FINAL REPORT

on

Rapid Geohazard Assessment of Vulnerable Area of Different parts of Nepal

(Molung Rural Municipality, Ward no. 7, Okhaldhunga)

Submitted To:

Government of Nepal
Ministry of Home Affairs
National Disaster Risk Reduction and Management Authority (NDRRMA)
Singhadurbar, Kathmandu

Submitted By:

MANIFOLD CONSULT
KATHMANDU, NEPAL

Manifold Consult Pvt. Ltd.
Banasthali, Kathmandu
Phone No: 9860816776

May, 2025

Table of contents

List of Tables

List of Figures

CHAPTER I

INTRODUCTION

This report summarizes the outcomes of a preliminary geological and geotechnical walkover survey conducted in the landslide affected areas of Suryagadhi Rural Municipality, located in Okhaldhunga District, Bagmati Province. It outlines key technical observations from the initial field assessment, evaluates the condition of impacted communities, and proposes appropriate remedial measures for each affected site. Additionally, the report provides a concise evaluation of whether short-term or long-term mitigation strategies are necessary for specific locations.

1.1 Background

A landslide is an outward and downward movement of slope-forming materials; rock, debris, earth, or soil under the influence of gravity. They can be triggered by a variety of factors, including intense rainfall, earthquakes, volcanic activity, slope saturation, and human-induced changes such as deforestation, road construction, and unregulated excavation. Landslides occur in all types of terrain, but areas with steep slopes, weak or weathered geological materials, and high precipitation rates are particularly susceptible. Globally, landslides are among the most damaging natural hazards, causing thousands of deaths and billions of dollars in economic losses each year.

The consequences of landslides are often devastating. In addition to loss of life, they result in the destruction of homes, infrastructure, and agricultural land. Disruption of road and communication networks can isolate communities for extended periods, delaying emergency response and recovery efforts. Landslides can also block rivers, leading to the formation of landslide dams and subsequent outburst floods, which further exacerbate the damage. In hilly and mountainous regions, the frequency and intensity of landslides are increasing due to both natural processes and anthropogenic pressures, posing ongoing threats to local populations and sustainable development initiatives.

The Himalayas, one of the youngest and most tectonically active mountain ranges in the world, are highly susceptible to landslides due to their complex geology, steep topography, and ongoing orogenic (mountain-building) activity. The region is characterized by intensely fractured and weathered rock formations, high rates of erosion, and frequent seismic events, all of which contribute to slope instability. Moreover, the strong influence of the South Asian

Monsoon brings heavy rainfall during the wet season, saturating slopes and triggering numerous landslides annually. Human interventions such as deforestation, poorly planned road construction, and unregulated settlement expansion have further increased landslide vulnerability in the region. As a result, landslides pose a persistent threat to life, infrastructure, and livelihoods throughout the Himalayan belt, particularly in countries like Nepal.

1.2 Objectives of the study

The main aim of the assessment is to study the settlements affected by slope failure, and landslides. The specific objectives of the assessment are:

- To perform rapid-geohazard assessment of pre-identified landslide/landslide prone areas.
- To prepare landslide inventory map for the designated landslide prone area.
- To prepare landslide susceptibility map of landslide/landslide prone areas.
- To prepare short-term/immediate investment plan and long-term Measure for effective risk mitigation and management.

1.3 Limitations of the assessment

This is a rapid geohazard assessment of pre-defined landslides of the Molung Rural Municipality Ward no. 7 hence does not encompass detailed mapping of landslides. It doesnot include geotechnical or geophysical investigations or slope stabilization design. The fieldwork was carried out over a limited timeframe, and as such, a comprehensive geological and geotechnical analysis of the area falls outside the scope of this study. Consequently, the recommendations presented are based solely on observations made during the walkover survey and should not be considered a substitute for instrument-based investigations.

CHAPTER II

METHODOLOGY

Understanding the project's background and objectives, following approaches and procedures were implemented. Details of the methodology followed for the geo hazard assessment are described below.

2.1 Desk study

During the desk study, reviewing various reports, books, journals, and bulletins—both published and unpublished—related to landslides in areas with similar geography and geology as Molung Rural Municipality Ward no. 7 was performed. Important datasets, including digital maps of topography, land use, geology, and climate data, were collected from the Department of Survey, the Department of Mines and Geology and the Government of Nepal. Additionally, Google Earth and satellite images were used to analyse the history and development of unstable slopes.

2.2 Field study

During field study, all necessary information regarding the landslide were collected. It included geological parameters such as landslide geometry, type of landslide, material/rock type, depth of landslide, hydrology, hydrogeology etc. Similarly, other primary data related to the location, history, presence or absence of settlements, post disaster response, etc. were collected. At the end, risk categorization of the settlements was performed.

2.3 Data analysis, report writing

The data gathered from fieldwork was systematically analysed in a ArcMap and Google Earth, incorporating expert observations to uphold the study's objectives. A detailed report was then prepared, presenting the analysis, findings, and field data, along with practical suggestions for risk reduction.

The digital topographic map layer was analyzed in GIS environment with Spatial Analyst tools to produce the Elevation Map in raster form. This raster image was further processed to produce different factors map like Slope Map, Aspect Map and Curvature Map. The geological map of Central Nepal, Department of Mines and Geology after modification was digitized to produce geological factor map. The Landuse map has also been prepared using google earth imagery and verification aided by fieldwork. The linear features like road, stream and thrust are being used by creating a buffer to produce Distance from Drainage, Distance from roads, and Distance from thrusts.

These altogether 9 different factor maps are categorized under appropriate classes.

The calculation was done for each classes of each factor to produce the FR and RF (Equation 1 and Equation 2). From the RF of different factor classes of each factor, the prediction rate was calculated by using Equation 3. The Susceptibility Index was calculated by using the Raster Calculator using Equation 4 in ArcGIS environment.

The calculation involves following Equations.

$$\mathrm{FR} = \frac{\frac{\text{Point in factor class}}{\text{Total points}}}{\frac{\text{Factor class area}}{\text{Total area}}} \quad \text{……………….. Equation 1}$$

$$\mathrm{RF} = \frac{\text{Factor class FR}}{\sum \text{FR of that factor}} \quad \text{………………… Equation 2}$$

$$\mathrm{PR} = \frac{(\text{RFmax} - \text{RFmin})}{(\text{RF min of all Factors})} \quad \text{………………. Equation 3}$$

Where, FR: Frequency Ratio, RF: Relative Frequency, PR: Prediction Rate

The susceptibility index is presented in the form of Landslide Susceptibility Map, which is categorized under five different class indicating the area susceptible to landslide. The area with high value indicates the area under high susceptible zone and with lowest value indicates very low susceptible zone for landslides (Figure 1).

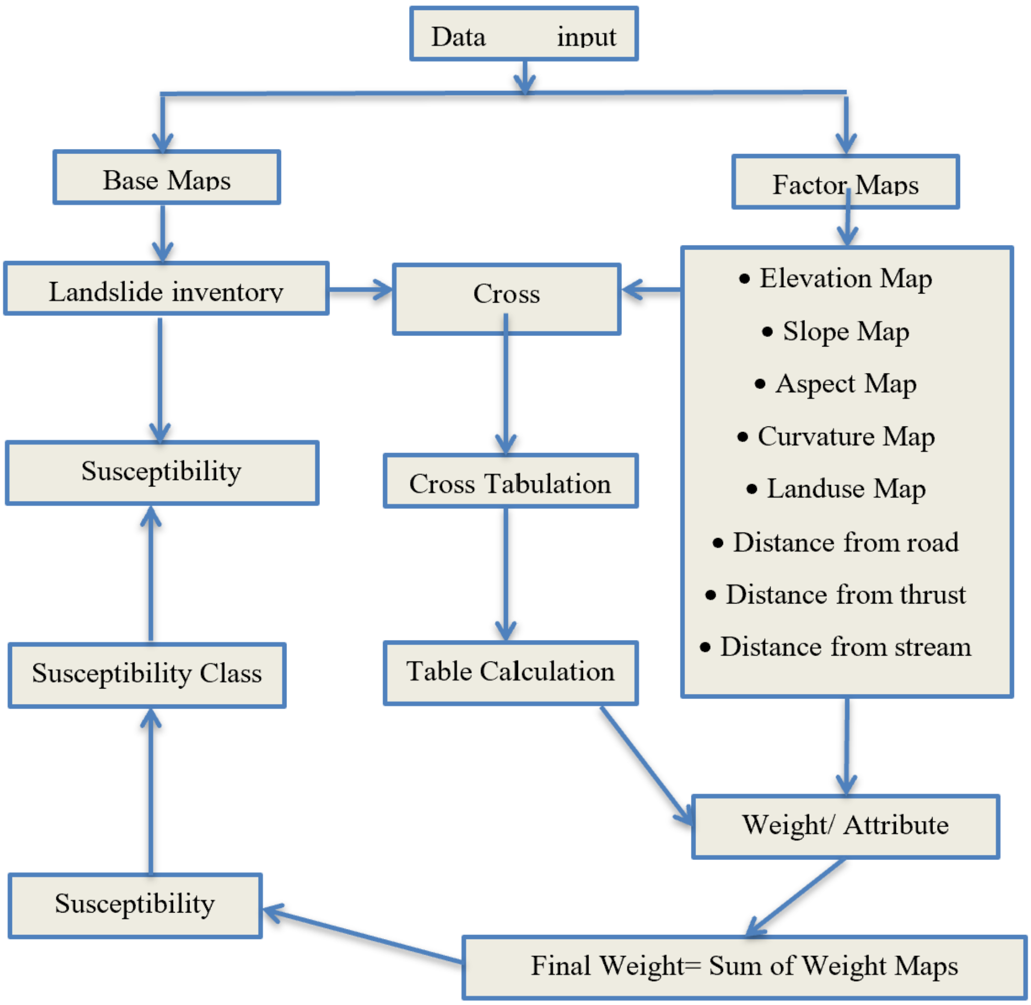

Figure 1: Details on the data preparation and analysis

CHAPTER III

GENERAL CHARACTERISTICS OF AREA

3.1 Regional geology

Geologically, the Molung Rural Municipality Ward no. 7 lies within the Midland Group and Himal Group of rocks. The Ulleri Formation, Kushma Formation, Seti Formation and Ghan Pokhara Formation lie within the Pokhara Sub Group of the Midland Group, while Dware Kharka Schist belong to the Himal Group of Rocks.

The Jesey-Gauridanda landslide lies within the Ulleri Formation and is dominated by augen gneiss, and feldspathic schist with augens of feldspar and quartz.

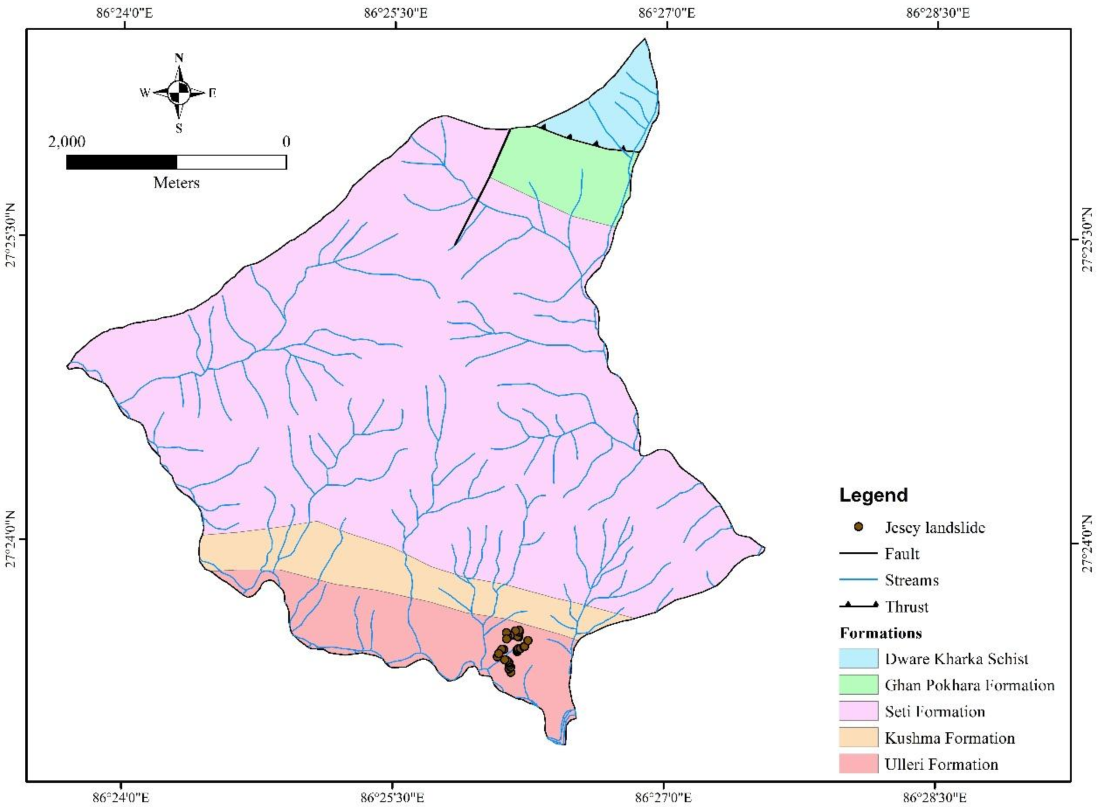

Figure 2: Geological map of the Molung Rural Municipality Ward no. 7 ward no. 7 (after DMG)

3.2 Causative factors map

Different factor maps such as, Geology (Figure 2), Elevation (Figure 3), Slope (Figure 4) and Aspect (Figure 5), Curvature (Figure 6), Landuse (Figure 7), Distance from road (Figure 8), Distance from Thrust (Figure 9) and Distance from stream (Figure 10) has been prepared and classified under appropriate classes.

3.2.1 Elevation

The elevation of the Rural Municipality is divided into seven categories: <1200 m, 1201 – 1500 m, 1501 – 1800 m, 1801 – 2100 m, 2101 – 2400 m. Most of the landslides lies within the elevation of 901 – 1200 m and 1201 – 1500 m (Figure 3).

3.2.2 Slope

The slope map of the study area is categorized into five different classes as <15º, 15-25º, 25-35º, 35-45º and >45º (Figure 4). The calculated Relative Factor (RF) for each factor classes and Prediction Rate for the slope using the Frequency Ratio method is given below in Table 1.

3.2.3 Aspect

The slope aspect of the study area is categorized into ten different classes as Flat, North (0-22.5º), Northeast (22.5-67.5º), East (67.5-112.5º), South-East (112.5-157.5º), South (157.5-202.5º), South-West (202.5-247.5º), West (247.5-292.5º), North-West (292.5-337.5º) and North (337.5-360º/0º) (Figure 5).

3.2.4 Curvature

The curvature of the hillslope of the study area is categorized into three different classes as Concave (+ve), Flat (0) and Convex (-ve) (Figure 6). The calculated Relative Factor (RF) for each factor classes and Prediction Rate for the curvature factor using the Frequency Ratio method are given below in Table 1.

3.2.5 Landuse

The landuse map of the study area along with the distribution of landslide has been developed (Figure 7). The landuse map consists of area such as Water body, Cultivation, Sand, Bush, Forest, Barren land and Cliff.

3.2.6 Distance from road

The road network along with major trails along the study area is studied by calculating the Euclidean distance from these roads. It is classified into seven different zones based on distance from the roads (Figure 8). The distance interval includes 0-50 m, 50-100 m, 100-150 m, 150-200 m, 200-250 m, 250- 300 m and >300 m.

3.2.7 Distance from thrust

A major thrust along the study area is analysed by calculating the Euclidean Distance from the thrusts (Figure 9). It is classified into six different zones based on distance from the thrusts. The distance interval includes 0-100 m, 100-200 m, 200-300 m, 300-400 m, 400-500 m and > 500 m.

3.2.8 Distance from stream

The stream along the study area is studied by calculating the Euclidean distance from the stream (Figure 10). It is classified into five different zones based on distance from the stream. The distance interval includes 0-50 m, 50-100 m, 100-150 m, 150-200 m and > 200 m.

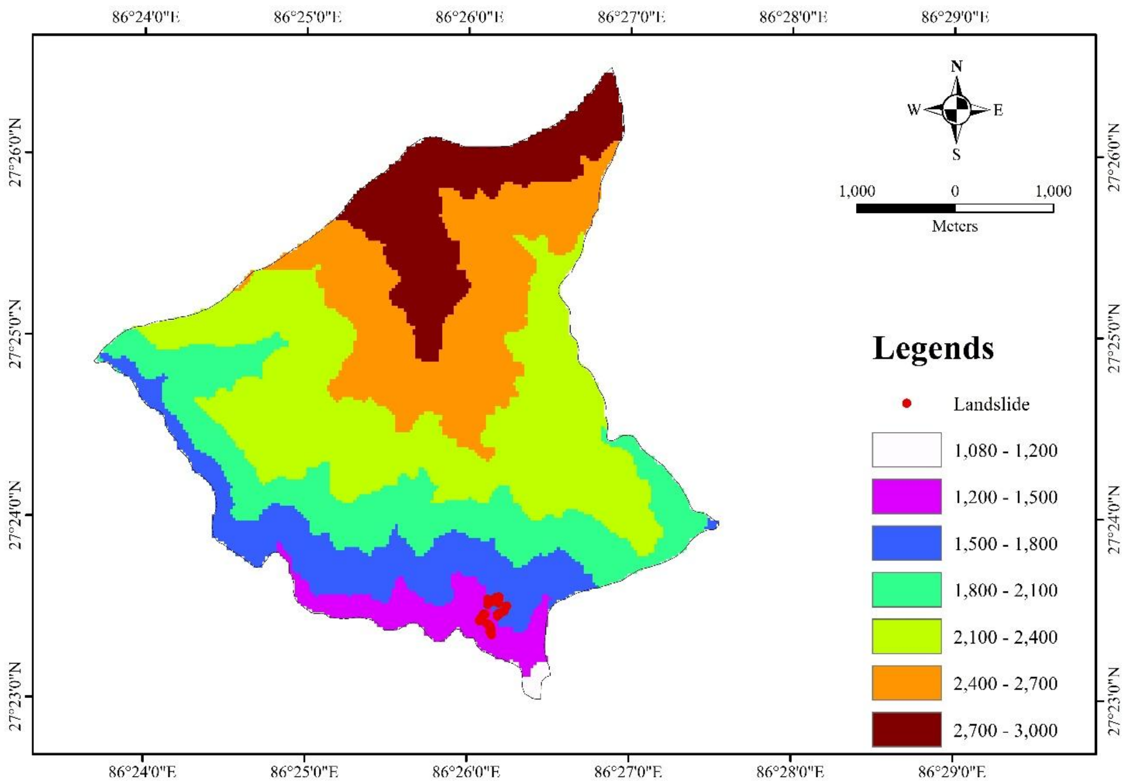

Figure 3: Digital Elevation Model of the Molung Rural Municipality Ward no. 7

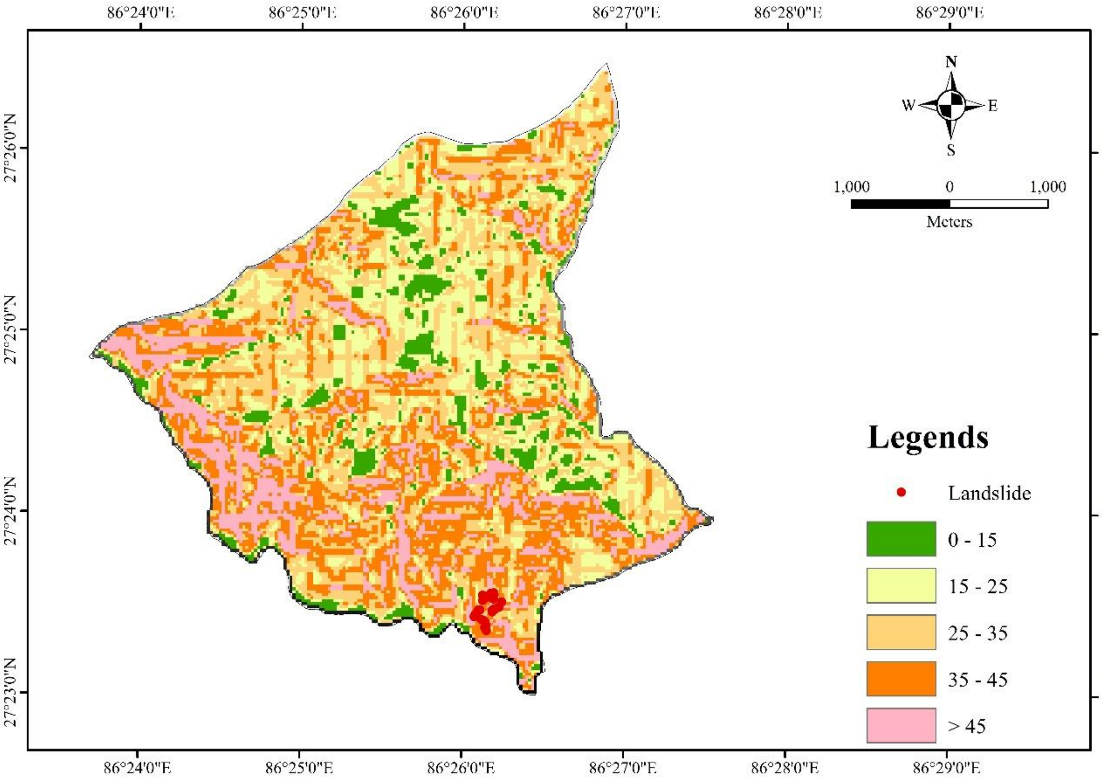

Figure 4: Hillslope map of the Molung Rural Municipality Ward no. 7

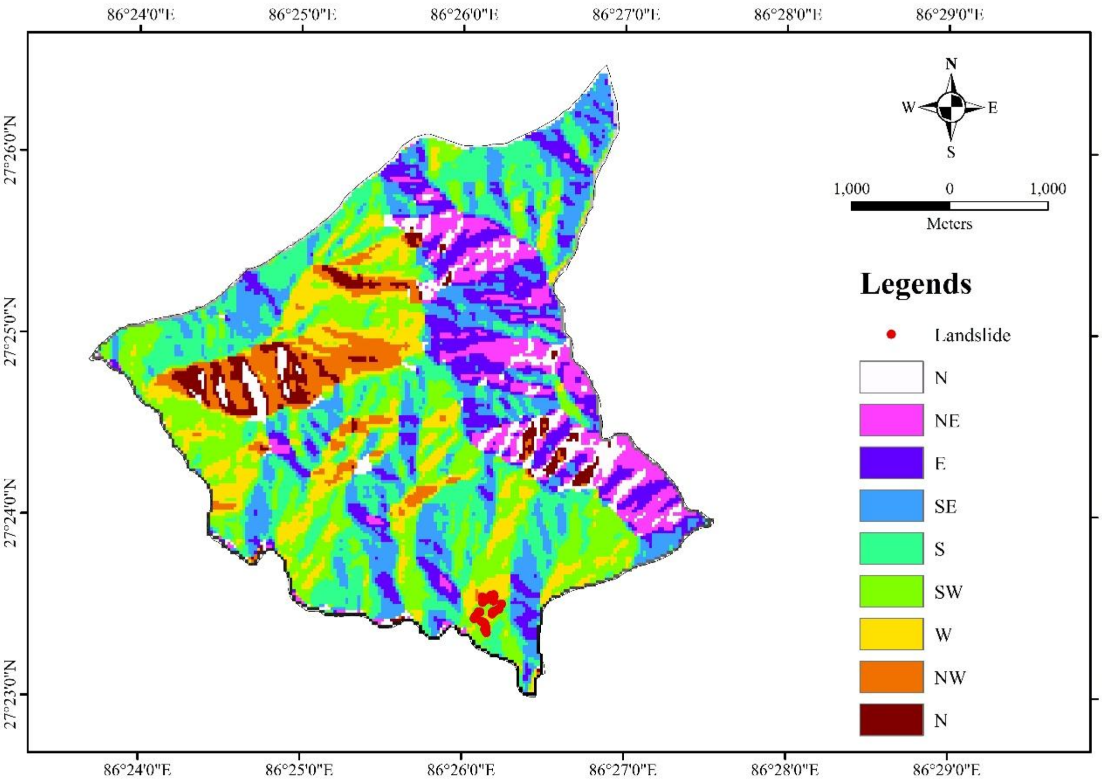

Figure 5: Aspect map of the Molung Rural Municipality Ward no. 7

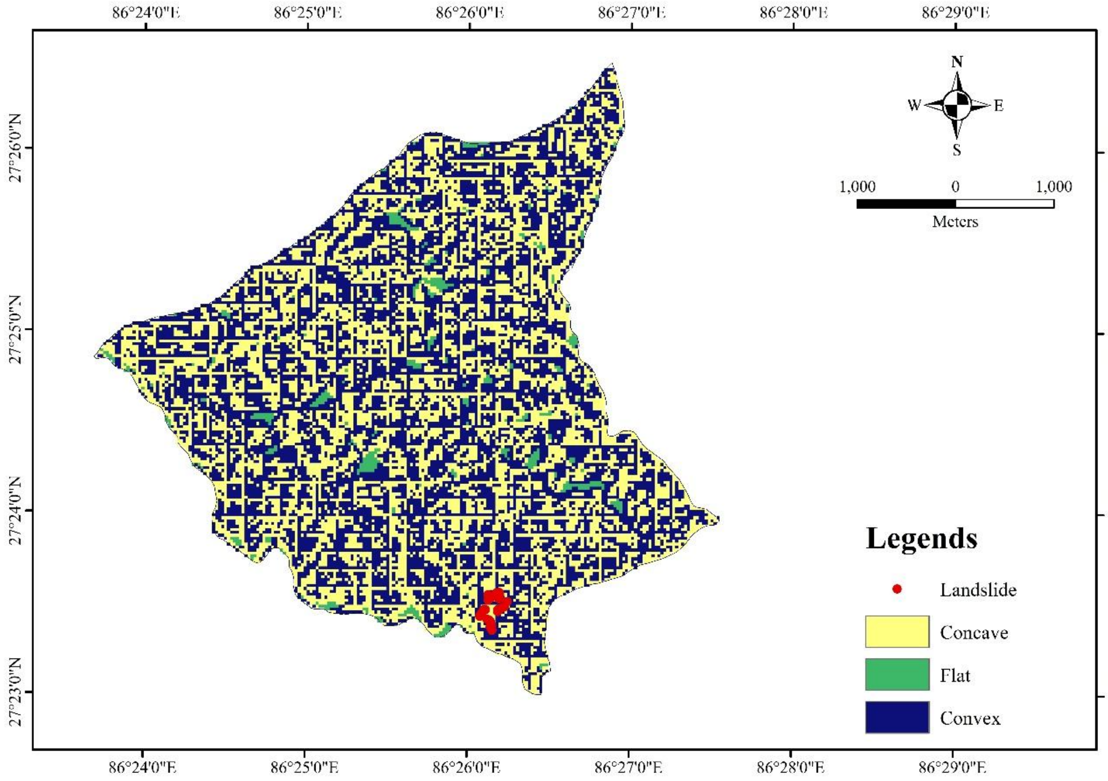

Figure 6: Curvature map of the Molung Rural Municipality Ward no. 7

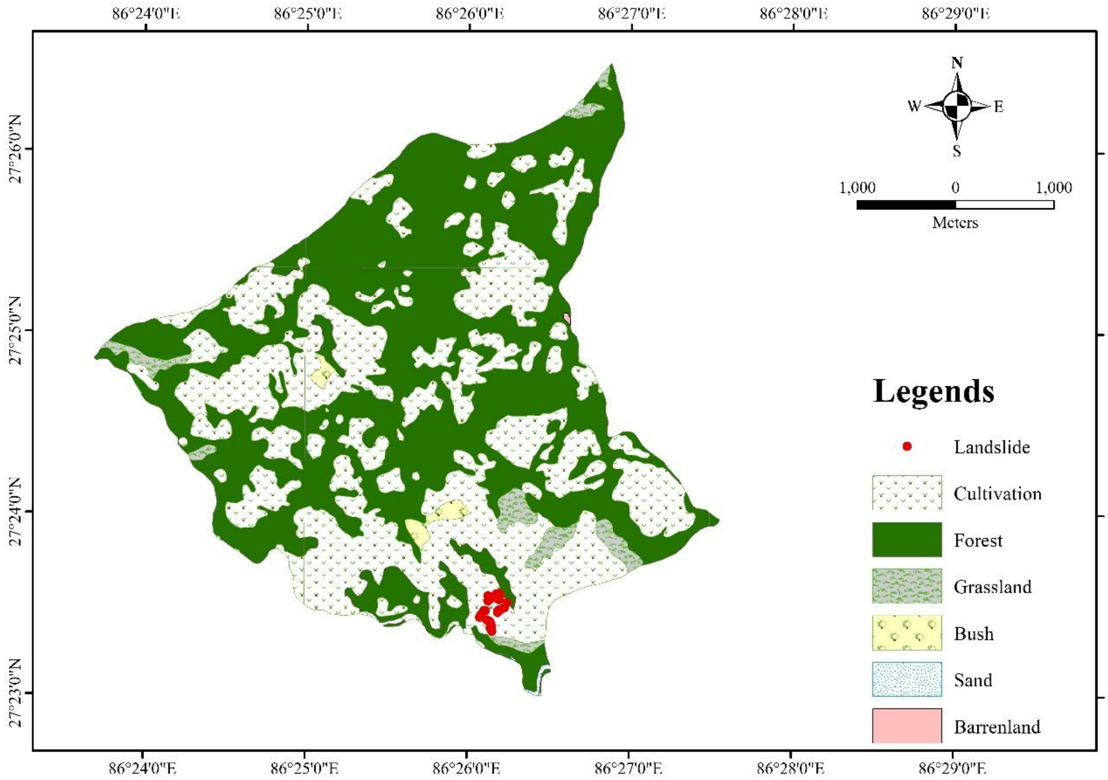

Figure 7: Landuse map of the Molung Rural Municipality Ward no. 7

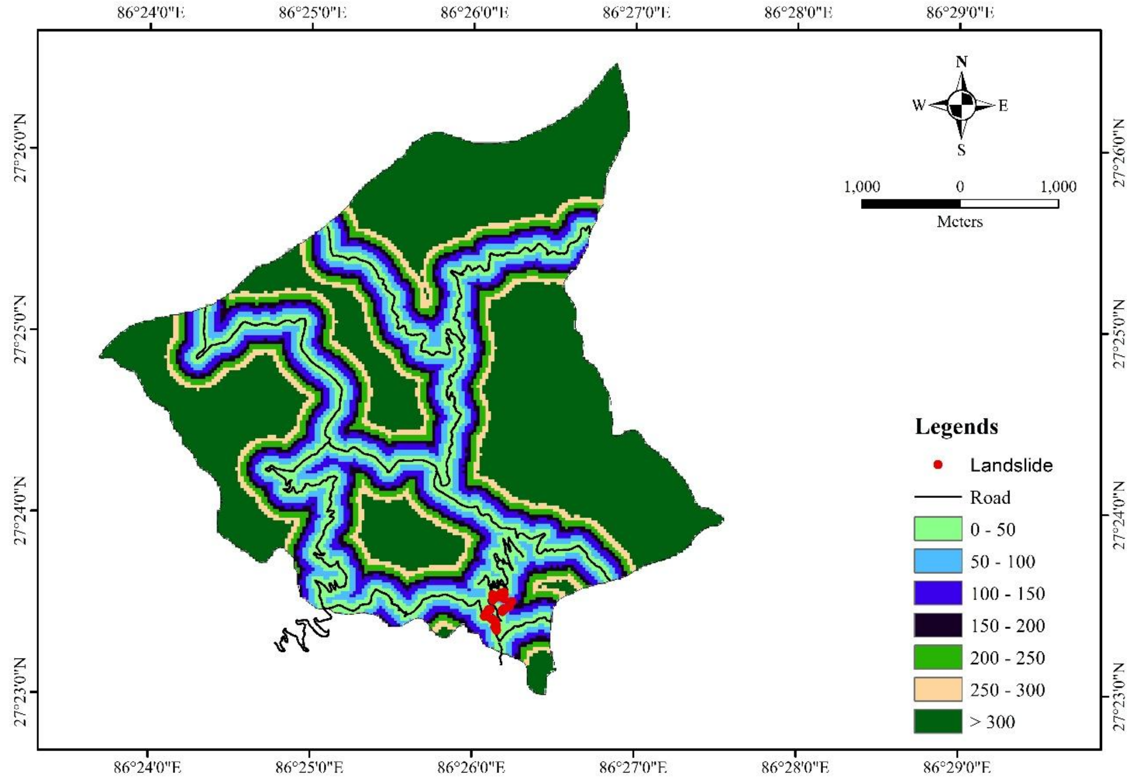

Figure 8: Distance from road map of the Molung Rural Municipality Ward no. 7

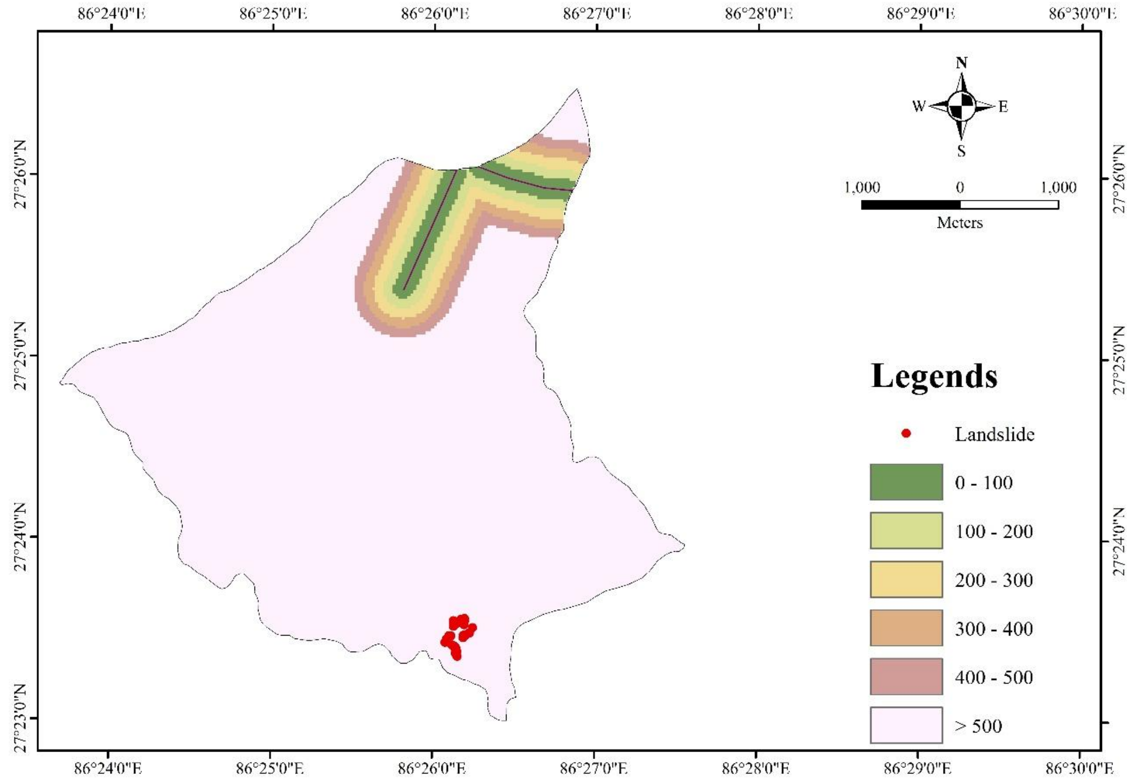

Figure 9: Distance from thrust map of the Molung Rural Municipality Ward no. 7

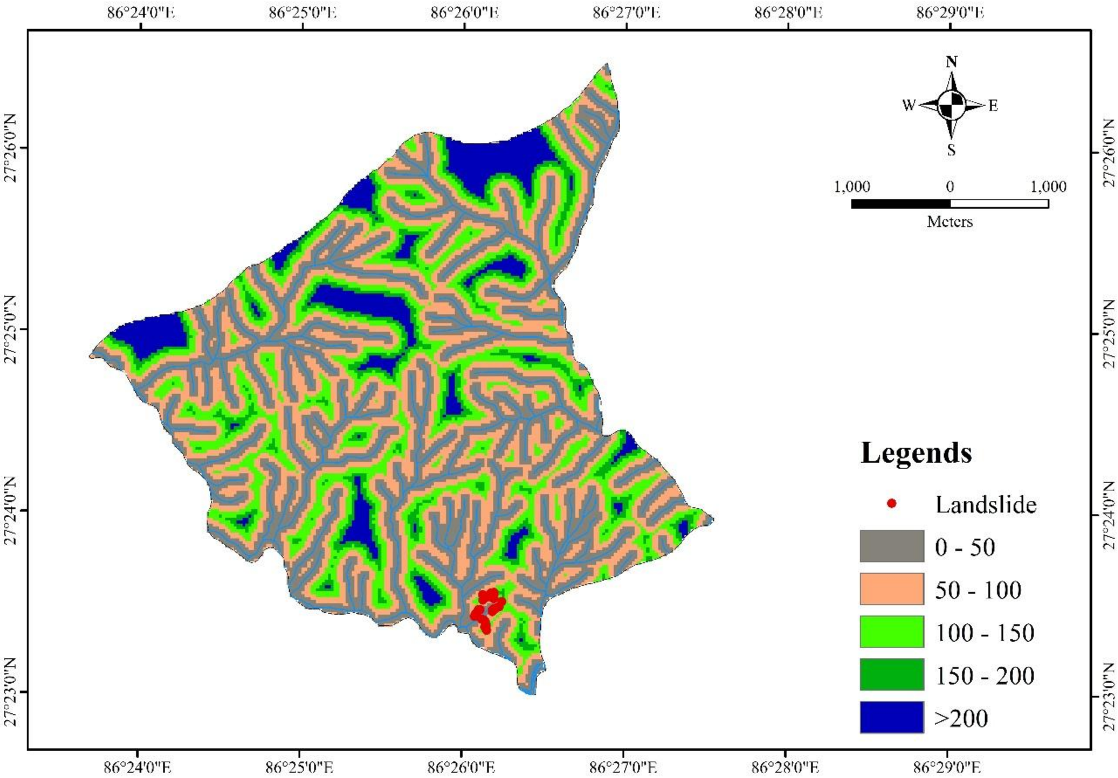

Figure 10: Distance from stream map of the Molung Rural Municipality Ward no. 7

Table 1:The calculated RF for each classes of the factor and Prediction rate for each factor.

Factor	**Factor Classes**	**% of points**	**% of Class area**	**Relative Frequency (RF)**	**Prediction Rate (PR)**
Geology	Ulleri Formation	9.28628036	100	1	2.167291
	Kushma Formation	7.095240315	0	0	
	Dware Kharka Schist	2.801734185	0	0	
	Ghan Pokhara Formation	3.999813529	0	0	
	Seti Formation	76.81693161	0	0	
		100.000	**100.000**	**1.000**	
Slope	0-15	8.055435253	12.5	0.297199	1
	15-25	20.75453539	50	0.461406	
	25-35	32.27948607	25	0.148334	
	35-45	25.72542226	12.5	0.093062	
	>45	13.18512102	0	0	
		100.000	**100.000**	**1**	
Landuse	Cultivation	41.82555592	95	0.961238	2.083281
	Forest	54.58952963	5	0.038762	
	Grassland	2.717822013	0	0	
	Bush	0.759871335	0	0	
	Sand	0.079250385	0	0	
	Barren land	0.027970724	0	0	
		100.000	**100.000**	**1.000**	

Elevation	<1200	0.354593384	0	0	1.269302
	1200-1500	5.04829002	37.5	0.585663	
	1500-1800	11.89287547	62.5	0.414337	
	1800-2100	17.88830308	0	0	
	2100-2400	31.72211076	0	0	
	2400-2700	20.47310223	0	0	
	2700-3000	12.62072505	0	0	
		100.000	**100.000**	**1.000**	
Curvature	1 (Concave)	47.23090561	41.66666667	0.432867	1.229142
	2 (Flat)	2.300191294	0	0	
	3 (Convex)	50.46890309	58.33333333	0.567133	
		100.000	**100.000**	**1.000**	
Slope Aspect	N	4.667725326	0	0	1.060447
	NE	7.16519898	0	0	
	E	11.23141331	0	0	
	SE	17.0732881	0	0	
	S	20.22520572	0	0	
	SW	19.71512439	41.66666667	0.249062	
	W	11.03892979	45.83333333	0.489296	
	NW	5.630142919	12.5	0.261642	
	N	3.252971464	0	0	
		100.000	**100.000**	**1.000**	
Distance from road	1 (0-50m)	13.19751993	70	0.629482	
	2 (50-100 m)	10.37247681	15	0.171627	
	3 (100-150 m)	8.950631672	15	0.198891	
	4 (150-200 m)	6.33536898	0	0	
	5 (200-250 m)	7.370285768	0	0	
	6 (250-300 m)	6.489207962	0	0	
	7 (>300 m)	47.28450888	0	0	1.36427
		100.000	**100.000**	**1.000**	
Distance from thrust	1 (0-100 m)	2.689851289	0	0	2.167291
	2 (100-200 m)	2.419467624	0	0	
	3 (200-300 m)	2.703836651	0	0	
	4 (300-400 m)	2.484732646	0	0	
	5 (400- 500 m)	2.7224838	0	0	
	6 (>500m)	86.97962799	100	1	
		100.000	**100.000**	**1.000**	
Distance from Stream	1 (0-50m)	36.87473777	30	0.199892	1.285695
	2 (50-100 m)	29.6909235	25	0.206881	
	3 (100-150 m)	18.63782574	45	0.593227	
	4 (150-200 m)	7.342315044	0	0	
	5 (>200 m)	7.454197939	0	0	
		100.000	**100.000**	**1.000**	

3.3 Susceptibility map

After the prediction ratio and relative frequency is calculated, the map is then reclassified into five different classes with equal intervals. The class with highest value indicates very high susceptible zone and the lowest value indicates very low susceptible zone (Figure 11).

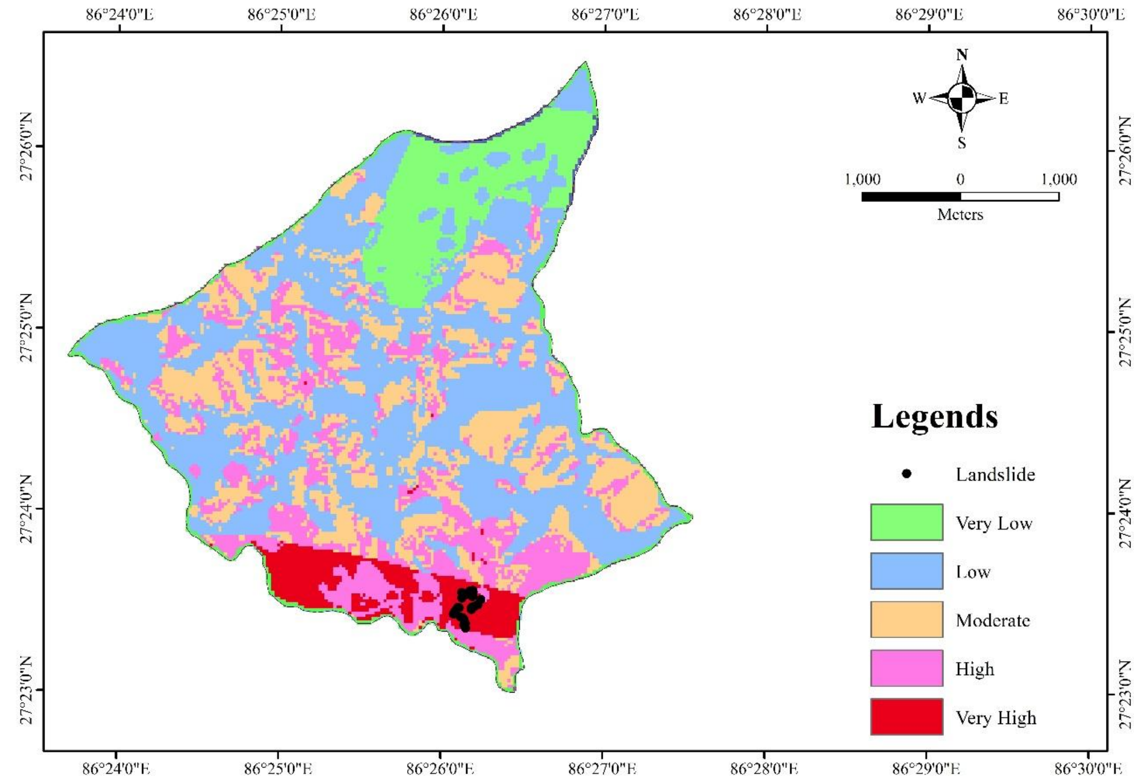

Figure 11: Landslide susceptibility map of the Molung Rural Municipality Ward no. 7

All of the landslides of the Molung Rural Municipality Ward no. 7 fall under very high susceptibility zone.

CHAPTER IV

INFORMATION ON THE ASSESSMENT AT MOLUNG RURAL MUNICIPALITY

4.1 Jesey Gauridanda

4.1.1 Location

The landslide lies along the road from Khani Khola towards Jesey, at 004-44-460 E and 030-30-290 N, and elevation of 1782 m.

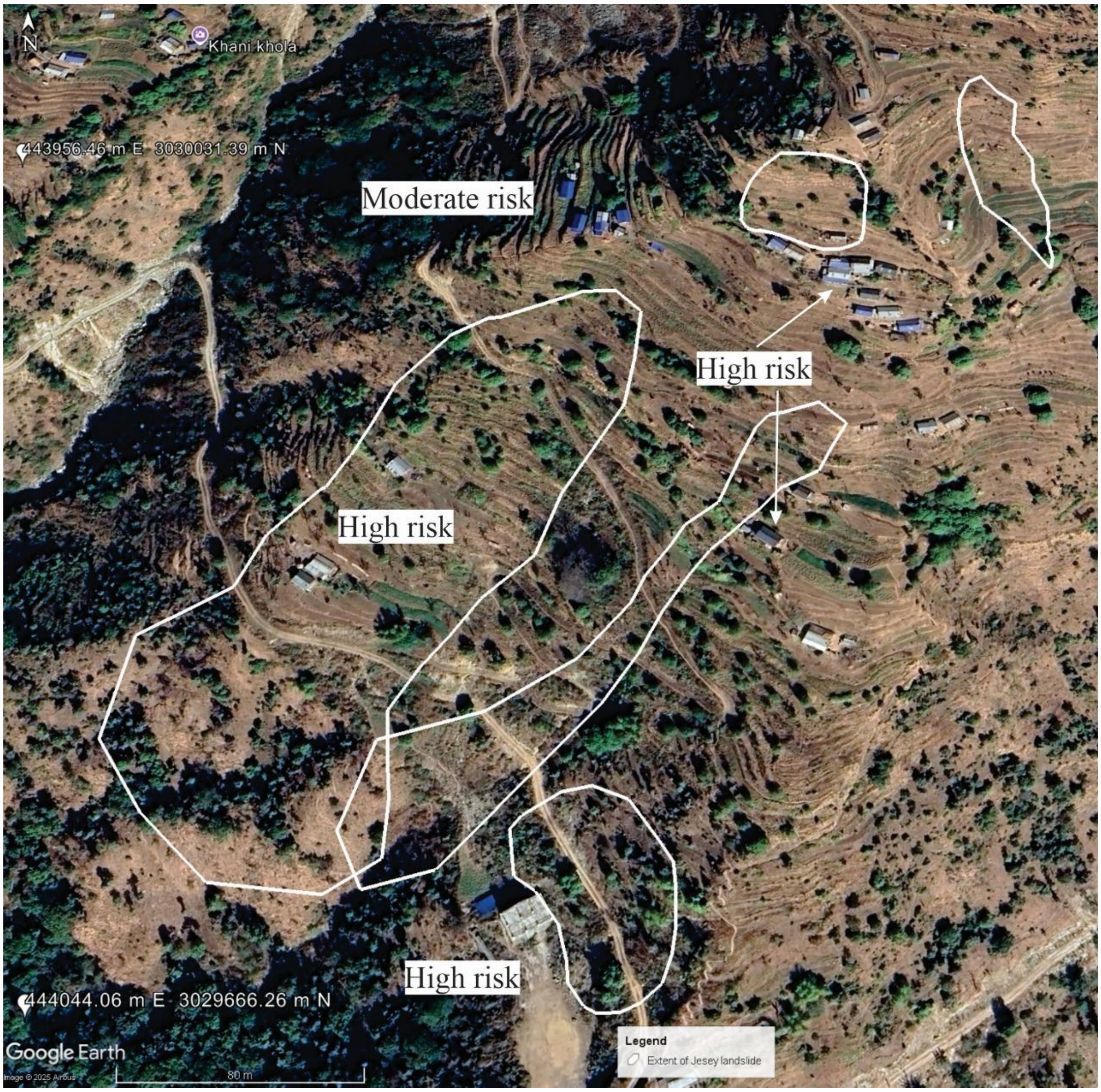

Figure 12: Google Earth image showing unstable landmass of the Jesey Landslide

4.1.2 Historical background

Debris flow occurred on 16th Ashad, 2081 at night 11 pm. There was high rainfall during th e night, and debris and mud flow occurred at the night, since then the flow has not occurred.

4.1.3 Geology of the area

The area is composed of ~ 2.5 m thick sand dominated to soil with boulders of augen gneiss. Moderately weathered augen gneiss with orientation S20°W/29°NW can be observed along the road cut section in the slope. The dip direction and dip of the joints observed are 250°/80°, 5°/52°, 185°/62°.

4.1.4 General features of unstable slope

The unstable mass is flowing towards 245°. The instability is present on concave as well as convex slope, with landslide active and still expanding. Gullies have been formed on the slope by surface runoff. As per the locals, numerous tension cracks were present in the landslide, most have been filled at present. The cracks ranged in length ~20-25 m, ~15 cm wide, and ~1 m deep.

4.1.5 Effects of geo hazard

The debris flow from slope has deposited at the back of building constructed for school while toilet of school has been partially covered by debris. The house of Tej Bahadur Sunar was completely destroyed by debris flow, killed his 2 oxen, and agricultural land was covered by debris flow deposits destroying crops. He has relocated away from landslide, while Ambar Bahadur Pahari, whose house was partially destroyed, still resides in the unstable mass. His 2 buffalo were also killed by landslide. Also, the house of Subash Pahari is also at high risk of the debris flow. Cracks can be observed in the house of Ganesh Pahari, structures near his house were destroyed by debris flow. 1 m subsidence can be observed along tension crack ~ 8 m long and 15 cm wide. Another tension crack observed is ~15 m in length and 8 cm wide with depth of 10 cm. Agricultural lands of several locals partially swept away.

Table 2: List of houses effected by the debris flow

Name of house owner	**Coordinates**
Tej Bahadur Sunar, Ambar Bahadur Pahari	004-44-445 E, 030-30-376 N
Subash Pahari	004-44-439 E, 030-30-385 N
Tek Bahadur Pahari	004-44-351 E, 030-30-462 N
Ram Bahadur Pahari	004-44-395 E, 030-30-498 N

Devi Maya Sunar	004-44-378 E, 030-30-500 N
Subash Pahari	004-44-519 E, 030-30-496 N
Fadindra Bahadur Tamang	004-44-578 E, 030-30-525 N
Umesh Tamang	004-44-586 E, 030-30-527 N
Dirgha Bahadur Pahari	004-44-615 E, 030-30-581 N
Man Bahadur Pahari	004-44-531 E, 030-30-612 N
Lalit Bahadur Pahari	004-44-522 E, 030-30-618 N
Santi Maya Pahari	004-44-456 E, 030-30-620 N
Bhola Bahadur Pahari	004-44-429 E, 030-30-622 N
Durga Bahadur Pahari	004-44-424 E, 030-30-652 N

Figure 13: Gully formed by debris flow on the slope

Figure 14: Debris flow deposit to the side of building constructed for school and on roof of toilet

4.1.6 Post disaster response

Series of stone stacked wall has been constructed for length ~10 m. This has been constructed locally by effected people at multiple locations.

Figure 15: Dry stone stacked wall constructed by locals to intercept debris flow

Table 3: General characteristics of Jesey landslide

General Information of Khurlu Khola Landslide			
Type of Landslide	**Debris flow and rotational slide**		
Dimension of the slide	Length: ~400 m	Width: ~150 m	Depth: 2-3 m
Tentative area of the village affected	>4000 sq meters		
Time of the landslide occurrence	Initiated on Ashad 16^{th} 2081, at 11 pm during heavy rainfall		
Failure orientation	200° (South West)		
Failure mechanism	Debris flow due to which rotational slide has started		
Possible cause	Caused by road cut and unmanaged drainage of surface runoff		
Status of slide	Active and expanding		
Landform type	Concave and convex		
Hydrology condition	Dry		
Features around the failed area	Multiple scarps, terraces, transverse tension cracks, tilted land and terraces, gullies, destroyed houses		
Material characteristics			

Depositional material	Sand and boulder dominated debris materials
Material forming the slope	Augen gneiss, covered by debris materials
Thickness of soil	2 to 3 m
Rock type	Augen gneiss
Rock Weathering Grade	Moderate to highly
Information of Settlement	
Total households at risk	About 20 houses
Post-Disaster Response	
Are there any mitigation measures adopted?	Stone stacked walls at multiple locations

4.1.7 Causes of slope instability

The slope is composed of easily erodible debris material. Construction of roads on the slope removed the underlying support for the materials leading to instability. The surface runoff from top of the slope flows into the same landmass and settlements, which acted as trigger mechanism for initiation of debris flow.

4.1.8 Conclusion and recommendations

As an immediate measure, the houses at high risk (Figure 12) should be relocated as the debris flow can be re-initiated even by slight rainfall and may affect the settlement.

- **Jesey Landslide**

  Immediate measure

  The settlement present at Jesey Landslide area is recommended for relocation soon as possible as debris flow can be re-initiated even by slight rainfall.

  Long-term measures

  - **Drainage management:** Surface runoff from upslope areas flows into the landslide causing erosion and debris flow into settlement. Hence the water from upslope should be drained away from slope using contour trenching, stone dams, catch drains, gabion chutes and/or cross-drainage structures.
  - **Retaining structures:** Retaining structures such as gabion walls should be installed on the slope to provide structural support to slope as well as trap debris flowing onto the settlement meanwhile providing porous passage for water to flow. For more structural integrity, reinforced concrete retaining walls with catch aprons or debris traps at their base are preferred.