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# Landslide Susceptibility Analysis along the Mugling-Narayanghat Highway in Nepal

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**Abstract**

This paper analyzes the landslide susceptibility of the Mugling-Narayanghat highway in Nepal. Nepal experiences annual landslide disasters, particularly along river corridors, causing frequent roadblocks and traffic jams during the monsoon season. The term landslide susceptibility refers to the likelihood of a landslide occurring in an area, influenced by terrain conditions. Mapping landslide susceptibility helps identify influential factors, estimate slope failure contributions, and establish associations between factors and landslides to predict future hazards. The Mugling-Narayanghat highway (MNH) is the busiest route connecting Kathmandu and Pokhara to the Indian border, serving over 6000 vehicles daily. The study was based on secondary data. The open sources digital data were taken from Google Earth Pro and Food and Agriculture Organization (FAO) published data. They were taken from different websites. And the collected data were analyzed into ARCMAP 10.8. There were nine different parameters were used to analyze landslide influence levels. This paper reveals that most of the road areas are to be considered vulnerable, and 18 points are to be identified as more vulnerable along the road in the study area.

*Keywords: Landslide, susceptibility, ArcMap, hazards, vulnerable, luvisoils*

## Introduction

Landslides are the downward movements of debris, rocks, or earth material due to gravity's influence. It has occurred when the driving force exceeds the resistance force due to the destabilization of natural soil or rock slopes (Brunsden, 1979; Cruden, 1991). Landslides are natural phenomena in mountainous countries like Nepal, characterized by rugged topography, talus cones, and debris flow, topples, falls, and slides during the monsoon season. Landslides are caused by a combination of natural and human factors, including complex geomorphological, hydrological, and geological processes, active geodynamic

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processes, and unplanned land use practices (Woldearegay, 2013; Wubalem & Meten, 2020). Other factors like steep slopes, fragile geology, sediment loss, heavy rainfall, weathered rocks, erosion, earthquakes, soil-rock interference, deforestation, unplanned human settlements, etc. are important to landslide.

Landslides in Nepal cause significant geomorphic disasters, causing significant loss of life and property and triggering floods, causing sediment loads in rivers, and affecting 40% of the total population (Ghimire, 2020). Human activities like improper land use, encroachment, and unplanned development increase landslide risk in Nepal's hilly districts, particularly in the Siwalik, Mahabharat range, and higher Himalayas (op. cit.). Nepal ranks as the 20th most disaster-prone country globally, with common floods, landslides, fires, and earthquakes due to its collision zone between the Eurasian and Indian tectonic plates (Nepal Disaster Report 2017).

Landslide susceptibility is the likelihood of landslides in an area influenced by terrain conditions. Mapping helps identify factors influencing landslides and their relative contribution to slope failures ((Brabb 1984; Chen & Wang 2007). The Uatzau basin of Ethiopia, characterized by settlements, intensive farming, and frequent landslide incidence, requires a landslide susceptibility map to evaluate factors causing slope failure and minimize socioeconomic impacts. Landslide susceptibility mapping has become easier with advancements in computers, remote sensing, and GIS tools, making it easier to associate factors with landslides and predict future hazards, a task previously difficult due to lack of data (Devkota K.C. et.al 2012)

In Nepal, highways are experiencing widespread disruption due to heavy rainfall, floods, and landslides, with police reporting frequent blockages and annual closures. Landslide debris has blocked the road, causing thousands of passengers to experience trouble, and even some dry land slides occur during dry seasons. Monsoons often block major highways like Koshi Highway, Mugline-Narayanghat Highway, Prithivi Highway, Siddhartha Highway, Ratna Rajmarg, and Tribhuvan Highway (Nepalgunj to Surkhet). Heavy-loaded highways have been serving mountain trade centers like Dhankuta, Kathmandu, Pokhara, and Surkhet.  They have been faced road blockage due to monsoon period landslides on the ways. In june and july on 2023, Mugling Narayanghat highway has been closed at nine times and thousands of travellers got trobles and economic loss.

The ADB's 2012 Environment assessment report highlights the Mugling-Narayanghat Highway as a crucial international link to Kathmandu, carrying 90% of international traffic daily. The Mugling-Narayanghat road, a vital artery connecting Nepal's federal capital to Kathmandu, is infamous for frequent landslides, with 84% heavy vehicle traffic, 9% medium vehicle, and 7% light vehicle traffic. Monsoon landslides often block this highway, causing thousands of passengers to get into trouble, especially during monsoon seasons, which is the busiest route for heavy-loaded carriers of food and other materials to serve Kathmandu and Pokhara. Woldearegay's (2013) research indicates that heavy rainfall and earthquakes primarily trigger Ethiopia's landslides. Mugling-Narayanghat highway faces a critical landslide problem, yet there is no adequate slope stability assessment across the country, just like the research findings of Waubalem and Meten 2020 in Ethiopia.

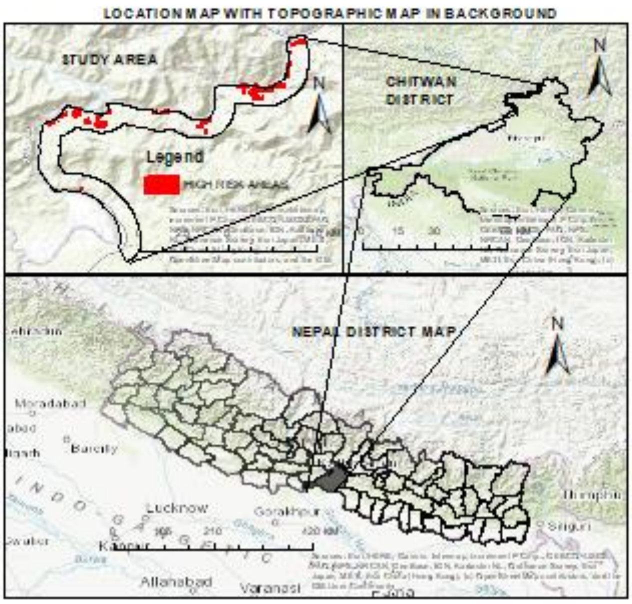
In this context, this paper analyzes landslide susceptibility mapping, providing valuable information for disaster loss reduction and sustainable land use planning around the Mugling-Narayanghat Highway. The study aims to map landslides and identify susceptibility along a 1 Kelometer wide area of the Trisuli riverbank from Mugling to Jugedi in Chitwan.

## Methods and Materials

This study area of this paper is lies in Mugling–Narayanghat highway, of Chitwan district of Nepal. The highway is along the left riverbank of Trisuli River. Trisuli and Marsangadi River confluence in Mugling. The Seti and the Trisuli river confluence in Ghumaune. It is 15.5 kilometers southwest of Mugling. In another 15 Kilometer the Kali Gandaki confluence with Trisuli at Devghat. Then after it is named Narayani River. And it flows towards boarder to India. Mugling to Jugedi has been drawn one kilometers wide boarder line in left riverbank and it is considered into study area. This area covers 27.23 Square kilometers. This area lies in Mahabharat Range from 205 meters to 1045 meters in altitude. The area has been fragmented into several divisions by the small temporary and permanent tributaries. The people migrate along the roadside is common practice and run their livelihood activities in Nepal. As the busiest road the immigration is high volume there.

**Figure 1**

*Location map*




Average daily traffic (ADT) on Narayanghat-Mugling road was 5963 with 3151 vehicles per day through Narayanghat-Mugling direction and 2812 vehicles per day through opposite direction. Out of which, 54 percent heavy, 40 percent light and 6 percent medium level vehicle were surveyed (Ojha, et. al. 2018). This part of the road is called the lifeline for Kathmandu and Pokhara, which are the largest cities. Thousands of people travel daily, and tons of commodities pass through the highway daily. The location of the highway is along the left riverbank of Trisuli River. High slope, fragile topography, and immigrant encroachment along the roadside has support more vulnerable to landslide. Almost all monsoon period innumerable road blocked cases happen.

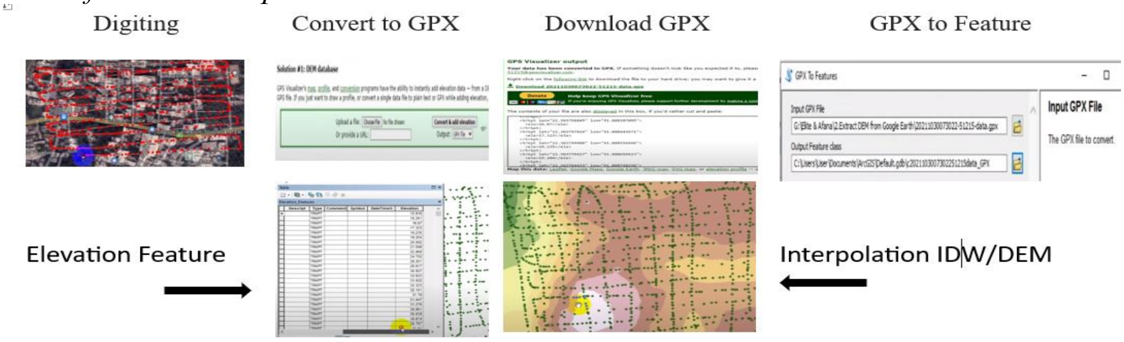
The present shown landscapes are the result of cumulative function of the natural agents. All developed landscapes pass through structure, process, and stage. Landslide is a process to develop a new physical feature in a local area. It is a gravitational process, and it is influenced by other several components. Slope gradients, land use, geology, rainfall, soil type, soil moisture, are the major influencing factors to landslides.

The open data sources like Google Earth Pro, Esri map, United State Geological Survey (USGS) map was widely used in this study. Besides those map data, the GIS map of Nepal that developed by survey department and Road department were widely used.

Most of the data sources were Google Earth Pro and Arc Google. The digitized point data were navigated to the chosen location of the computer. It had been taken as many points as needed for accuracy and high resolution. Taken points were saved into "KML" type file in desire directory. Using GPS Visualizer website, the taken elevation points values had been converted into GPX type file. After converting them into a GPX file, they had been downloaded them and extracted in desire path location. To convert the GPX file into feature file, conversion tool had been used (Conversion tool -- from GPS -- GPX to features). The DEM file was extracted by the study boundary as 1 Kilometer left riverbank of Trisuli river from Mugling to Jugedi.

**Figure 2**

*DEM file extracted process.*




**Slope Map**

The digital elevation model (DEM) raster map was the main source to develop slope map. Spatial analysis tools, surface tools and slope tools of ArcMap were used to make slope map. The five slope categories were identified. And they are as 0 to 15, 16 to 25, 26 to 35, 36 to 45 and 45+ degree.

**Topographical Roughness Index (TRI)**

The level of topographical roughness map was produced from DEM file. Spatial analysis tools under Neighborhood tool were used for the focal statistics. There were 3 different focal statistics (Mean, Medium and Maximum focal statistics) map has been developed. Later, the raster calculator calculated the TRI. And the roughness index was reclassified into 3 major categories as smooth, medium roughness and maximum roughness.

$$\text{TRI} = \frac{(\text{*focal mean} - \text{focal medium*})}{(\text{*focal maximum} - \text{focal Medium*})}$$

**Land use, River Network and Road Network**

These types of data were developed in ArcMap. The data source was Google Earth Pro. The KML type file was converted into feature class file by getting help of ArcMap and analyzed it as required.

**Soil Map**

It was found the single type of soil in the entire study area. The shallow and rocky boulder mixed soil (luvisoil) was found in the study area. The soil data were extracted from soil and water assessment tools (SWAT) model of south Asia.

**Geological Map**

The geological map of the study area was downloaded and extracted from the website of geological map of South Asia. The website was (https://certmapper.cr.usgs.gov/data/apps/world-maps/). It was found a single geological cover that was sandstone, siltstone and mudstone type geology.

**Rainfall Data**

The rainfall raster map was developed by the writer himself. The raw tabular annual rainfall data (CSV type data) of different 424 stations had been carried out from environment statistics of Nepal 2019, published by Central Bureau of statistics. The website was (https://cbs.gov.np/environment-statistics-of-nepal-2019). The available 5 different years rainfall data of 424 metrological stations have been averaged. The five different years were 2013, 2014, 2015, 2016 and 2017 years. The calculated average rainfall data were interpolated with IDW tools in ArcMap and developed raster map.

All available digital maps were GCS_WGS_184 coordinate system and they all were projected into WGS_1986_UTM_Zone_45N for data analysis.

**Study Method**

The overall methodology of the project was based on ArcMap 10.8 version. The weighted overlay method had been used. All raster data were converted into 30m X 30m grid for the processing. Some of the data has been categorized into five different classes, some of the data categorized into three and some land categories found single land character type. The study area was small. It was found a single soil and geology type throughout the area. All map categories had been given different weight values and they were divided as different influenced percentages that is given table no. 1.

**Table 1**

*Parameters, influence percentage and weighted values*

| Slope | Weg.* | Aspect | Weg. | Roughness | Weg. | Road Distance | Weg. | River distance | Weg. |
|---|---|---|---|---|---|---|---|---|---|
| 0 -15 | 1 | South | 5 | Minimum | 2 | 25 M | 5 | 25 M | 5 |
| 16 – 25 | 2 | West | 4 | Medium | 3 | 50 M | 4 | 50 M | 4 |
| 26 – 35 | 3 | North | 3 | Maximum | 5 | 75 M | 3 | 75 M | 3 |
| 36 – 45 | 4 | East | 2 | N/A | N/A | 100 M | 2 | 100 M | 2 |
| 45+ | 5 | N/A | N/A | N/A | N/A | 125 M | 1 | 125 M | 1 |
| **Influence** | **15%** | **5%** | | **10%** | | **15%** | | **15%** | |
| **River den**** | **Weg.** | **Land Use** | **Weg.** | **Soil** | **Weg.** | **Geology** | **Weg.** | **Rainfall** | **Weg.** |
| Minium | 3 | Landslide | 5 | Luvisoils | 5 | Sandstone | 5 | 1900 mm | 1 |
| Medium | 4 | Agriculture | 3 | N/A | N/A | N/A | N/A | 2000 mm | 2 |
| Maximum | 5 | Forest | 1 | N/A | N/A | N/A | N/A | 2100 mm | 3 |
| N/A | N/A | Grass land | 2 | N/A | N/A | N/A | N/A | N/A | N/A |
| N/A | N/A | Build up | 4 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Influence** | **20%** | **5%** | | **5%** | | **5%** | | **5%** | |

Note: * weightage, ** Density

The findings of the study are explained through descriptive, tabular presentation, graphic presentation, statistical tools, and map presentation has been widely considered in discussion section.

## Results and Discussion

The entire area is on the foothills of Mahabharat Mountain. The highway was designed along the Trisuli River. Trisuli river starts to lateral cutting after crossing Muglin. So Trisuli river has been pushing the road more vulnerable to landslide. And again, due to the more population encroachment along the road and upper slope that rise the hazard materials.

### Landslide Inventories

The total study covered 2723.54 Hectors. It had found 54 existing landslide inventories. That covered 22.12 hector of land in 2023. Table No. 2 explained the landslide inventories distribution pattern and coverage areas.

**Table. 2**

*Landslide inventories distribution (Area in Ha.)*

| Political territory | Ward No | Area cover | inventories | Area cover |
|---|---|---|---|---|
| Bharatpur Metropolitan City | 1 | 57.49 | 0 | 0 |
| | 29 | 1555.15 | 36 | 15.54 |
| Ichhakamana Rural Municipality | 5 | 222.70 | 7 | 3.64 |
| | 6 | 888.20 | 11 | 2.94 |
| Total | | 2723.54 | 54 | 22.12 |

Source: Deriver from Google Earth Pro Image@2023 Airbus/Image@2023 Maxar Technologies and ArcMap Analysis

Table 2 shows the distribution of landslide inventories in the study area. The study area covers two political entities, such as Bharatput Metropolitan City (Ward No. 1 and 29) and

Icchakamana Rural Municipality (Ward No. 5 and 6). The largest area covered by Ward No. 29 of Bharatput Metropolitan city (1555.15 ha) and lowest in the Ward No. 1 of the same Metropolitan City (57.49 ha). The study area recorded 54 number of inventories and 22.12 ha landslide inventories. The result reveals that Ward No. 29 of Bharatput Metropolitan city has recorded the largest inventory area (15.54 ha) and lowest in the Ward Now. 6 of Icchakamana rural municipality (2.94 ha).

## Land Use

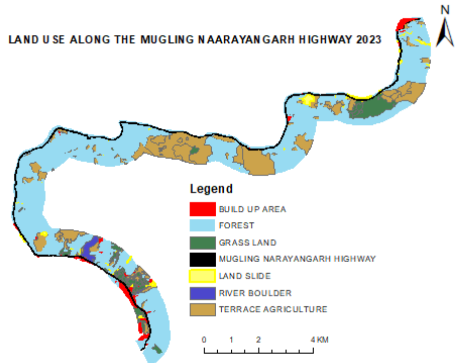
The land use patterns of the study area comprise seven different land cover types. Table 3 describes the land cover of the area. Forest land cover is the dominant land cover. Forest covers 1743.63 hector (64.02%) of the land and forest area can be reclassified into degraded forest that covered to 24 % (418.47 hector of land. Terrace agriculture is the second dominant type that covers 631.14 hector (23.17%) of land.

**Table: 3**

*Land use Types*

| Sno | Land Cover Type | Cover Area | Cover % |
|---|---|---|---|
| 1 | Forest Area | 1743.63 | 64.02 |
| 2 | Terrace Agriculture | 631.14 | 23.17 |
| 3 | Grass Land | 169.2 | 6.21 |
| 4 | Highway | 68.65 | 2.52 |
| 5 | Build Up Area | 60.35 | 2.22 |
| 6 | River Boulder | 28.45 | 1.04 |
| 7 | Land Slide inventories | 22.12 | 0.81 |
| **Total** | | **2723.54** | **100** |

Source: GIS Analysis




Grass land covers 6.21 percent of the land and it is concentrated to northeast part. Mugline Naarayangarh Highway elongated along the Trisuli River that comprise 68.65 hector of land. Land slide inventories spread to random pattern across the area. Agriculture land covered 631.14 hector It can be further reclassified to sloppy agriculture land (Khoriya) that covered 7 % (1.57 hector) of land.

### *Landslide susceptibility analysis*

There were 10 different parameters that have been taken into consideration for land slide susceptibility analysis. Table one explored the parameters, their weightage value and influence proportion. Some of the parameters did not have enough data classification. So, they were considering the same weightage value for the entire area. They are soil and geology maps. Landslide vulnerability levels are categorized into very low, low, moderate, high, and very high areas. The preparation of landslide hazard map is determined by combining factors based on different weightage values for different land classes (Table 4).

**Table 4**

*Land slide vulnerability identification 2023 (Area in Hector)*

| SN | Vulnerability Level | Area Coverage | Coverage % |
|---|---|---|---|
| 1 | Very Low Vulnerable | 2359.84 | 86.65 |
| 2 | Low Vulnerable | 83.79 | 3.08 |
| 3 | Moderate Vulnerable | 200.31 | 7.35 |
| 4 | Highly Vulnerable | 78.35 | 2.87 |
| 5 | Very Highly Vulnerable | 1.25 | 0.05 |
| | Total | 2723.54 | 100.00 |

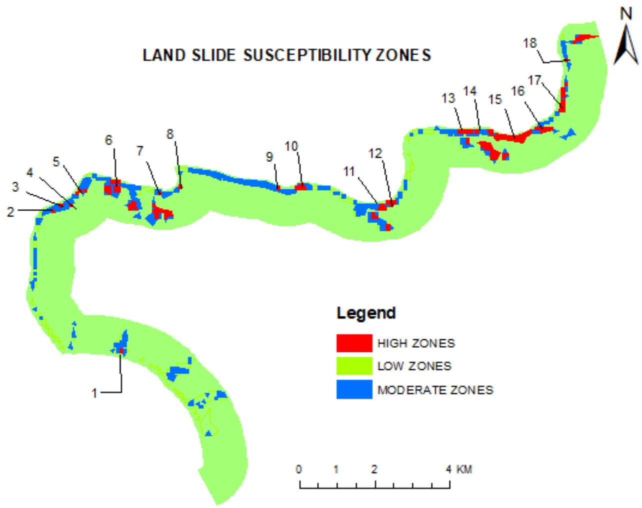
Source: Derived from Google earth Pro, 2023 and ARCMAP 10.8. analysis

All the study area covers are mountain and slopy area. Along the roadside looks more vulnerable with high slope, unmanaged terrace agriculture and degraded forest land. It was found around 86.65 percent of the area comparatively safe and other rest areas (13.35%) found vulnerable categories. Out of which low vulnerable found 83.79 hector (3.08 %), Moderate vulnerable found more than 200 Hector (7.35 %), High and very highly vulnerable areas found 2.87 % and 0.05 % respectively. The roadside 18 different points found most vulnerable points that might blocked the road. They are located within the distance of 24 Kilometers (point 1 to point 18). The first point is near Presidency Resort of 12.70 Kilometer from Pulchowk Narayanghat and 18th point away to 36.83 kilometer from Pulchowk near Mugling Bridge.

**Table 5**

*Vulnerable points and distance from Pulchowk Narayanghat*

| Point | Lat. | Long. | Dis. |
|---|---|---|---|
| 1 | 27.778 | 84.453 | 12.70 |
| 2 | 27.814 | 84.437 | 18.60 |
| 3 | 27.815 | 84.438 | 18.77 |
| 4 | 27.815 | 84.440 | 19.01 |
| 5 | 27.818 | 84.443 | 19.36 |
| 6 | 27.820 | 84.453 | 20.66 |
| 7 | 27.818 | 84.463 | 21.76 |
| 8 | 27.819 | 84.466 | 22.21 |
| 9 | 27.819 | 84.490 | 25.11 |
| 10 | 27.820 | 84.497 | 27.31 |
| 11 | 27.815 | 84.517 | 29.51 |
| 12 | 27.832 | 84.537 | 33.21 |
| 13 | 27.833 | 84.547 | 34.21 |
| 14 | 27.833 | 84.552 | 34.76 |
| 15 | 27.838 | 84.558 | 35.56 |
| 16 | 27.842 | 84.559 | 36.01 |
| 17 | 27.843 | 84.560 | 36.18 |
| 18 | 27.849 | 84.561 | 36.83 |




Source: GIS Analysis

8 vulnerable points (point 2 to point 9) were located nearby kamalpur, bhorle and Umit Jharana . They are situated quite opposite of Sumeru Hill near Seti and Trisuli confluence point. 6

vulnerable points (point 13 to point 18) were located beside of Jalbire Jharana to Khahare Bridge near the Mugling Gumba.

## Conclusion

Mugling- Narayanharh highway is considered a high landslide vulnerable area. There were 18 most probable landslide points that were identified within 36-kilometer distance. Landslides are an uncertain natural phenomenon over the areas. The various dependents factors can invite catastrophic events in the local area and create disaster. The study carried out that almost 13.35 percent of land surface was categorized as vulnerable to landslides. There were four different vulnerable zones classified as low, moderate, high and very highly vulnerable areas. There were 35 different polygons identified as high land slide prone area. Out of which 18 polygons were along the highway. There were 22 households found under high landslide prone area including Devibhanjyanj Basic School of Icchakamana Rural municipality (Former Chandibhanjyang). The school is located looks like to hilltop. The identified settlements need to be displacement and in future using these landslide hazard maps in land use planning would be invaluable for the mitigation of losses as well as management of the environment at local level.

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