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Assessment of Landslide Susceptibility along Chainpur-Taklakot Road Section

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Abstract
The slope stability problems are very common in Nepal because of the steep slopes and fragile geological formations. Landslides in Nepal have caused extensive damage to infrastructure, loss of life, and displacement of communities. This study focused on the assessment of landslide hazard along Chainpur Taklakot road section by preparing the landslide susceptibility map of Chainpur catchment using ArcGIS. Eight causative factors considered for the analysis are altitude, curvature, aspect, distance from road, land use, distance from drainage, geology and slope. Individual causative factor maps are prepared and then by using frequency ratio method, the final landslide susceptibility index map is produced. Landslide susceptibility index map is reclassified into four categories: (1) Low Susceptibility, (2) Medium Susceptibility, (3) High Susceptibility and (4) Very High Susceptibility. The final Susceptibility map suggests that the 59.5 percent landslides fall on the very high and high hazard zone which covers only 12 percent of the total area. The success rate for testing landslide data set is 81.8 percent which shows the good prediction performance. Buffer zone along the Chainpur-Taklakot road alignment is selected to examine the hazard level along the route. Almost half of the entire 100-kilometer length of the Chainpur-Taklakot road alignment passes through areas with high to very high hazard levels. This indicates that the chosen road route is considerably expensive when it comes to addressing slope stability issues.

Keywords
landslides, hazard zonation, frequency ratio, Chainpur-Taklakot

1. Introduction

Nepal, situated in the Himalayan region, is susceptible to slope stability issues owing to its rugged topography, geological characteristics, and prevailing climate conditions. Among different slope stability problems, landslide is major problem in Nepal. [1] states that during a 49-year span (1971–2019), Nepal saw about 3729 occurrences of landslides, resulting in 5141 fatalities, 2053 injuries, 7758 family impacts, and the destruction of 1000 homes. In Nepal, 35.6 percent of all fatalities from disasters are caused by landslides [2]. According to data provided by the Department of Roads (DoR), during the period from Baisakh 2080 to Bhadra 2080, a total of 29 highways experienced disruptions at 270 different locations. These interruptions were primarily caused by landslides. The recurring issue of highway disruptions caused by landslides is a persistent challenge that Nepal faces year after year. The Chainpur-Taklakot road having alignment in hilly areas of Northern Bajhang district is also facing the landslides several times in every monsoon. The database suggests that there is a high level of variability in the occurrence of landslides from year to year, but that the overall trend is upward [3].

Landslides in Nepal have caused extensive damage to infrastructure, loss of life, and displacement of communities. repair expenses, and shutdowns. Globally, landslide is a catastrophe that has claimed thousands of lives, injured tens of thousands more, and destroyed billions of dollars' worth of property [4]. Understanding the occurrence mechanism, making predictions through hazard assessment, hazard zonation, and early warning systems can all help to mitigate these effects [5, 6]. In such a situation, creating a map of the landslide hazards could be the first step in mitigation and management. According to [7], proper land use management for infrastructure development and environmental preservation can assist authorities prevent and decrease damage.

The mitigation measure for slope stability is more sustainable and practical only after considering the landslide hazard index as well as the causative factors. The mitigation map of Achham revealed that only 6.8 percent of roadside slopes required retaining structures. Therefore, high hazard always doesn't demand expensive structures to stabilize it. More often, they are stabilized by very simple measure as per its mechanism and causing factor of instability[8] .

Landslide hazard is the probability of occurrence of landslide with in specified period and within a given area [9]. The process of classification of land with equal landslide hazard value is known as landslide hazard zonation which provides information on the susceptibility of the terrain to the slope failures. It can be done by different methods like heuristic, semi quantitative, quantitative, probabilistic and multicriteria decision making process. In probabilistic hazard zonation, different methods like weight of evidence method, frequency ratio method, relative effect method etc. are used. In last decades, remote sensing and GIS are used as powerful tool for hazard zonation. This study mainly focuses on landslide hazard zonation by frequency ratio approach using GIS software. Numerous researchers have investigated landslide hazard analysis in various regions of Nepal, yet there is a lack of studies along Chainpur Taklakot road section.

This research is done with the help of GIS software to prepare the landslide hazard zonation map. In this study only eight factors viz. aspect, slope, curvature, land use, geology, distance from drainage, distance from roads, elevation is used to prepare the landslide hazard zonation map. Landslides data in the catchment were collected from direct field visit, Google Earth and from the topographic maps. The Chainpur Taklakot road section is taken to analyze the hazard along it. Landslide hazard zonation map can help to make future planning of development activities and assess the economical alignment of road which ultimately reduces the loss of life and property.

2. Study Area

The Chainpur catchment is located in Bajhang District, Far-western province of Nepal. The Chainpur Taklakot road segment spans 100 kilometers, running from Chainpur to the Urai pass in the Bajhang district, with elevation ranging from 1250 masl to 6938 masl, creating a vital link to China. The study area encompasses Jayaprithvi Municipality, Talkot, Masta, and Saipal rural municipalities. Seti is the main river of the study area originating from Saipal peak and receives flow contribution from many streams such as Dungri khola, Sunigad, Rumauli Khola, Talkot Khola. Catchment area of the study zone is 2048 km2 extending from 29ˆ 29'35" N to 30ˆ 04'14" N latitudes and 81ˆ00'30" E to 81ˆ34'52"E longitudes as shown in Figure 1.

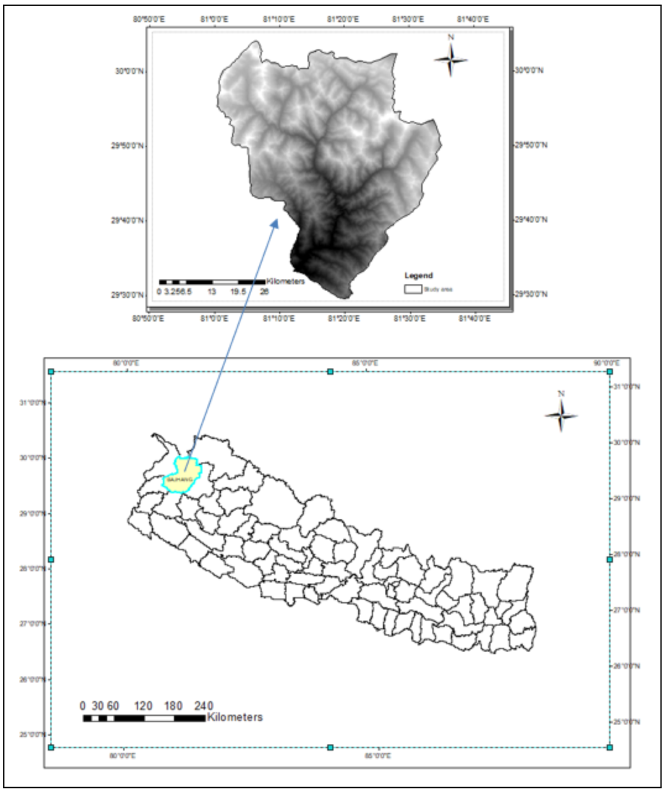

Figure 1: Location of Study Area Chainpur Catchment Bajhang

3. Methodology

The initial step in order to generate a landslide susceptibility map for the study area, the initial step involves preparation of a landslide inventory map. This map was prepared by gathering landslide data on historical and current landslides through a combination of sources, including satellite imagery from Google Earth and direct field inspections. The overall study design and reserch methodology is shown in Figure 2.

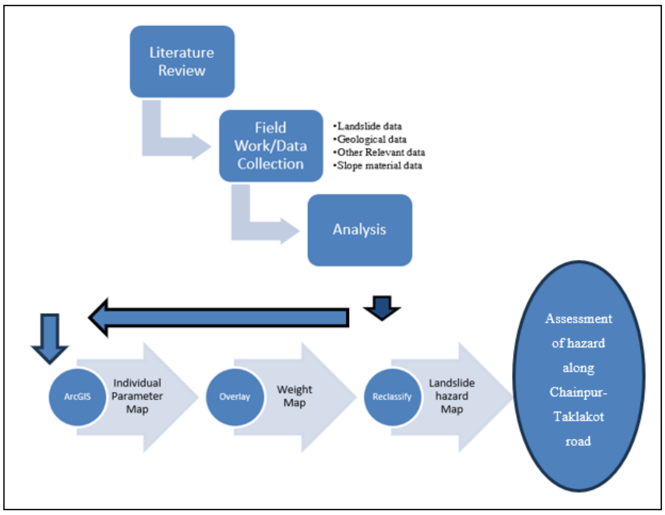

Figure 2: Flow chart showing overall research methodology

3.1 Preparation of Map of Causative factors

Landslide events are influenced by various factors, and there's no universal guideline for factor selection in hazard mapping [10]. Some factors hold significant sway in one area but not in others. This study incorporates eight factors for landslide hazard zonation mapping: slope, altitude, aspect, geology, curvature, land use, distance from drainage, and distance from roads. Terrain features exhibit varying susceptibility levels to landslides. Each factor is individually mapped, culminating in the final landslide hazard map.

3.1.1 Altitude Class

Elevation is not directly related to the landslide but as the elevation changes, other factors such as temperature, slope gradient, geology, precipitation etc. changes [5]. In this study, altitude map is prepared from the DEM file which is classified into six classes having interval of 1000m. The altitude map of study is shown in Figure 3.

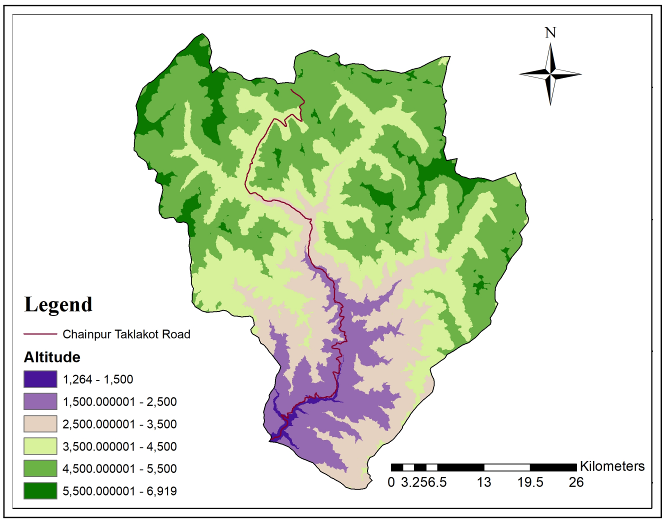

Figure 3: Altitude Map of the Study Area

3.1.2 Terrain Slope

Landslides are more likely to occur on steeper slopes because the friction angle of the materials and the influence of Earth's gravity have a greater effect on steep slopes compared to gentle ones. The slope angles in the study area were determined using DEM data and are divided into six different categories. The altitude map of study is shown in Figure 4.

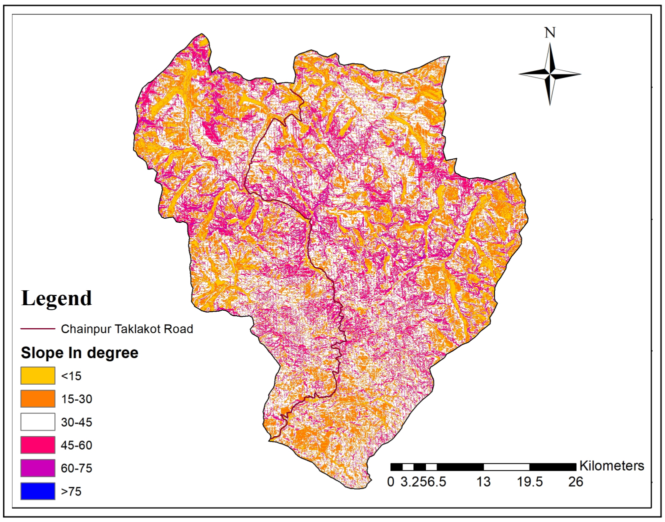

Figure 4: Slope Map of the Study Area

3.1.3 Aspect Factor

Landslide susceptibility is influenced by slope orientation (aspect factor) as it may interact with other factors. Exposure to rainfall, sunlight, and wind activities are important factors influencing aspect factor [5]. Therefore, aspect map was prepared by using the surface analyst tool of ArcGIS from the DEM and grouped into 9 classes which are E, SE, S, SW, W, NW, N, NE and flat. The altitude map of study is shown in Figure 5.

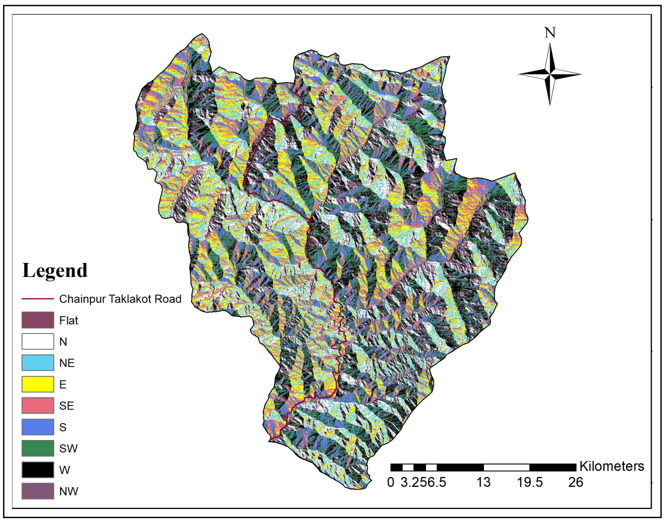

Figure 5: Aspect Map of the Study Area

3.1.4 Land Use Map

The land use map of study area was prepared by maximum likelihood classification after polygon map was prepared dividing it into five classes: Water/Sandy bank, Snow, Settlement/Cultivated area, Forest and Barren land for the study. The altitude map of study is shown in Figure 7.

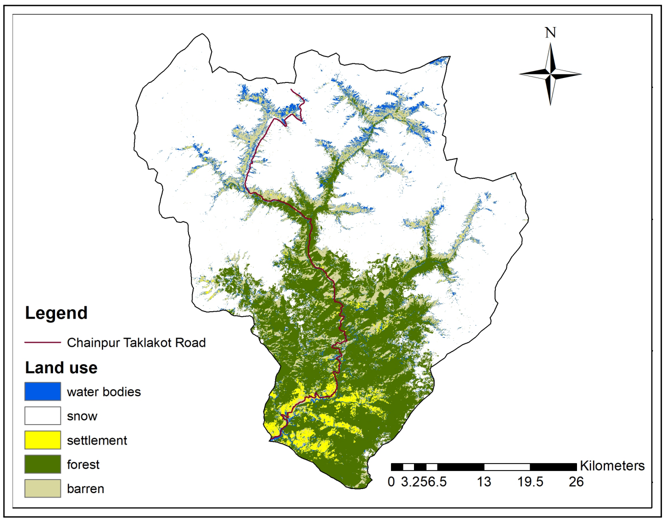

Figure 6: Land use Map of the Study Area

3.1.5 Curvature

The curvature of a slope has notable impact on stability of steep terrain, as it affects the concentration or dispersion of both surface and subsurface water throughout the landscape. Slope curvature was also derived from DEM and divided into three different classes: Concave (< -0.5), Flat or straight (-0.5 to 0.5) and Convex (> 0.5).The altitude map of study is shown in Figure 7.

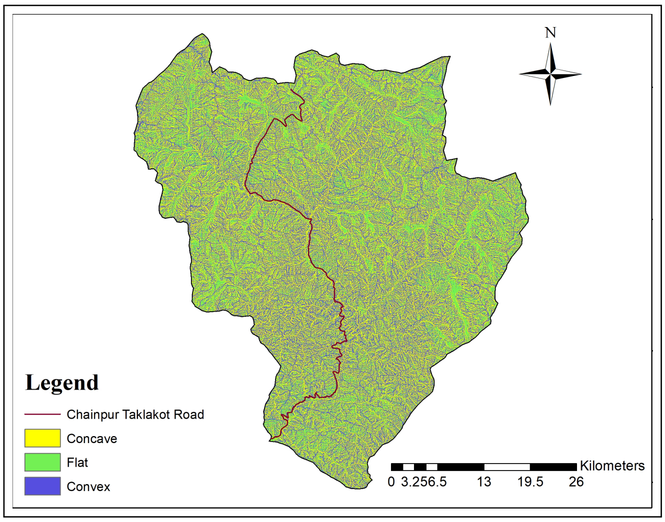

Figure 7: Curvature Map of the Study Area

3.1.6 Distance to drainage

The landslide occurrence events are also affected by the distance from the drainage. To know the effect of drainage on landslide, distance from drainage was taken for study. Euclidean distance tool was used in ArcGIS software application and reclassification was done into five classes. The altitude map of study is shown in Figure 8

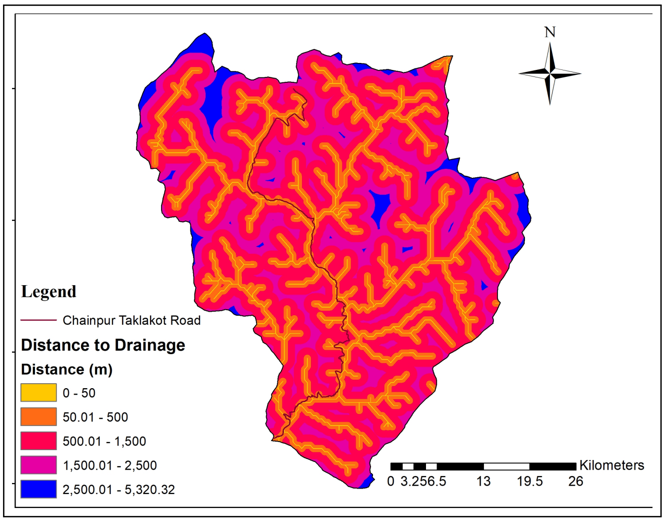

Figure 8: Distance to drainage Map of the Study Area

3.1.7 Distance from road

Slope stability problems are more observed in recently cut roads. Shape file of the existing roads within study area was created. An euclidean distance function of spatial analyst tool was used to classify the distance from road into five categories. The altitude map of study is shown in Figure 9.

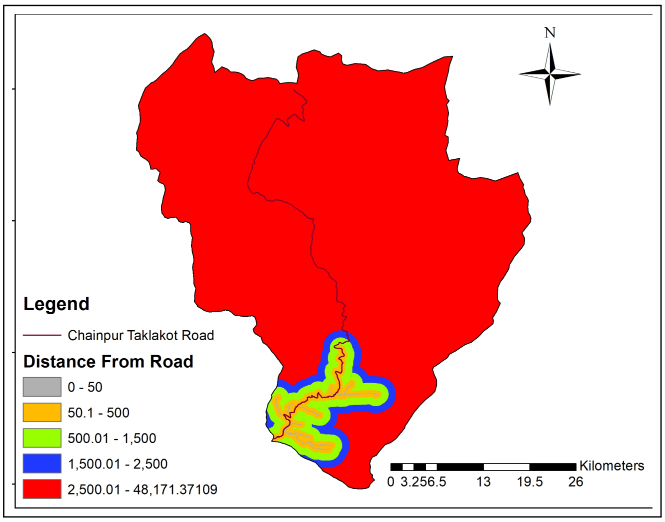

Figure 9: Distance from Road Map of the Study Area

3.1.8 Geology

Geology is a key factor contributing to slope instability in the study area. According to approved DPR of Chainpur-Taklakot road project, geological classification reveals eleven formations, including Paleozoic Sedimentary rock, Nawakot Group, Kushma Formation, and others. Predominantly, the area comprises Paleozoic sedimentary rocks, Himal group, and Nawakot group, with increased landslide occurrences in the Galyang, Suntar, and basic rocks formations. The altitude map of study is shown in Figure10.

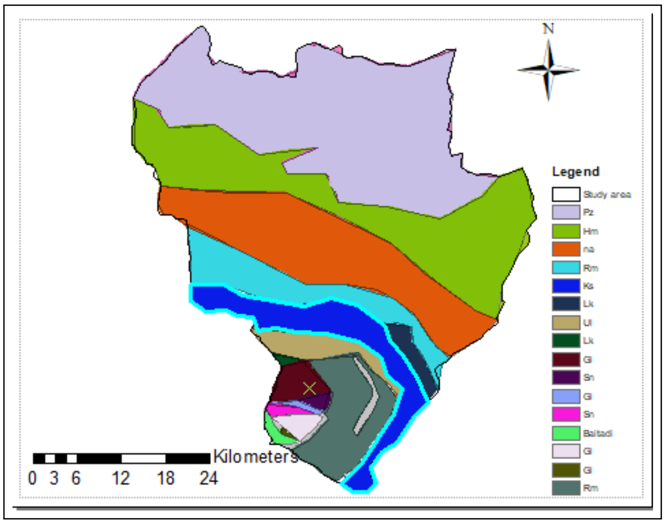

Figure 10: Geological Map of the Study Area

The prediction rate for all eight factors is different which is shown in Figure 11.

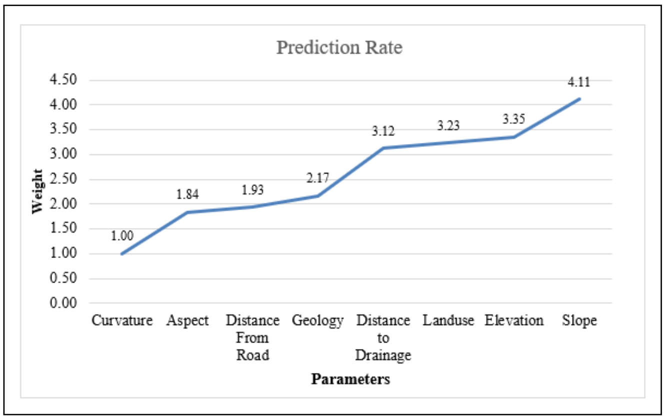

Figure 11: Weightage of Prediction rate for all eight parameters

3.2 Landslide Hazard Mapping

It is crucial to presume that the landslide causative factors affect the spatial distribution of landslides and that future landslides will occur under the same conditions as prior landslides while carrying out the landslide susceptibility mapping[11]. In this study, the frequency ratio method was used to prepare a landslide susceptibility map.

Frequency Ratio Method

Frequency ratio is a quantitative technique for landslide susceptibility assessment using GIS techniques and spatial data [12]. The frequency ratio technique is frequently and effectively used for landslide susceptibility mapping [13]. It is based on the quantified association between the landslide inventory and the landslide causative factors [14]. The Frequency Ratio (FR) method has been used in landslide susceptibility mapping because of its straightforward and practical nature. It examines historical landslide events in connection with factors like slope and geology, pinpointing areas prone to landslides. Its simplicity and reliance on basic data make it applicable in regions with limited resources. This method assists in making well-informed decisions regarding disaster management and land-use planning.

A combination of the factor map and the landslide inventory map has been constructed in order to determine the frequency ratio for each class of the causative factors utilizing Eq. (1) [15].

$$Fr = \frac{\text{Npix}(1)/\text{Npix}(2)}{\Sigma\text{Npix}(3)/\Sigma\text{Npix}(4)} \quad (1)$$

where, N pix (1) = The number of pixels containing landslide in a class

N pix (2) = Total number of pixels of each class in the whole area

ΣN pix (3) = Total number of pixels containing landslide

ΣN pix (4) = Total number of pixels in the study area The derived frequency ratio is summed to develop a Landslide Susceptibility Index (LSI) map using Eq. (2) [12].

$$LSI = Fr_1 + Fr_2 + Fr_3 + \ldots\ldots\ldots + Fr_n \quad (2)$$

where Fr is the frequency ratio, and n is the number of selected causative factors. The value of one is an average value, greater than one means the percentage of the landslide is higher than the area and indicate a higher correlation, whereas value lower than one indicate a lower correlation [16]. In order to create a landslide susceptibility map, the LSI map is reclassified.

4. Results and Discussion

4.1 Landslide Inventory

From the examination of both Google Earth imagery and on-site inspections, a total of 354 landslides were identified within a study area of 2048 square kilometers. Different types of landslides were observed in the study zone as shown in Figure 12. Rock fall, translation as well as rotaional landslides were found. In most of the cases, complex types of landslides

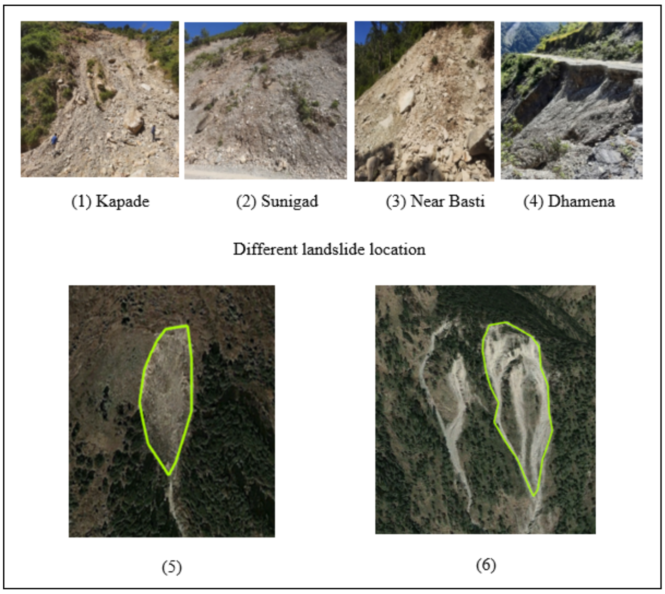

Figure 12: Field Photographs and satellite images outlined of different Landslide Locations

were observed. Rotational landslides primarily occur due to the erosion and undercutting of the recent terraces, leading to instability.

4.2 Landslide Hazard Zonation Map

Analysis of the landslide susceptibility index of the study area is performed using equation 1. Hence, LSI values are the summation of all the eight parameter factors. The percentage coverage of different parameters and landslide occurance in each class of these eight parameters with frequenecy ratio is shown in Table 1.

By using raster calculator from ArcGIS, the weighted overlay LSI map was prepared as shown in above Figure 3. The LSI values vary from 141.56 to 1274.58. Reclassification of LSI map into different hazard zone is necessary for the further study. Classification can be done in many ways. There is no statistical rule for the purpose and many researchers have their own methods of classifications of the index values into hazard zones. In this study, natural break method is applied to classify into hazard zones. The resulting hazard zonation map is shown in Figure 13.

According to the LHZ map, 54.7% of the study area lies in the low hazard zone whereas the area occupied by very high and high hazard zone is 5.4% and 6.6% respectively. Remaining 33.3 % area is under medium hazard zone.

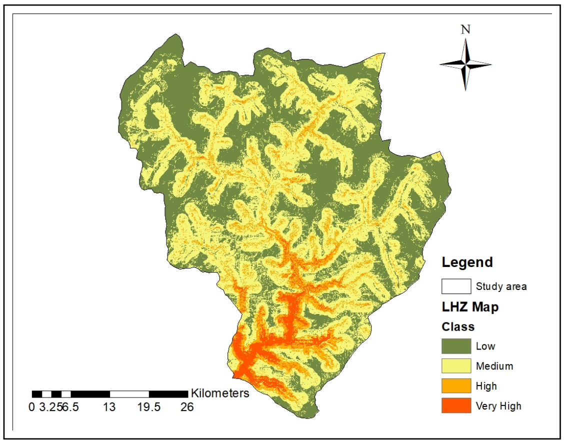

Figure 13: Landslide hazard zonation map of the study area

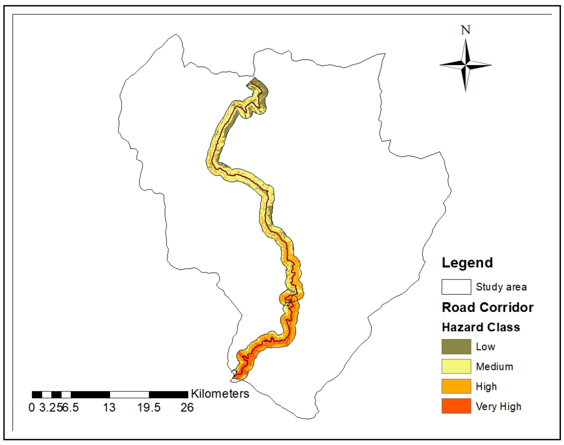

Figure 14: Landslide hazard along Chainpur Taklakot road section

Table 1: Percentage coverage of different parameters and landslide occurrence in each class with frequency ratio

Parameters	Classes	No of pixel in class	No of pixel in class% (a)	No of Landslide pixel in class	No of landslide % (b) pixel in class	Frequency Ratio (b)/(a)
Altitude class	1264-1500m	132205	0.65	1027	3.29	5.09
	1500-2500m	2301033	11.24	8042	25.75	2.29
	2500-3500m	3399996	16.60	4468	14.30	0.86
	3500-4500m	5631469	27.50	11808	37.80	1.37
	4500-5500m	7871900	38.44	5891	18.86	0.49
	> 5500m	1144006	5.59	0	0.00	0.00
Slope class	< 15°	1643420	8.02	203	0.65	0.1
	15-30°	5293864	28.85	6949	22.25	0.9
	30-45°	8889588	43.40	14318	45.84	1.1
	45-60°	4137687	20.20	8845	28.32	1.4
	60-75°	502268	2.45	860	2.75	1.1
	> 75°	13782	0.07	61	0.20	2.9
Aspect Factor	Flat	21798	0.11	0	0.00	0.00
	North	2499593	12.20	1507	4.82	0.40
	North East	2561132	12.51	3638	11.65	0.93
	East	2783589	13.59	5568	17.83	1.31
	South East	2189809	10.69	4555	14.58	1.36
	South	2532083	12.36	8540	27.34	2.21
	South West	2759541	13.47	4133	13.23	0.98
	West	2849772	13.91	2288	7.32	0.53
	North West	2283292	11.15	1007	3.22	0.29
Land use	Water/Sandy Bank	1089483	5.32	104	0.33	0.06
	Snow	11829831	57.76	11134	35.64	0.62
	Settlements/Cultivated	575705	2.81	2527	8.09	2.88
	Forest	5163282	25.21	5871	18.80	0.75
	Barren	1822308	8.90	11600	37.14	4.17
Curvature	Concave	7683611	37.52	10790	34.54	0.92
	Flat	5701744	27.84	11331	36.28	1.30
	Convex	7095254	34.64	9115	29.18	0.84
Distance to drainage	<50 m	697238	3.40	2716	8.70	2.55
	50-500m	5225078	25.51	13432	43.00	1.69
	500-1500m	9499888	46.38	13053	41.79	0.90
	1500-2500m	4341472	21.20	2035	6.51	0.31
	> 2500m	726933	3.50	0	0.00	0.00
Distance from road	<0.05km	71123	0.35	555	1.78	5.12
	0.05-0.5km	468500	2.29	3315	1.61	4.64
	0.5-1.5km	724327	3.54	2926	9.37	2.65
	1.5-2.5km	532454	2.60	1322	4.23	1.63
	> 2.5km	18684205	91.23	23118	74.01	0.81
Geology	Pleozoic Sed Rock	6471262	31.60	14138	45.26	1.43
	Nawakot Group	3459045	16.89	4115	13.17	0.78
	Kushma Formation	1628508	7.95	715	2.29	0.29
	Ulleri Formation	579585	2.83	594	1.90	0.67
	Ranimatta Formation	2155845	2.83	594	1.90	0.67
	Himal Group	5083965	24.82	2246	7.19	0.29
	Lakharpata Formation	327401	1.60	50	0.16	0.10
	Basic Rocks	78050	0.38	400	1.28	3.36
	Galyang Formation	503405	2.46	3644	11.67	4.75
	Sunatar Formation	161832	0.79	652	2.09	2.64
	Baitadi Bed	31711	0.15	0	0	0

Assessment of Landslide hazard along Chainpur Taklakot road section is done by using the final prepared LHZ map. The road buffer zones is extracted and evaluated from ArcGIS. Hazard zonation map shows that the out of total 100-kilometer road length, 46.7-kilometer road is under the high to very high hazard zone of the study area as shown in Figure 13.

5. Conclusion and Recommendations

The analysis of the landslide inventory in conjunction with the factors contributing to landslides revealed that slope gradient, elevation and land use exert the greatest influence on the spatial distribution of landslides in the area.

Landslide frequency ratio increases with increase in slope angle of terrain. Terrain having slope angle greater than 30°are more susceptible to landslide.

From the landslide hazard zonation map, it can be observed that barren lands and settlement/cultivated lands have higher frequency of landslide.

Straight curvature has higher degree of hazard compared to concave and convex curvature; Close proximity to drainage lines and road alignments increases the susceptibility of landslides.

Almost half of the entire 100-kilometer length of the Chainpur-Taklakot road alignment passes through areas with high to very high hazard levels indicating that the chosen road alignment is considerably expensive when it comes to addressing slope stability issues.

The study proves that the effective use of the frequency ratio technique can serve as a reliable source of data for places in Nepal's mountainous regions that are susceptible to landslides.

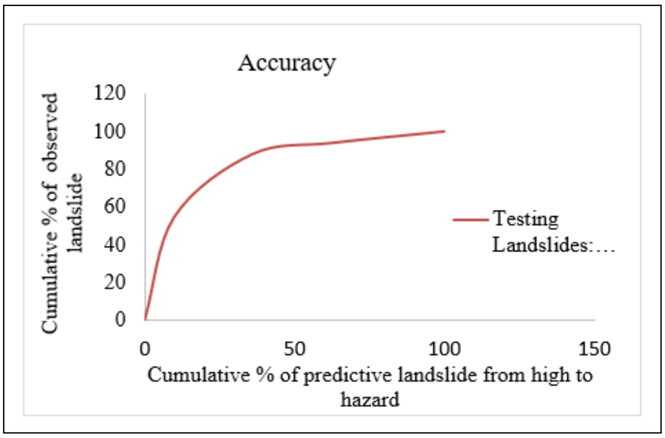

Figure 15: Cumulative percentage of study area classified as susceptible (horizontal axis) in cumulative percent of landslide occurrence(vertical axis)

In conclusion, this study illustrates that landslides are more likely to occur in locations close to drainage systems because of erosion and water saturation. In areas where landslides are likely to occur, efficient management and careful planning are essential to reducing this risk and improving community safety.

The research is constrained by the fact that it has only taken into account eight contributing factors for the development of the landslide hazard map. Consideration of more causative factors, detail study on each parameter and soil properties helps to increase the quality of hazard map.

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