave upward plane curvatures are known as hollows, convex outward plane curvature are known as noses, and straight counters are known as planar regions. Water flow is concentrated in concave plan terrains, while it diverges in convex plan terrains.

Converging/diverging flow and soil-water content are thus influenced by plan curvature. Landslide material converges in hollows into a small area at the slope's edge. In hollows, landslide materials converge into a narrow region at the slope's base. The plan curvature for the present study area for each of the past six years was developed from the digital elevation model (DEM).A Plan curvature subclass map was prepared for three categories: (a) Concave, (b) Flat and (c) Convex as shown below.

Distance from Stream/River map

Figure 10 shows lost/eroded surfaces on Distance from Stream/River map for the last 6 years. The slope's proximity to the stream course is an important determinant of the area's landscape evolution as well as an indicator of landslide and other erosional issues. Since rivers erode the slope foundation and saturate the underwater portion of the slope forming material, they have a high chance of causing landslides

In landslide sensitivity studies, this parameter is considered one of the causal factors. As a result, five subclasses were defined for this analysis based on their respective distances. 0-5 meters, 5-10 meters, 10-15 meters, 15-20 meters, 20-25 meters, and 25-35 meters from the stream's center.

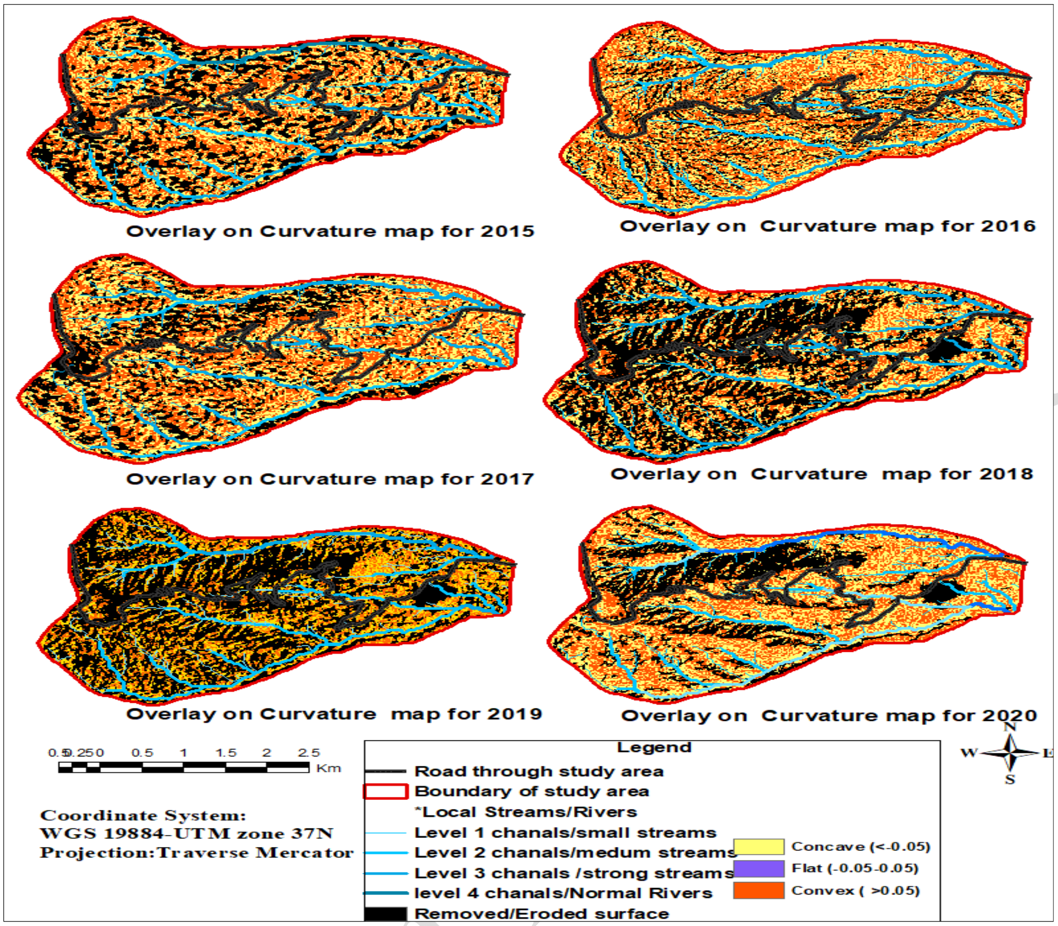


Figure 9. Mapping the lost/eroded surfaces on curvature map for the past six years

Result and Discussion

Extraction of eroded/ removed surface

The cut/fill spatial analyst tool in GIS-10.3.1 can be used to create a map centered on two input surfaces (before and after), showing the areas and amounts of surface material that have been changed by the addition or removal of surface material. For this study, the two consecutive years DEM (Digital elevation model) or Slope map was used as an input data. After running the cut/fill processing, the output results are lost, unchanged, and gained. Since the aim of this study is to evaluate landslides, only the loss surface pixel number in each causative factor is calculated and counted. After determining the number of eroded pixel numbers (13x13m size), they were projected or overplayed techniques were applied with each causative factor subclass (lithology/soil mass, elevation, slope, aspect, plan curvature, and distance from stream) in each of the previous six years (2015-2020) using the zonal statistics tool in GIS.

Landslide susceptibility mapping using frequency ratio (FR)

This study has analyzed the relationship between six causative factors and landslide incident. Using frequency ratio (FR), the relative frequency values and the weight of values were calculated. The causative factors were classified in to different classes as presented in Table 9. The values of FR shows that the relative vulnerability of each causative classes for landslide occurrence.

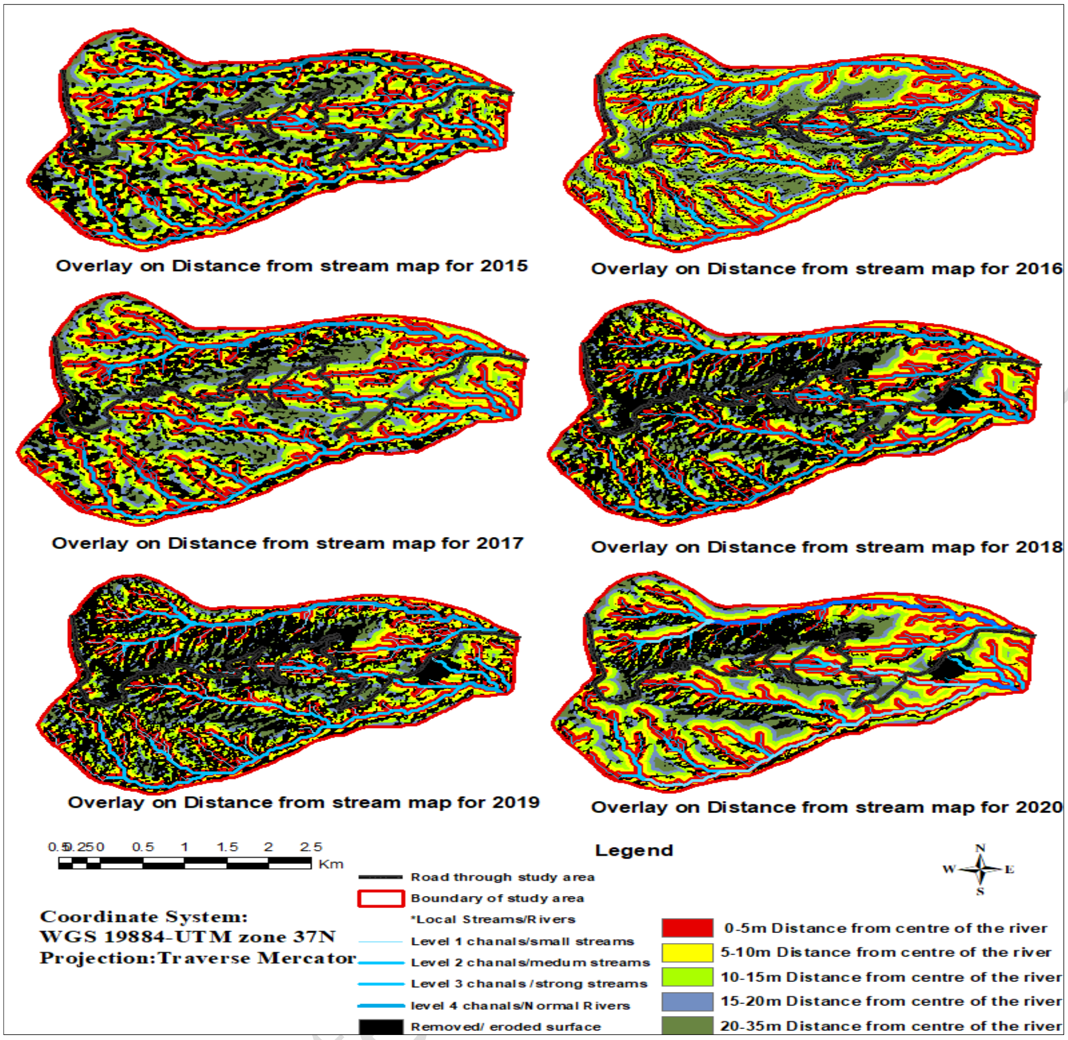


Figure 10. Mapping the lost/eroded surfaces on distance from the river map for the past six years

It indicates that, if the value is higher the susceptibility will also be higher and vice versa. The causative factor class with value greater than unity shows high degree of landslide occurrence. The frequency determination method follows conditional probability principles, in which the ratio is greater, the strongest relationship between causative factors and landslide and vice versa. From this frequency analysis, it is observed that the stronger the relationship of landslide/removed surfaces and causative factor subclasses for each of the past consecutive six years were identified.

Lithology/soil mass map

Since each class of materials has different shear strength and permeability characteristics, lithology is one of the most important limiting parameters in slope stability. Different types of rock have different compositions and structures, which can be increase or decrease the slope material resistance. In comparison to the softer/weaker rock units, the stronger rock units have greater resistance to the pushing forces. As a result, the number of lost surface pixels in each elevation or slope map subclasses were determined using GIS software and tabulated in excel sheet for the previous six consecutive years. Pelitic vertisols are soils with high shrink-swell potential, which are characterized by high clay content, cracks that open and close periodically and wedge-shaped aggregates and slickenside that occur at a specific depths (Heidari et al., 2008). Chromic containing luvisols is dark reddish-brown luvisols extracted from calcareous parent material. It's usually silty, with clay buildup. In this study, Pelitic vertisols occupy 87.7 percent of the study area, Stone surface accounts for 12.2 percent, and chromic luvisols account for 0.1 percent.

Elevation map

Elevation map changes in altitude affect the vegetation, geomorphology, and erosion rate in a particular area, changing its susceptibility to landslide. As a result, the number of missing surface pixels in each elevation map subclass was determined and tabulated using GIS software for the previous consecutive six years. Elevation classified in to 5 classes for the landslide hazard analysis. The result show that the most landslide have occurred in elevations of 2900-3100m for the year 2016 with FR value of 1.274 followed by 3100-3370m for the year of 2017 with FR value of 1.24. In contrary, the least landslide occurred in elevation of 2221-2450m with value of FR 0.5. The analysis by (Ayalew L, 2005; Nedala, 2020) showing the landslide occurred in the middle altitude zone (1500-1800 m.a.s.l). However, in this study, the probability of landslide occurrence is more concentrated at higher altitude zone, which is similar with study conducted by (Meten et al., 2020) observed higher frequency of landslides at higher altitude than lower altitude

Slope map

According to the literature reviewed, slope is a critical parameter for studying landslides because it has a clear relationship with the frequency of landslides. As a result, it is often used to map landslide vulnerabilities. As a result, in each slope map subclasses, the amount of removed/eroded surface pixels was calculated and tabulated using GIS tools for each of the previous six years. For this study, slope was categorized in to five classes; (0-5°), (5-25°), (25-50°) and (50-100°) as shown in Table 1. past landslide distributions show that , the slope class of 50-100 degree has contributed significantly to the occurrence of landslide in the year of 2020 which had higher value of FR (1.4) indicates that landslide were more frequent. However, the area with slope class of 0-5 degree has least contribution for landslide occurrence with the same year. This findings, however, in contrast to (Borgomeo et al., 2014) who observed that all landslide occured on the slopes between (10-15°), similarly, (Depicker et al., 2018) observed slope threshold of 24.8 degrees whereas Gupta noted that slopes of (21°-30°) had maximum landslide frequency. However, (Zhuang et al., 2015) found that the highest density of landslide is found in higher slope range of 15°-40°. The slope gradient controls the shear forces acting on the hillside (Silalahi et al., 2019) and thus the stepper slope is more susceptible for landslide. In conclusion in the current study, the distribution of landslides was less frequent on the lower and more prone to higher slope gradient.

Aspect map

In landslide studies, this aspect is important since it impacts the slope's exposure to sunshine, wind speed, rainfall (degree of saturation), and geological discontinuity conditions. As a result, all the eroded/removed surface pixel numbers in the elevation or slope map were counted in each aspect of subclass and tabulated. The distribution of earlier landslide using the training points reveals that, the maximum landslide occurred on slope which are inclined towards the Southwest with PR (2.939) in the year of 2017. Which is followed by the Northeast with PR (2.50) in the year of 2020 and the landslide is least affected by Southeast direction with PR

(0.4) at year of 2020. This is due to the fact that, weathering is very high to Northeast direction in the study area and decrease the shear strength of the soils. According to the study conducted by (Silalahi at al., 2019) Moisture retention and vegetation cover influenced by slope aspect, which influences soil strength and landslide occurrences. (Nedala & Nakileza, 2020) Identified that the landslide frequency concentrated in the Easter direction, this is in contrast to current study, in which the distribution of landslides are more prone to Southwest direction.

Curvature map

To determine the frequency of landslide occurrence, all eroded/removed surface pixel numbers counted in each plan curvature subclass and shown in Table 1. Analysis show that areas dominated by landslide and rock falls, in concave curvature have the highest probability of land slides in a regions dominated by earth slide and rock fall. The probability of land slide increased as the hillside become more flat in the study area. The planar curvature had the highest FR of 2.7 in the year of 2020, implying its greater influence on landslide occurrence. Value of Hollows has slightly lower probability of landslide than noses. In flat curvature the thickness and cohesive nature of fine grained soils increases and creates for the development of pore water pressure which increases the instability of the slope. Plan curvature controls the convergence and divergence of landslide materials and water within the direction of landslide motion (Ohlmacher, 2007). The landslide in the study area is severe due to curvature of the plane.

Table 1. Frequency ratio of eroded/removed surface on each causative factor for past six years

No	**causative factors**	**Causative factor subclasses**	**Frequency (FR)**					
			Year					
			2015	**2016**	**2017**	**2018**	**2019**	**2020**
		Pelitic vertisols	0.982	0.994	0.976	1.000	1.000	1.000
1	Lithology	Stone surface	1.150	1.043	1.201	1.200	1.100	0.800
		Chromic luvisols	0.125	1.108	0.101	0.600	0.800	0.500
		2221-2450	0.899	0.757	0.658	0.700	0.800	0.500
		2450-2670	1.040	0.808	0.925	1.000	1.000	1.000
2	Elevation (m)	2670-2900	0.979	1.007	1.059	1.100	1.100	1.200
		2900-3100	1.011	1.274	1.156	1.100	1.100	1.200
		3100-3370	1.084	1.161	1.240	1.200	1.200	1.200
3	Slope (percent)	0-5%	0.929	0.695	0.835	0.700	0.800	0.400
		5-25%	1.009	1.013	0.919	0.900	1.000	0.900
		25-50%	0.995	1.058	1.059	1.100	1.100	1.300
		50-100^{oo}%	1.090	0.992	1.240	1.100	1.100	1.400
		FLAT	1.207	0.654	1.856	1.200	1.100	2.300
		N	0.779	1.043	1.124	1.100	1.100	1.600
		NE	0.675	0.942	0.526	1.000	1.000	0.900
		E	0.966	1.042	0.622	0.900	0.900	0.600
4	Aspect	SE	1.393	1.214	1.287	0.900	0.900	0.400
		S	2.103	1.277	2.026	1.000	1.000	0.800
		SW	1.865	1.077	2.939	1.000	0.900	1.000
		W	1.414	0.698	2.484	1.200	1.200	2.100
		NW	1.433	0.644	2.237	1.200	1.200	2.500
		Concave (<-0.05)	1.016	0.979	0.966	1.000	1.000	0.900
5	Plan Curvature	Flat (-0.05-0.05)	0.136	1.616	0.834	0.800	0.400	2.700
		Convex (>0.05)	0.986	1.021	1.035	1.000	1.000	1.100
		0-5	0.859	1.202	0.760	1.000	0.800	0.800
		5-10	0.944	1.192	0.996	1.000	1.000	0.900
6	Distance from Stream(m)	10-15	1.213	1.128	1.035	1.000	0.900	1.100
		15-20	1.087	0.538	1.158	0.900	1.100	1.300
		20-35	1.044	0.341	1.437	1.000	1.500	1.300

He observed that the planar curvature has the very best probability of for landslide within the study area conquered by rock fall and earth slide. However, this study is in contrast with (Zhuang et al., 2015) observed those landslides occurrences are abundant at convex curvature.

Distance from Stream/River map

Rivers with many drainage networks are more likely to cause landslides when they erode the foundations of slopes and saturate the submerged parts of the slope-forming soil. In this study, the number of lost parts or surfaces were counted and tabulated for each distance subclass for each year. Landslide is very high in stream distance of between 20-35 in the year of 2019. This is due to the fact that, the existence of a river at the toe of the slopes and distance of the slopes from the river is a matter rather than the steepness of the slopes in this study area. Because, at the toe of the slope, the bank erosion and river incision have a great impact on stability of slopes, that can initiate the mass movement of the study area. Rivers with number of drainage networks have high probability of landslide occurrence as they erode the slope base and saturate the underwater section of the slope forming materials. In contrast to this study, (Meten et al., 2020), landslides were found to occur at a distances greater than 150mfrom the stream class.

Landslide Susceptibility index (LSI)

Average Probability ratios of eroded/removed surface on each causative factor are shown in Table 2. Landslide susceptibility index (LSI) indicates the degree of susceptibility of the region for occurrence of landslides. The higher the value of landslide susceptibility index (LSI), the higher the probability of landslide occurrence, but the lower the landslide susceptibility index (LSI) value indicate the lower the probability of landslide occurrence. Based on the value of LSI for each causative factor subclasses in each year, the following hierarchal rank of causative factors were developed for each year.

Lithology and plan curvature were the main triggering factors among causative factors and they equally accounts 27% followed by slope and distance from the stream/river by 14% and 12% respectively. The percentage contribution of the selected factors based on the prediction rate summarized on Figure 11.

The LSI analysis shows, the LSI of the study area varies from 6.7 (the most vulnerable area) to 2.1 (the least vulnerable area). Accordingly, the following average landslide hazard zone map groups were established based on the statistical analysis approach. The index classified into five classes with free from landslide, low hazard zone to landslide, susceptible to landslide and very high hazard zone to landslide as presented in Figure 12.

The landslide hazard assessment showed that 27 percent (4.8 km2) of the study area is in the "no hazard" or "no landslide" category, with 588 (41%) households residing there. The study area which covers 29 percent (5.2 km2) shows medium to landslide hazard zone, with 555 households (38.7%) residing there. 23 percent (4.1 km2) of the study area is in a low-risk landslide zone, with 228 (16%) households residing there. 21 percent (3.8 km2) of the area is in a high-risk landslide zone, with 61 (4.3%) households living there.

Validation of landslide hazard zone map

Few scientists argue for another different validation approach that compares current landslides to the landslide susceptibility map and applies the success-rate curve of the area under the curve (AUC) to qualitatively assess forecast accuracy. The success rate curve depicts how well the model and factors accurately forecast landslides.

Table 2. Average Probability ratio of eroded/removed surface on each causative factor for study area

Causative factors	Causative factor subclass	2015	2016	2017	2018	2019	2020	Average	2015	2016	2017	2018	2019	2020	Average (PR)
		Years							Years						
		Integer (INT)							Probability Ratio (PR)						
Lithology	Pelitic vertisols	43	31	42	35	34	44	38							
	Stone surface	50	33	52	42	38	34	42							
	Chromic luvisols	5	35	4	21	27	21	17							
	Total								12	1	6.8	10.1	3.4	6.8	6.7
Elevation (m)	2221-2450	17	15	13	13	15	9	13							
	2450-2670	20	16	18	19	19	18	18							
	2670-2900	19	20	21	22	21	23	21							
	2900-3100	20	25	22	21	21	23	22							
	3100-3370	21	23	24	23	22	24	23							
	Total								1	2.9	1.6	5.36	2.47	4.1	2.9
Slope (percent)	0-5%	23	18	20	18	20	10	17							
	5-25%	25	26	22	24	24	22	23							
	25-50%	24	28	26	29	27	32	28							
	50-90^{o}%	27	26	30	27	27	34	28							
	Total								1.1	2.7	1.4	5.2	2.2	6.9	3.3
Aspect	FLAT	10	7	12	12	12	18	11							
	N	6	12	7	11	11	13	10							
	NE	5	10	3	9	10	7	7							
	E	8	12	4	9	9	4	7							
	SE	11	14	8	9	9	2	8							
	S	17	14	13	10	10	6	11							
	SW	15	12	19	10	9	8	12							
	W	11	8	16	12	12	17	12							
	NW	12	7	14	12	13	20	12							
	Total								3.3	2.0	2.3	1.7	1.0	5.1	2.6
Plan Curvature	Concave (<-0.05)	47	27	34	34	39	19	32							
	Flat (-0.05-0.05)	6	44	29	28	17	57	32							
	Convex (>0.05)	46	28	36	37	42	22	34							
	Total								11	4.9	1	4.4	7.9	11.1	6.7
Distance from	a. 0-5	16	27	9	20	8	5	16							
	b.5-10	18	27	12	20	9	6	17							
	c.10-15	23	25	12	19	8	7	17							
	d.15-20	21	12	14	18	10	8	15							
	e.20-35	20	7	17	19	14	8	15							
	Total								1.9	5.4	1.1	1	1.9	1	2.1

The number of landslides classified into each susceptibility class was obtained by an overlay analysis of landslides with the best landslide susceptibility map. If the number of landslide is high and very high susceptibility classes is significant, the landslide susceptibility map can be trusted to predict feature landslide. The success-rate curves were used to calculate the forecast accuracy that was utilized to choose the best susceptibility map (Meten et al., 2020; Baharin et al., 2014). In this study, for all the past six years, an average total of 26707 removed/eroded pixels were calculated. From this 26707, 80% (21366 pixels) were used as training and (20%) as validation landslide.

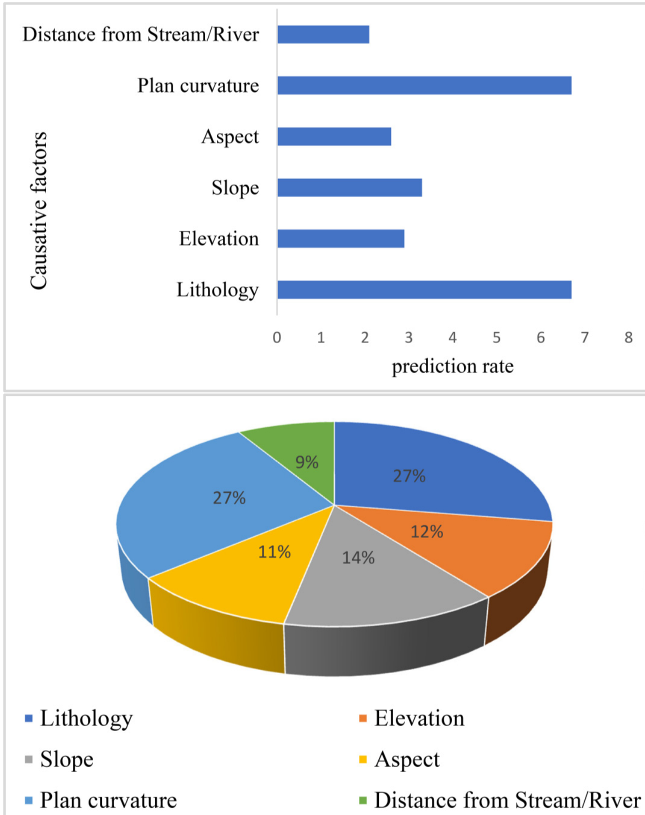


Figure 11. Percentage contribution of causal factors depend on prediction rate

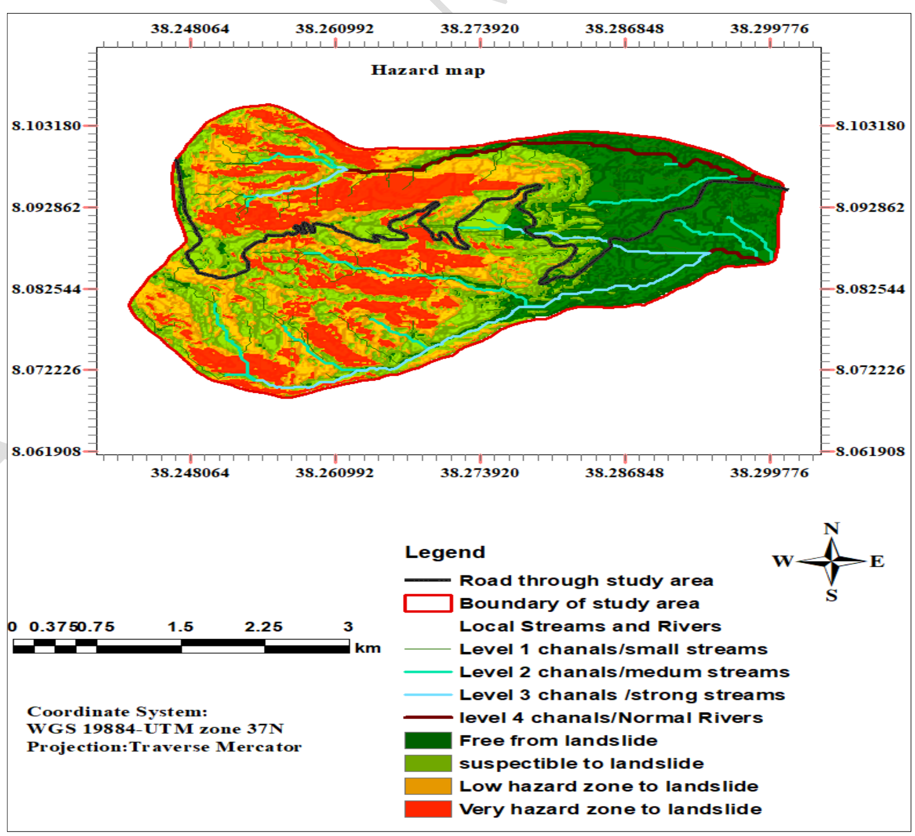


Figure 12. Hazard map of study area for previous years

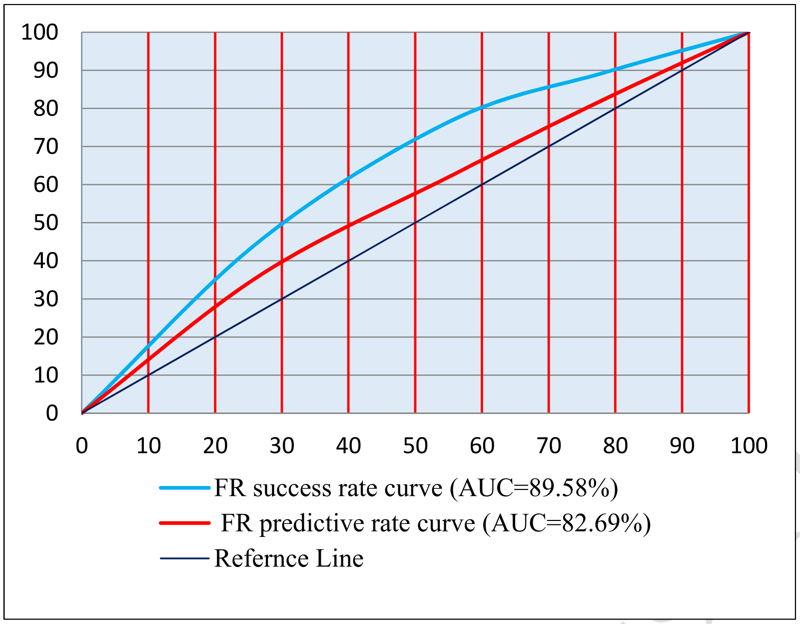


Figure 13. Success and Predictive rate curves of FR

To validate the landslide hazard zone map, zonal overlay statistical analysis was applied. The success and predictive rate curves can be created for the FR model. The success rate curve is based on the comparison between the predictive model and the training landslide. The predictive rate curve is based on the comparison between the predicted map and the validation landslide. The developed curve shows a success rate of 89.58% and a predictive rate of 82.69% (Figure 13). In addition to this, a Google Earth image and a field visit (reconnaissance) were also used to confirm the final production of the landslide danger zone map. For example, all the six slope failure points along the road corridor shown in Figure 13 in the study area are the best evidence for validation. As a result, approximately all of the previous landslide locations were in strong agreement with the landslide hazard zone map.

Conclusion

Landslides are one of the world's most common natural problems, especially in mountainous terrain, where they have resulted in substantial injury and loss of life, as well as property and infrastructure damage. Ethiopia is one of the experienced countries in which rainfall-induced landslides of various forms and sizes often occur on hilly and mountainous terrains. As a result, if an appropriate landslide hazard map (LSM) is produced for the region, these landslide concerns handled.

The current research was carried out in the Gurage zone along the Zabidar mountain road corridor. According to the study's results, the main triggering factors of landslides in the current research area are linked to hydrology, geometry, human activity, geological and geomorphological conditions and gravitational force. Six landslide causative factors including lithology, slope, aspect, curvature, distance from the steam and elevation were considered to evaluate the spatial relationship between landslides. The spatial relationship between causative factors and landslide frequency was derived using the probability approach as part of the methodology used. In this analysis, the governing parameters were rated using a GIS-based statistical and frequency ratio approach, and the landslide hazard map was created using a customized raster calculation.

The map created showed that 27 percent (4.8 km2) of the study area is no landslide or free from landslide, 29 percent (5.2 km2) shows susceptible to landslide zone, 23 percent (4.1 km2) low-risk landslide zone and 21 percent (3.8 km2) of the area is in a high-risk landslide zone. The landslide hazard assessment showed in free landslide zone 588, in susceptible to landslide zone 555, in a low-risk landslide zone 228 and in a high-risk landslide zone 61 households are living.

References

Abay A., Barbieri G., 2012. landslide susceptability and causative factors evaluation of the landslide area of Debresina. in Southweaster Afar scarpment: Ethiopia. journal of earth science engineering 2: 133-144.

Abeebe B., Dramis f., Fubeli g., Umer M., Asrat A., 2020. Landslide in ethiopian highlands and the rift margin. african earth science 56: 131-138.

Baharin A., Farshid S., Javad M., Barat M., 2014. Using Frequency Ratio Method for Spatial Landslide Prediction journal of applied science and technology 7: 3174-3180.

Bai SB., Wang J., Lu G-N., Zhou P-G., Hou S-S., Xu S-N., 2010. GIS-based logistic regression for landslide susceptibility mapping of the Zhongxian segment in the three gorges area, China, Geomorphology 115: 23-31.

Borgomeo E., Hebditch KV., Whittaker AC., Lonergan L., 2014. Characterising the spatial distribution, frequency and geomorphic controls on landslide occurrence,. Molise: Italy.

Crosta GB., Imposimato S., Roddeman D., 2003. Numerical modelling of large landslides stability and run out." Natural Hazards and Earth System Sciences 3: 523- 528.

Depicker A., Govers G., Van Rompaey A., Havenith HB., Mateso JM., Demitte O., 2018. Landslides in a changing tropical environment: North Tanganyika-Rift. Kivu zones: https://www.researchgate.net/publication/325176935,.

Eberhardt E., Stead D., Coggan JS., 2004. Numerical analysis of initiation and progressive failure in natural rock slopes the1991 Randa rockslides. Rock Mechanics and Mining Sciences, 41: 69 -87.

Heidari A., Roozitalab MH., Mermut AR., 2008. Diversity of clay minerals in the vertisols of three different climatic regions in western Iran. Journal of Agricultural Science and Technology 10: 269-84.

Hong H., Xu C., Bui DT., 2015. Landslide Susceptibility Assessment at the Xiushui Area (China) Using Frequency Ratio Model. Procedia Earth and Planetary Science 15: 513-7.

Lee S, Min K. 2001.Statistical analysis of landslide susceptibility at Yongin, Korea. Engineering Geology 40(9): 1095-113.

Meten M., Bhandary NP., Yatabe R., 2015. Effect of landslide factor combinations on the prediction accuracy of landslide susceptibility maps in the Blue Nile gorge of Central Ethiopia. Geoenviron Disast 2:9. Geoenvironmetal disasters 9, https://doi.org/10.1186/s40677-015-0016-7: 2.

Nedala, B. R., Nakileza S., 2020. Topographic influence on landslides characteristics and implication for risk management in upper Manafwa catchment, Mt Elgon Uganda. Geoenvironmetal Disasters 7, 27: 1-13.

Ohlmacher. GC., 2007. Plan curvature and landslide probability in regions dominated by earth flows and earth slides. .Engineering Geology 91: 117-134.

Silalahi FES., Arifianti PY., Hidayat F., 2019. Landslide susceptibility assessment using frequency ratio model in Bogor, West Java, Indonesia, Geosciece Letter 6(10) https://doi.org/10.1186/s40562-019-0140-4

Woldearegay. K., 2013. Review of the occurrences and influencing factors of landslides in the highlands of Ethiopia: With implications for infrastructural development. Momona Ethiopian Journal of Science.

Woldearegay K., Schubert W., Klima K., Mogessie A., 2000. Landslide hazards mitigation trategies in the northern highlands of Ethiopia. Landslide Risk Management, 27-37.

Yalcin A., Reis S., Aydinoglu AC., Yomralioglu T., 2011. A GIS-based comparative study of A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibility mapping in Trabzon, NE Turkey, CATENA 85, 3: 274–87.

Zhou S., Chen G., Fang L., Nie Y., 2016. GIS-Based Integration of Subjective and Objective Weighting Methods for Regional Landslides Susceptibility Mapping. Sustainability 8(4): 334.

Zhuang J., Peng J., Iqbal J., Liu T., Liu N., Li Y., MA P., 2015. Identification of landslide spatial distribution and susceptibility assessment in relation to topography in the Xi'an Region, Shaanxi Province, China. Frontier Earth Science 9(3): 449-462.