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Landslide Hazard Mapping Along the Beni-Lete Road Section, Myagdi-Mustang Districts, Western Nepal

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Abstract

Mountainous country like Nepal is highly susceptible to the geo-hazard like landslide. Due the drastic variation into the topography there exists steep-gentle slope with their variation there found several types of hazards related to the topography, soil, rock and various intensity of rainfall. In this study model output in the form of landslide hazard map has been evaluated by correlating training landslide and validating landslide. The study shows that 12% of Beni to Lete road section of the Kaligandaki corridor have very high hazards, 27% of the area of Beni to Lete road section in high hazard, 30% of the area lies in the moderate hazards, 24% of the area lies in low hazard zone and 7% of the area of Beni to Lete road section lies in the very low hazard area. The study concludes that effect of geology is highest among all factors and is followed by elevation and drainage proximity. The phyllite and augen gneiss rich rock unit has found more suffered landslides which indicate reasonable predictive capabilities compared to other work of this nature.

Keywords: Landslide; Himalaya; Geology; Susceptibility; Hazard; Slope

Introduction

The Myagdi and Mustang districts are located in western Nepal of Gandaki Province. The active and historically youngest tectonically active Himalaya has been formed around 50 My ago and is still ongoing due to continental-continental collisions between Indian and Eurasian plates. The methodical process of mapping the potential for landslides and scientific way to determine the likelihood of landslides occurring within a certain time frame. The road segment from Beni to Lete that can be connected across the Chinese border is the Kaligandaki corridor. The shallow (about 0.5 to 2.5 m) seated landslide that caused the small-scale landslides that are brought on by the alteration in the physical characteristics of the soil strata during precipitation [1-5].

The tropical and sub-tropical climatic areas have steep slope, after the precipitation occurs for longer period of time area is unstable as the results, landslide may occurs. The landslide hazard maps are prepared by the use of Intrinsic factors such as geomorphology, slope gradient, slope aspect, elevation, engineering properties of materials exposed on slope and land use pattern. Geographic Information System (GIS) is a tool for managing, analyzing and visualizing spatial data [6-8]. The weight of evidence modelling technique is a statistical method for identifying relationship between variables and predicting outcomes. The extrinsic factors which are used to prepare the landslide hazard maps are rainfall, volcanoes, and earthquake. The various factors that can trigger landslide in the region, including rainfall, earthquake and human activities such as deforestation and construction. The input parameter used for the landslide hazard maps are geology and engineering geology, Digital elevation based morphometric maps, Soil map, land use map, drainage map, landslide inventory map etc. For the preparation of landslide hazard map, qualitative and quantities methods are used. The deterministic and statistical are the quantitative methods. Deterministic methods based on the factor of safety of the individual slopes [9,10].

GIS is the tools used for the preparation of landslide hazard map. It helps to collect the data and information, storing, processing, transforming and displaying the spatial data make GIS an effective tool while aspect, elevation, engineering properties of materials exposed on slope and land use pattern. Geographic Information System (GIS) is a tool for managing, analyzing and visualizing spatial data [11-16]. The weight of evidence modelling technique is a statistical method for identifying relationship between variables and predicting outcomes. The extrinsic factors which are used to prepare the landslide hazard maps are rainfall, volcanoes, and earthquake. The various factors that can trigger landslide in the region, including rainfall, earthquake and human activities such as deforestation and construction. The input parameter used for the landslide hazard maps are geology and engineering geology, Digital elevation based morphometric maps, Soil map, land use map, drainage map, landslide inventory map etc. For the preparation of landslide hazard map, qualitative and quantities methods are used. The deterministic and statistical are the quantitative methods. Deterministic methods based on the factor of safety of the individual slopes [17,18-20].

GIS is the tools used for the preparation of landslide hazard map. It helps to collect the data and information, storing, processing, transforming and displaying the spatial data make GIS an effective tool while running the GIS software need of the Digital Elevation Model (DEM) from to generate the topographic parameter to identify the landslide activity in a study area. To fulfill the objectives, the study area has been started from Beni (Headquarter of Magdi district) to end to Lete along the Kaligandaki corridor [21]. Along the section the Lesser, Higher and Tibetan-Tethys Himalayan rocks are found along the road corridor. The landslides are observed in the rocks of the Lesser and Higher Himalayas [22-26].

Study Area

The study area lies in Myagdi and Mustang districts, Gandaki

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Province of Nepal as shown in Figure 1. It includes three wards (6, 7 and 8) of Beni Municipality and Annapurna Rural Municipality. The work is carried out along the Beni–Lete road section of the Kaligandaki corridor [27,28-32].

Geology of study area

Study area includes the Lesser, Higher and Tibetan-Tethys Himalayas. The two major thrusts are the Main Central Thrust (MCT) and South Tibetan Detachment System (STDS) are observed in the Ghatte Khola and Chhaktan Khola, respectively. The Lesser Himalaya includes rock units of the Kuncha Formation, Fagfog Quartzites, Dandagoan Phyllites, Nourpul Formation, Dhading Dolomites, Benighat Slates of the Lower Nawakot Group. The rocks are found in the Lesser Himalayan zone are phyllite, quartzite, amphibolite and mylonitic gneiss. The Higher Himalaya includes the Formation I, Formation II and Formation III, respectively [33]. The rocks are found in the Higher Himalaya are high metamorphic rocks like schist, gneiss, banded gneiss and augen gneiss. The Tibetan-Tethys Himalaya includes the Annapurna Yellow Formation. The sedimentary rock sequences of the Tibetan-Tethys Himalaya is composed of limestone is found (Figure 2). Within the rocks of the Benighat Slates, Lesser Himalaya, a fault is seen in the Duwari Khola near to the Dana village is called as the Duwari Khola Thrust. Towards north from the Duwari Khola Thrust, the regional thrust is called as the Main Central Thrust (MCT) can be seen. The MCT separates the rocks of the Lesser Himalaya in south and the Higher Himalaya in north where the STDS separates the rocks of the Higher Himalaya in south and Tibetan-Tethys Himalaya in north. The geology of the area has been complicated, steep slope, high drainage density as the result landslide hazard occurs in Beni to Lete road section [34-38].

Methodology

Different materials and methods are used during fieldwork and laboratory investigation. The details of methodology are discussed below in details.

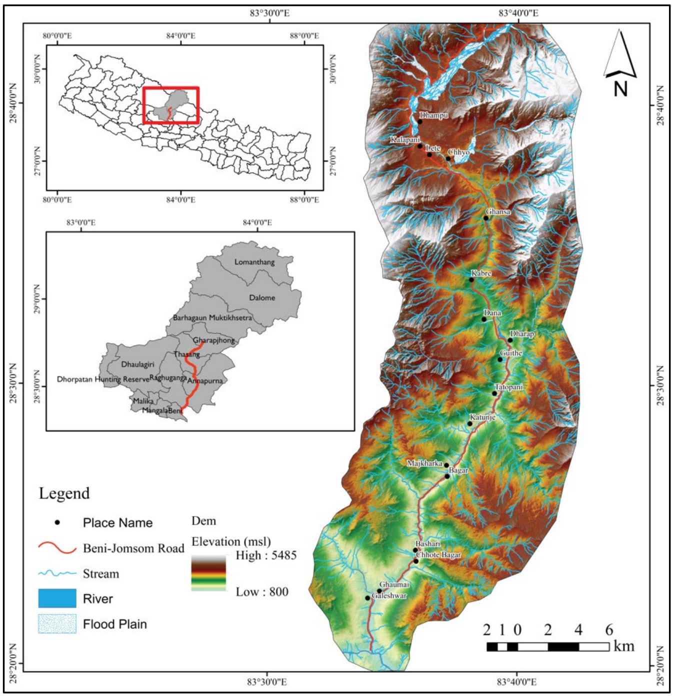

Figure 1: Study area location map.

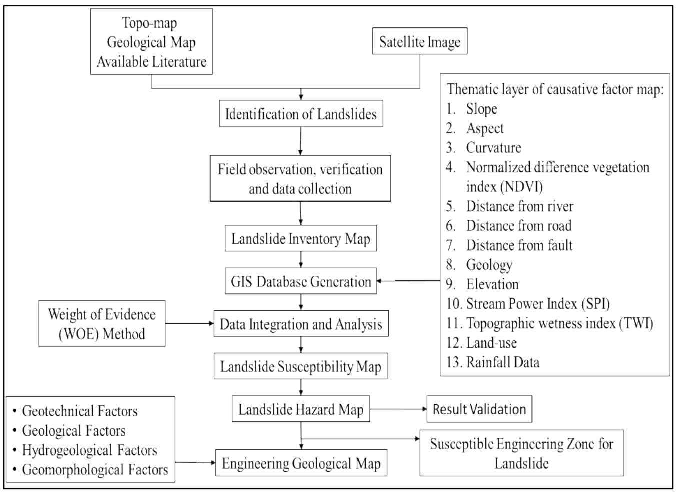

Figure 2: Methodology Flow Chart of Landslide Hazard Analysis by Weight of Evidence Method

Preliminary study

The preliminary study includes collecting secondary data and generating the idea for the analysis process. Preliminary study area carried out for the relevant literatures, field study for data collection, verification and geo database preparation to calculate the factors maps for analysis [39-43].

Data base generation

Landslide Inventory map is prepared from the Google imaginaries from the data of April 2006 to December 2022. Sentinel-2 (A) imaginaries of date 2022/4/25 are collected from the Copernicus open access hub with 10 by 10 m resolution. The DEM is used for the preparation of factor maps such as slope, aspect, elevation, topographic index [44,45].

Landslide hazard analysis

The primary data includes the image extracted from the Google imageries. The secondary data include the DEM, contour map, satellite image and geological map. The parameters used for the preparation of hazard map are slope, aspects, distance from road, distance from river, rainfall data, topographic wetness index, normalized difference vegetation index, land use, elevation, stream power index (Figure 3). First the landslide inventory maps are prepared by certain polygon on the Google imageries. After the preparation of the factor maps are overlaid with the landslide inventory [46,47-52]. The susceptibility map will develop than the weightage of each factors maps is calculated and reclassified the weightage of each factor in five categories than prepare the hazard map.

Landslide inventory mapping

While preparing the landslide hazard map by using the weight of evidence method, the landslide inventory is the basic parameter from where we can know the landslide distribution and its patterns. From the landslide inventory map are known the causative factors of the past, present landslide and predict the future landslide. The landslide inventory map is prepared from the Google imageries of the last 16 years [53].

Landslide hazard modelling

The landslide hazard modelling is started from the factor's maps are preparation. The factors maps are prepared by the GIS software of

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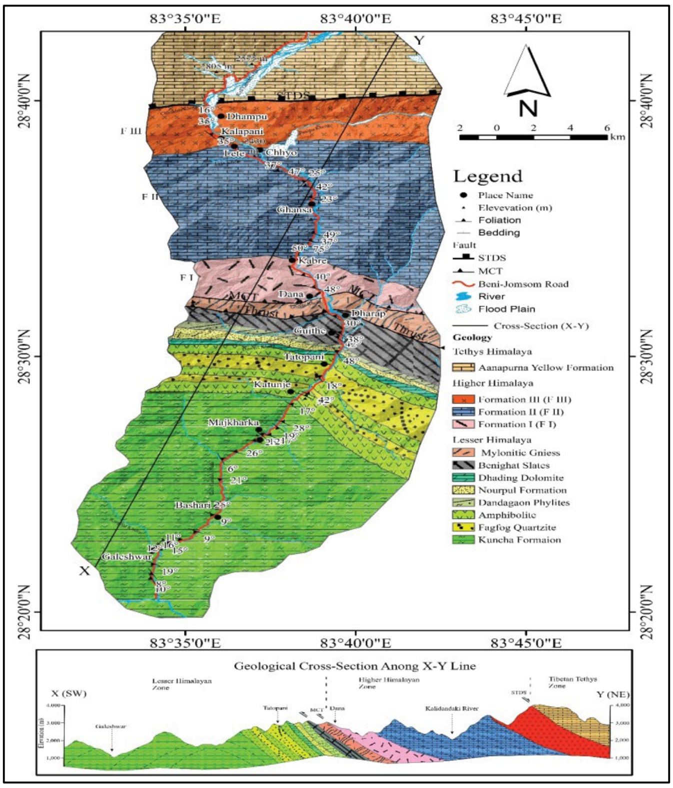

Figure 3: Geological Map modified from Upreti and Yoshida (2005).

10.8 versions. The weight of each landslide causative factors is based on the presence or absence of the landslide with in the area [54].

In landslide susceptibility prediction, the weight contrast $W_f = W+ -W-$ ………(i)

is used to measure and reflect the spatial association between the landslide conditioning factors and landslide occurrence. The positive and negative weightage of the hazard can be calculated as follows:

$$w_+ = \ln\left[\frac{Npix\ landslide\ area\ in\ a\ class}{Npix\ total\ landslide\ area}\right]\left[\frac{\text{Npix stable area inclass}}{\text{Npix total stable area}}\right]$$

$$w_- = \ln\left[\frac{Npix\ landslide\ area\ \text{outside class}}{Npix\ total\ landslide\ area}\right]\left[\frac{\text{Npix landslide area outside class}}{\text{Npix total stable area}}\right]$$

The contrast values give a first overview to accept or reject a predictor in estimating the spatial correlation between this and the landslides. The formula used for the predating the future probability of landslide by calculating the prior landslide probability. The total landslide hazard index for the single pixel all the predictive values are combined numerically as:

$$W_{ij} = W_{slope} + W_{aspect} + W_{elevation} + W_{landuse} + W_{lithology} + W_{NDVI} + W_{TWI} + W_{dis\ from\ road} + W_{dist\ from\ River} + W_{dist\ from\ fault} + WSPI + W_{rainfall\ data}$$

Where;

Wij= Landslide hazard index

Wslope= Weight of slope

Waspect= Weight of aspect

Welevation= Weight of elevation

Wlanduse= Weight of landuse

Wlithology= Weight of lithology

WNDVI= Weight of normalized difference vegetation index

WTWI= Weight of topographic wetness index

Wdistancefom road= Weight of distance from road

Wdistance from river= Weight of distance from river

Wdistance from fault= Weight of distance from fault

WSPI= Weight of stream power index

Wrainfall= Weight of annual rainfall

Results

Beni to Lete area by using Google image of different time between 2006 April to 2022 December total 156 landslides are identified. The landslide is converted into the raster format with pixel size of 5 m to 5 m. The area of the landslide ranges from the 400 to 439100 m^2 Out of the total area 523.48 km^2 the landslide accounted in Beni-Lete ~~area~~ section is about 2.82 km^2 (Figure 4). Training landslide are 117 and testing landslide are 39 [55-59].

Factors affecting landslides

The different factor such as slope, aspect, land use, normalized difference vegetation index, distance from fault, distance from river, distance from road, topographic wetness index, geology, elevation, stream power index, and rainfall -are considered for the development of the hazard map. The different map (Figure 5 (a)-(l) is prepared to analyzed the landslide hazard [60-62].

Landslide hazard mapping

For the preparation of the landslide hazard map, thirteen parameters have been used. The hazard map index of the area is

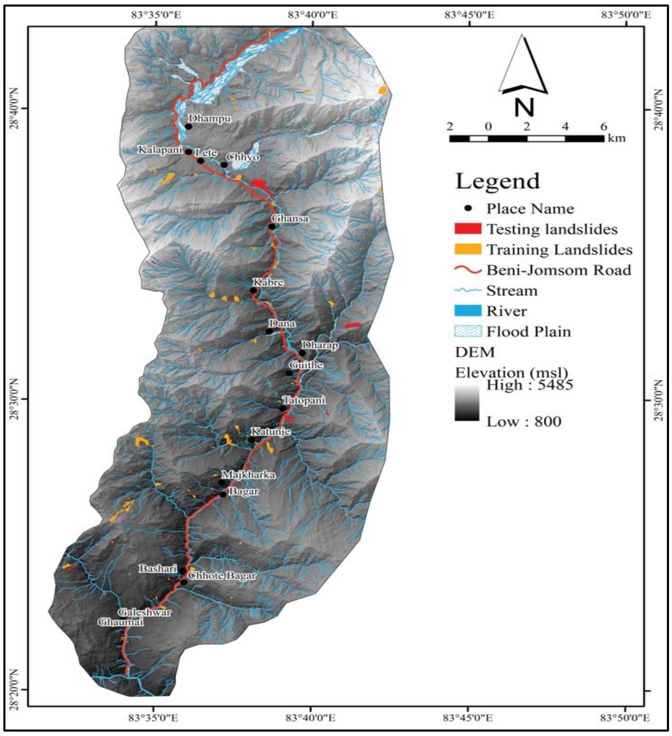

Figure 4: Landslide inventory map of study area.

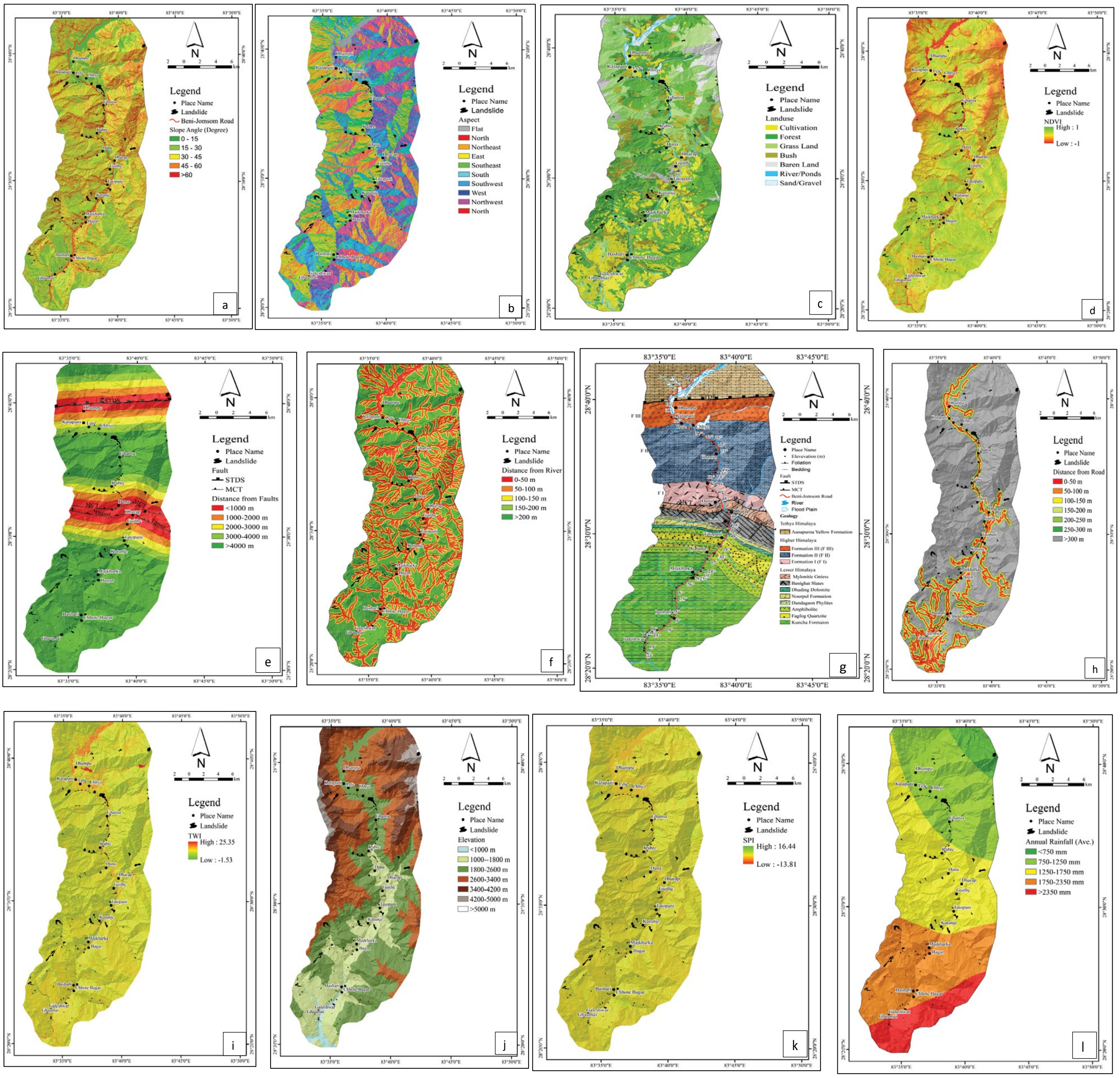

Figure 5: a. slope map, **b.** Aspect map, **c.** landuse map, **d.** normalized difference vegetation index, **e.** distance from fault, **f.** distance from river, **g.** geology, **h.** distance from road, **i.** Topographic wetness index map, **j.** elevation map, **k.** stream power index, **l.** average rainfall map.

calculated after adding all the weightage of the factors. The Landslide Hazard Index is expressed as;

$$W_{ij} = W_{slope} + W_{aspect} + W_{elevation} + W_{landsue} + W_{geology} + W_{NDVI} + W_{TWI} + W_{disfrom\ road} + W_{disfrom\ river} + W_{dis\ from\ fault} + W_{curvature} + W_{SPI} + W_{annual\ rainfall}$$

Hazard area divided into five different classes namely very high, high, medium, low and very low and illustrated in Figures 6 and 7. About 12% of the study area belonged to very high hazard zone as shown in light blue color. The high hazard zone covered 27% of the total study area. The moderate hazard zone occupied 30% of total study area. The low hazard zone occupied 24% of the total study area, the very low hazard zone occupied 7% of the total study area [63].

Validation of hazard map

Among collected 156 total numbers of landslides from the Google earth. The total number of landslides separated into training and testing landslides. About 80% of the total 117 landslides are used to calculate the landslide hazard zone and remaining 39 landslides for the validation of the results (Figure 8). Then the 39% of landslides lies within the very high and high hazard zone and 30% of the landslide lies in the moderate hazard zone. The 19% of the landslide lies on the low hazard zone. Therefore, we can conclude that landslide hazard map is validated (Figure 9). The AUC graph shows the landslide hazard map validated upto 81.9% [64].

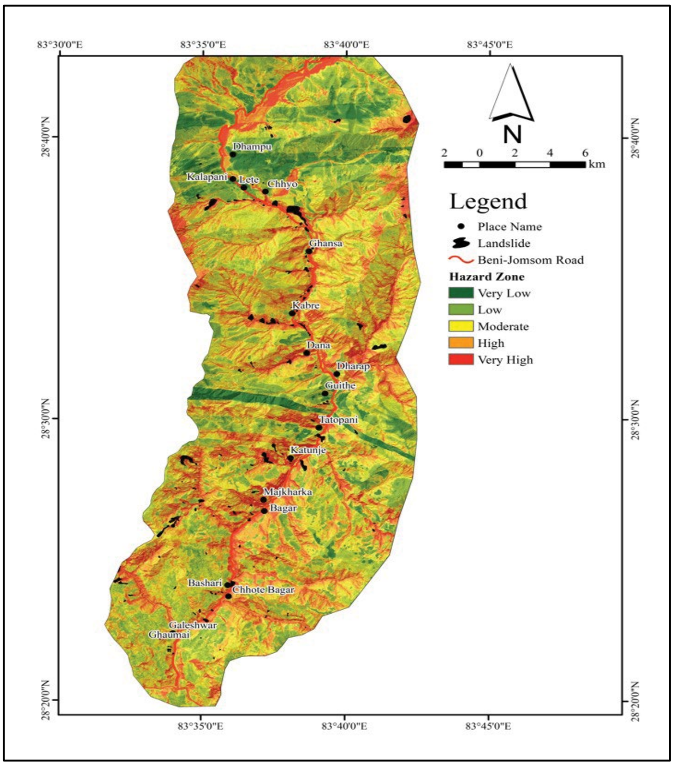

Figure 6: Landslide Hazard Map Calculated by Weight of Evidence Method.

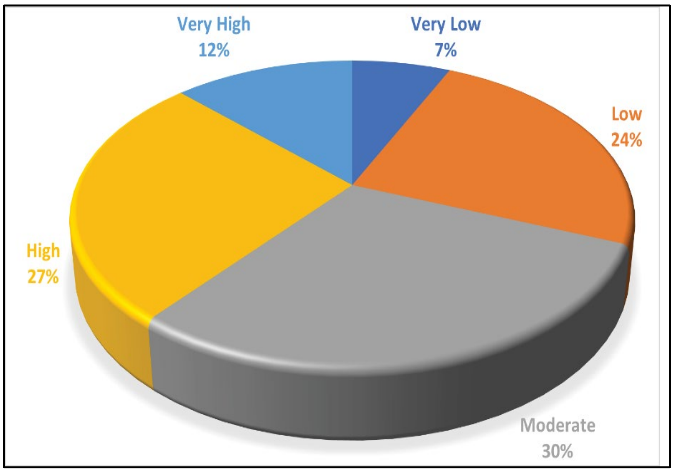

Figure 7: The pie-chart shows the Very High hazard, High Hazard, Moderate Hazard, Low Hazard and Very Low Hazard.

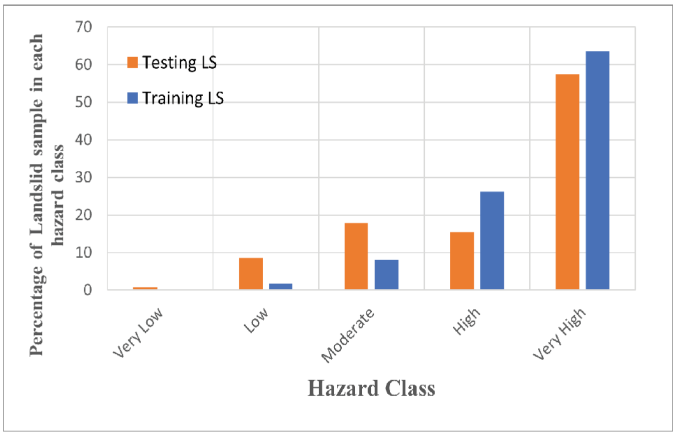

Figure 8: Landslide Distribution in Different Hazard Zone Using the Training Data Sets and Validating Data Sets.

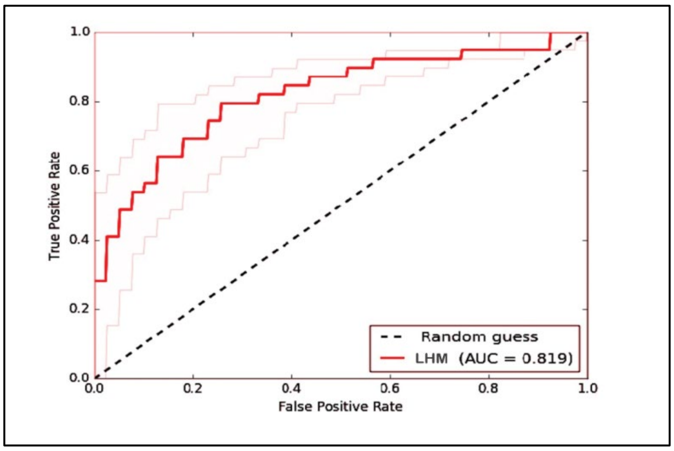

Figure 9: AUC graph shows the Landslide Hazard Map Validation up to 81.9%.

Discusssion

Discussion is elaborated in terms of landslide hazard map, geological and engineering geological condition and role of geotechnical parameters. A catastrophic loss on lives, property and environment has been increasing due to human activities. Among them weight of evidence model is widely used and more concise for the preparation of the landslide hazard map. For this reason, the weight of evidence method is applied for the landslide hazard mapping of Beni to Lete road section of the Kaligandaki corridor [65]. The training and testing landslide are present in the landslide inventory map. There are two classes of the landslide inventory, event based and historical landslide inventory (Rosi et al. 2018). The landslide susceptibility mapping of West Central Nepal Lesser Himalaya Baglung Municipality by using the different causative factor such as elevation, slope, curvature, land use, geology, rainfall, soil type, soil thickness topographic wetness index, stream density, were used to prepare the landslide susceptibility map. All the thematic layers of these parameters were made using ArcGIS 10.4.1. [66]. In this study testing landslide has been used for the landslide hazard analysis. There are some classification techniques for the landslide hazard maps in GIS software such as manual, define interval, natural break, equal interval, standard deviation, geometrical interval and landslide percentage. But, manually classification could be done with analysis of field condition of field condition which is very difficult to interpret and justify. In this study, the classification of values has been done by the help of field condition of landslides. Slope, the primary factors, takes higher value of weightage as gravity pull affects the slope condition and continuously pull the slope materials down. In this study the slope angle ranges from 30 to 45° included maximum percentage of landslide 35.06%. Aspects are another parameter for the preparation of landslide hazard map. As aspects can categories high moisture area where sunlight hits less and dry area where sunlight hits the most. So, that the weightage of aspect is lower than other factors. Among other classes south, northeast, east and north parts contain maximum landslide. Land use is another parameter for the preparation of landslide hazard map [67]. The land use gives information about human activities and water managements practices that can be easily related with the landslide occurrences. Maximum landslide is seen in the cultivated land. This is because cultivated land cover 52% of the total area and other remain classification exerts only small parts of the area. From the calculation the weightage of cultivate land is found as 0.49 and shrub land having weightage 0.21. As the result, the main reason for landslide concentrated on the cultivated land due to steep slope and high drainage density. To conform of this conclusion, we used the normalized difference vegetation index with classification about four main section and we find the maximum landslide 44.56% at low index class 1 to 0.1, respectively. The cultivated land is not the triggering factors of landslide.

Conclusion

In this study, landslide is extracted from high resolution image and weight of evidence method is used to prepare the landslide hazard map. Beni to Lete road section of the Kaligandaki corridor of Mygadi to Mustang districts has complex geology, steep slope and high drainage density. Thirteen parameters are used for the preparation of landslide hazard map they are slope, aspect, curvature, elevation, rainfall, distance from road, distance from river, distance from fault, stream power index, topographic wetness index, normalized vegetation index, geology and land use. The thematic layers are classified into different classes using natural breaks for continuous data and later reclassified using weight of evidence method. The major threshold values are aspect, rainfall and topography. Following are the conclusion of this study.

The generally three types of soil are observed along Beni-Lete road section of the Kaligandaki corridor they are alluvial soil, colluvial soil and residual soil. In which well graded gravelly sand (GS) and sandy gravel (SG) are dominated.

Rock mass rating and kinematic analysis are performed in the study area to calculate the stability of rock. The poor to very poor rock found in the Lesser Himalaya zone while fair, good and very good rock like augen gneiss, and banded gneiss are observed in the Higher Himalayan zone. The plane failure and wedge failure are observed Lesser and Higher Himalayan rocks.

The cohesion is low and the friction angle is high in the sandy soil where porosity and permeability are high as the result the failure possibility is found in the soil.

Moisture contains in the soil range from 6.37% to 37.66% as the result it increases the weight of the soil which helps to downwards movement of the rocks and soil with the influence of gravity.

The clay minerals like chlorite, muscovite, biotite, serpentine observed in the field they are the platy minerals with the low hardness and easily weathered in presence of water as the result they show the expansion and contraction nature of the soil which caused the failure of the rock and soil.

Several delineated units in engineering geological map with other causative parameters are used for analysis and characterizing the hill slope.

Total 156 landslides have been traced in this area by the help of Google earth. The results show the slope between 30 to 45°, topographic wetness index less than 3, geology (Kucha Formation) of the Lesser Himalaya and rainfall are the four primary factors that influence more create landslide than other factors.

The 12% of the total area belonged to very high hazard zone, 27% of the total study area lies to be high hazard zone, 24% of the study area lies on the low hazard zone and 7% of the total study area lies on the very low hazard zone.

The landslide hazard map is valid by making the area under cover (AUC) by the helps of testing landslide and its validation percentage is 81.9%. The landslide hazard can be used as base map for preparing risk and vulnerability map of Beni to Lete road section.

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