



NDRI

Landslide Disaster: Causes and Impact

Case Study: Lidi, Sindhupalchowk, Nepal

Prepared By :

Nepal Development Research Institute

 info@ndri.org.np

 www.ndri.org.np



Landslide Disaster: Causes and Impact

Case Study: Lidi, Sindhupalchowk, Nepal

This report comprehensively evaluates past and present landslide disaster data and trends in Nepal. It also reviews the framework of landslide disaster management policies, strategies, acts, regulations and associated institutions in Nepal. Furthermore, the report presents a detailed case study on the small catchment area of the Balephi River in Lidi, Sindhupalchowk district to prepare landslide susceptibility map.

Study Team

Dr. Tara Nidhi Bhattarai, NDRI

Er. Shanmukhesh Chandra Amatya, NDRI

Dr. Jaya Kumar Gurung, NDRI

Ms. Durga Khatiwada, NDRI

Published by:

Nepal Development Research Institute (NDRI)

Lalitpur, Nepal

Reproduction of this content for commercial/non-educational use is prohibited.

All Rights Reserved. © Nepal Development Research Institute, 2020

Landslide Disaster: Causes and Impact

Case Study: Lidi, Sindhupalchowk, Nepal



Image from Nāyapatrika, 9th Dec, 2020

TABLE OF CONTENTS

1. Background.....	6
1.1. Objectives.....	7
1.2. Scope of work.....	7
2. Literature review	8
2.1. Past Study of Landslide Disaster in Nepal.	8
2.2. Methods for Landslide Susceptibility Mapping.	8
3. LandUse Categorization in Nepal	10
3.1. Water Induced Disaster Management Policy 2072	13
4. Technical background on types of landslides and landslide triggering events.....	14
4.1. Types of landslides	15
4.2. Classification of Mass Movement	17
4.3. Causes of Landslide (Landslide Hazards (usgs.gov)).....	18
5. Methodology	19
5.1. Review of Policy, Acts and Institutions.....	20
5.2. History of landslide evidences in Nepal (2010-2019).	20
5.3. Situation of landslide in Monsoon 2020.....	20
5.4. Landslide inventory mapping on the selected (pilot) watershed.	20
5.5 Case study of selected watershed area for landslide susceptibility mapping.	20
6. Analysis and Output.....	23
6.1 Review of Policy, Acts and Institutions.....	23
6.1.1 National Policy.....	23
I. Act No. 20 of the Year 2039 B.S. (1982)	23
II. National Policy for Disaster Risk Reduction 2018	24
III. National Strategic Action Plan on Search and Rescue 2013	25
IV. National Strategy for Disaster Risk Management in Nepal (NSDRMN)	26
6.1.2 International and National DRR Initiatives	27
I. International Initiatives	27
II. National Initiatives	30
6.2 History of landslide evidences in Nepal	36
6.3. Status of landslides in the Monsoon of 2020 (01/03/2020-30/08/2020).....	38
6.4. Case Study of Selected Watershed of Sindhupalchowk	38

6.4.1 Preparation of Landslide Inventory Maps.	40
6.4.2 Preparation of Landslide Susceptibility Maps	41
7. Conclusions And Discussions.....	50
8. Limitations/Issues	52
9. Recommendations	52
10. References.....	53

LIST OF FIGURES

Figure 1: Physiographic regions of Nepal (Amatya SC and Joshi J., 2016).	6
Figure 2: Classification of landslide risk zone. (Source: Water Induced Disaster Management Policy 2072).....	13
Figure 3: An idealized slump-earth flow showing commonly used nomenclature for labeling the	15
Figure 4: Major types of landslide movement. (Source: USGS, 2004)	16
Figure 5: Preventive classification of Mass Movement (Source: Technical Guide on Landslide Mitigation Work, 1999).....	18
Figure 6: Number of human causativeties with affected family and estimated loss in Nepal due to landslide (2010-2019). (Source: NDRR, MoHA).....	37
Figure 7: Landslide events Verses Human Death in Nepal (2010-2019) (Source: NDRR, MoHA).	37
Figure 8: Status of landslide events in Monsson 2020 (01/03/2020-30/08/2020). (Source: Bipad.gov.np)	38
Figure 9: Location map of the study area.	39
Figure 10: Landslide inventory map of study area. Source: Final Report: J-RAPID Program)....	40
Figure 11: Landslide inventory map of study area in 2014 and 2016 after Gorkha Earthquake. (Source: Google Earth).....	41
Figure 12: Slope map of the study area.	42
Figure 13: Aspect map of the study area.	43
Figure 14: Curvature map of the study area.	44
Figure 15: Elevation Map of the study area.	45
Figure 16: Distance to river map of the study area.	46
Figure 17: Distance to road map of the study area.	47
Figure 18: Geological map of the study area.	47
Figure 19: Landuse map of the study area.....	48
Figure 20: Landslide Susceptibility Map of study area.	50

LIST OF TABLES

Table 1: Land cover classes on different studies in Nepal (Source: MoFE, 2019).	11
Table 2: Top level land categories prescribed in the Good Practice Guidance of IPCC (Source: MoFE, 2019).....	12
Table 3: Classification of landslide types with its area description.	13
Table 4: Classification of landslide hazard zone and its land use.	14
Table 5: Landuse pattern based on slope degree.	14
Table 6: Varne's Classification of Mass Movement.	17
Table 7: Mechanism of landslide Phenomenon.	18
Table 8: Landslide Data Analysis (2010-01-1/2019-12-30) Source: MoHA, GoN.....	55
Table 9: Landslide Data Analysis (2020-03-01 - 2020-08-30) Source: MoHA, GoN.	58
Table 10: : Landslide details of selected watershed of year 2014	60
Table 11: Landslide details of selected watershed of year 2016.	61
Table 12: Calculation of landslide prediction rate using frequency ratio method.	64

1. BACKGROUND

The Himalayan Range is one of the youngest mountain range on the world. It is a broad continuous arc along the northern fringes of the Indian subcontinent, from the bend of the Indus River in the north- northwest to the Brahmaputra River in the east-southeast. The Himalayan mountain chain measures 2400 km in length and remains one of the most active and fragile mountain ranges on the earth. Nepal, being a Himalayan country and owing to the rugged topography, complex geological settings, soft soil cover, high intensity rainfall during monsoon periods, the natural phenomena such as earthquakes, landslides, debris flows, soil erosion, and other mass wasting processes are some of the common forms of natural disasters. Landslide is one of the very common natural hazards in the hilly region of Nepal. Natural factors such as steep slopes, fragile geology, and high intensity of rainfall are the major causes of landslide. The risk of landslide is further exacerbated by anthropogenic activities like improper land use, encroachment into vulnerable land slopes, deforestation, unplanned human settlements and unplanned development activities such as construction of roads and irrigation canals without proper protection measures in the vulnerable mountain belt (Figure1). The hilly districts of Nepal located in the Siwalik, Mahabharat range, Mid-land, and Higher Himalayas are more susceptible to landslide because of steep topography and fragile ecosystem.

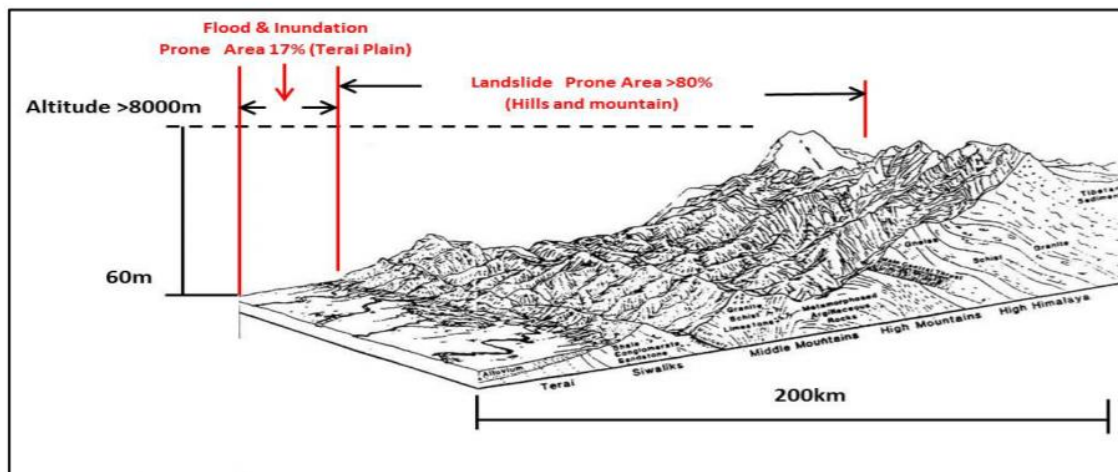


Figure 1: Physiographic regions of Nepal (Amatya SC and Joshi J., 2016).

Despite the highest fatality rate in the world relative to population in Nepal, the authorities have failed to provide plausible solutions in regards to landslide risks, with haphazard road building, unplanned settlements and climate change are making the situation worst.

(<https://www.thethirdpole.net/2020/09/14/why-are-landslides-so-deadly-in-nepal/>). According to a report by the United Nations' Food and Agriculture Organization published in 2011 (<https://www.thethirdpole.net/2020/09/14/why-are-landslides-so-deadly-in-nepal/>) Nepal has one of the highest fatalities from landslides in the world. Hence, to comprehend the causes, impacts (damages and losses), and risk reduction and management practices of landslides in Nepal, we will analyze the historical trend of landslide in Nepal, variations of landslide occurrence across different parts of Nepal; assess the policies, strategies, acts, regulations; prepare the landslide inventory of the selected watershed area; and prepare landslide susceptibility map.

1.1. Objectives

The major objectives of the study is to prepare the landslide susceptibility map of the study area. The various specific objectives to achieve it are as follows:

- (i) To assess and analyze the past and current landslide disaster data, their trend, and impacts.
- (ii) To review and assess the policies, strategies, acts, regulations, and the institutions related to landslide disaster risk management.
- (iii) To prepare the landslide inventory of the selected (pilot) watershed area.
- iv) To conduct case study of the selected watershed area for the landslide susceptibility mapping.

1.2. Scope of work

- i) Collection and review of policy and strategy of government on landslide risk management, Institutional set up: government, Non-governments, projects/programs.
- ii) Collection of historical data and listing of landslides in Nepal (Maps).
- iii) Collection and review of publications: International publication, National publication, Reports, and others.
- iv) Case study of selected watershed to formulate and test the methodology of landslide risk sensitive land use planning, including the preparation of the landslide hazards inventory.
- v) Study on types and risk assessment considering key landslide affecting factors and vulnerability factors such as proximity to settlements, infrastructure etc.
- (v) Recommendations for further research activities based on the gaps and problems identified.

2. LITERATURE REVIEW

Various studies on landslides has been done in Nepal since the past few decades. The information about the landslide study has been done by various organization as well as thesis and researches by the students of Tribhuvan University. Also, the articles on various newspapers, published and unpublished researches have been reviewed during the literature review.

2.1. Past Study of Landslide Disaster in Nepal.

Various studies on the landslide history of Nepal had been done in past years. Among them, few research papers had been reviewed during this study. There should be a systematic landslide studies and hazard mapping in the country to focus on the most vulnerable areas of Nepal (Upreti and Dhital, 1996). The detail study of landslide of 9,000m³ at head valley of 39° which occurred on Matatirtha village on 23rd July, 2002 after daily rainfall of 300mm, was done by Paudel et al., 2003 which stated that to minimize sudden disaster, warning system development of standards such as promotion of education level to people and preparation of hazard mapping are highly needed in Nepal. The database of occurrence of landslides in Nepal is in upward trend in Nepal (Petley et al., 2007). Analysis of trends suggested that the occurrence of landslide fatality is the result from the rural road building programs which has caused physical and natural changes (Petley et al., 2007). Different types of hazards are frequently taking place in Nepal since 1971-2016 where altogether 26,665 events with 43,865 human deaths have been recorded (Shrestha B.R, 2019). The trend of disaster events was gradually increasing from the 1971 to 2000 but after 2000 it went rapid increase until 2016 where 9,092 died by landslide and flood which had indicated that province no 3 and 1 have the more vulnerable in terms of disaster occurrences and human death than province 4,5,6 and 7 (Shrestha B.R, 2019). The main critical factors that increases landslide frequencies in Asia are road and rail construction, hill-side construction, water impoundment, agriculture and livestock rearing, logging and surface mining (Forbes and Broadhead, 2019). Forests and trees plays a vital role in providing a physical barrier to the movement of landslide material, as well as trapping material and gradually releases it with reduced impact (Forbes and Broadhead, 2019).

2.2. Methods for Landslide Susceptibility Mapping.

There were different methods and methodologies used for the study of landslide susceptibility mapping. Some of the researches with their findings are:

- i) (Lee and Pradhan, 2007), developed landslide hazard mapping at Selangor, Malaysia using the frequency ratio and logistic regression models in which the validation results showed that the frequency ratio model had better predication accuracy of 2.7% (93.04–90.34%), which was better than the logistic regression model. The factors chosen that influence landslide occurrence were: slope, aspect, curvature, and distance from drainage, lithology, and distance from lineaments, land cover, vegetation index, and precipitation distribution.
- ii) Pradhan et al. 2012 delineated the landslide susceptibility prone areas in the Kulekhani watershed area of Makwanpur district. During the study, the potential landslides were studied with application of GIS based statistical evaluation by Frequency Ratio Method, Statistical Index Method, Landslide Susceptibility Analysis and Certainty Factor. The major causative factors related to slope instability used for study were Slope, Aspect, Relief, Internal Relief, River Distance, Landuse and Geology to determine their relationship with the existing landslide distribution of study area.
- iii. Javad et al., 2013, performed spatial landslide prediction using the frequency ratio method in which the study area do not have any landslide inventory and landslide predicted maps. The landslide inventory was produced based on field research (GPS) and satellite image (Geoeye and Ikonos). Finally, the results of the susceptibility map was validated with the Receiver Operating Characteristics (ROC) curve. Result of validation represented more than 80% of prediction of the landslide occurrence was suitable compared to past landslide occurrence.
- iv) Rasyid et.al. 2016 prepared a landslide susceptibility map (LSM) for Lompobattang Mountain area in Indonesia. The LSM was prepared by Frequency Ratio (FR) and Logistic Regression (LR) statistical methods. Lithology, distance from the road, distance from the river, distance from the fault, land use, curvature, aspect, and slope degree were used as conditioning parameters during the study. This research had shown the performance of both Frequency Ratio (FR) and Logistic Regression (LR) models. Two stages of validation were carried out in this study, first, performances of each landslide model were tested using AUC curve for success and predictive rate and second, ratio of landslides falling on high to very high class of susceptibility was obtained, which indicates the level of accuracy of the model.
- v) Jazouli al.2019 conducted research at high basin of OumErRbia River of Morocco prone to landslide problems which includes preparation of landslide inventory maps for establishment of landslide susceptibility map using GIS-based spatial multi criteria approach. The eight landslide-

related factors (land cover, lithology, distance to road, distance to fault, distance to drainage network, elevation, aspect and slope gradient) were selected for the study. Weight for each factor was assigned using Analytic Hierarchy Process (AHP) depending on its influence on the landslide occurrence. Afterwards, the landslide susceptibility map was derived using weighted overlay method and categorized into five susceptible classes namely, very low (VL), low (L), moderate (M), high (H) and very high (VH). Thus, prepared landslide susceptibility map of the OumErRbia high basin later provided the valuable information about present and future landslides. Such map was helpful for planners and decision makers for land-use planning and slope management.

vi) Solari et al., 2020 did the literature review of landslides recurrently having impact on the Italian territory and confirmed that InSAR was a consolidated tool for many landslide-related applications. This research had reviewed a variety of InSAR-related applications for landslide studies in Italy. More than 250 papers were analyzed in which the first application dates back to 1999. The average production of InSAR-related papers for landslide studies was around 12 per year, with a peak of 37 papers in 2015. Almost 70% of the papers were written by authors in academia. InSAR was used (i) for landslide back analysis (3% of the papers); (ii) for landslide characterization (40% of the papers); (iii) as input for landslide models (7% of the papers); (iv) to update landslide inventories (15% of the papers); (v) for landslide mapping (32% of the papers), and (vi) for monitoring (3% of the papers). Sixty-eight percent of the authors validated the satellite results with ground information or other remote sensing data.

3. LANDUSE CATEGORIZATION IN NEPAL

The land classification is based on the composition and use of the land. This classification has not clearly pinpointed Guthi land, which is religious land in the name of temples or shrines, from the revenue of which the religious ceremonies or festivals associated with the temples or shrines are celebrated and the repairs and maintenance of the temples or shrines are carried out. Agricultural land occupies 28.8 per cent (arable land 15.1 per cent, permanent crops 1.2 per cent and pastures and rangelands 12.5 per cent), forests 25.4 per cent and others 45.8 per cent in Nepal. But not all agricultural land is under cultivation; only about 20 per cent is used for agricultural purposes (<http://therisingnepal.org.np/news/34254>). According to the Land Use Act, 2019 that has come into force in Nepal, land has been classified into 10 categories:

- i) Agricultural land
- ii) Residential land

- iii) Commercial land
- iv) Industrial land
- v) Mining and mineral
- vi) Forest
- vii) River, stream, pond and wetland
- viii) Public use
- ix) Cultural and archaeological and
- x) Others

Some of the land use classes on different studies in Nepal is shown in Table 1 and the top level. land categories prescribed in the Good Practice Guidance of IPCC is shown in Table 2.

Table 1: Land cover classes on different studies in Nepal (Source: MoFE, 2019).

PROJECT	ORGANISATION	LAND COVER CLASSES
First NFI 1960s	FORESC	[7 Classes]: Forest, Cropland, Grassland, Urban, Water, Badly Eroded Barren
LRMP 1970s/80s	DoS	[13 Classes] Forest, Shrub, Grassland, Cultivated lands, Non-cultivated lands, Abandoned, Settlement, Rock, Ice, Water bodies, Others
WECS 1988	WECS	[6 Classes] Forest, Shrub land, Grassland, Cultivated land, NCI, Other land
MPFS 1989	MoFSC	[6 Classes]: Forest, Shrub land, Grassland, Cultivated land, NCI, Other land
Second NFI 1989-1992	DFRS	[3 Classes]; Forest, Shrub land, Non-forest
Land Cover Mapping 2010	ICIMOD	[7 Classes]; Forest, Shrubs, Grass, Agriculture, Bare Areas, Snow, Built-up
Forest Resources Assessment 2010-2014	DFRS/FRA	[3 Classes]; Forest, Other Woodland Land, Other Land
LandUse Project/Topographic Mapping	DoS	[7 Classes]; Agriculture, Built up Area, Forest, Riverine and Lake Area, Shrubs and Grassland, Snow and Glacier, Others

Land Use Policy, 2015	MoLRM	[11 Classes]; Agriculture, Residential, Commercial Industrial, Mines, Cultural, Water body, Forest, Public Use Zone, Construction material extraction, Other
-----------------------	-------	--

Table 2: Top level land categories prescribed in the Good Practice Guidance of IPCC (Source: MoFE, 2019)

S. No	Land Categories	Description
1.	Forest Land	This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and also by ecosystems type as specified in the IPCC Guidelines. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.
2.	Cropland	This category includes arable and tillage land and agro-forestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.
3.	Grassland	This category includes rangelands and pasture land that is not considered as occupied. It also includes systems with vegetation that fall below the thresholds used in the forest land a category and are not expected to exceed, without human intervention, the threshold used in the forest land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastoral systems, subdivided into managed and unmanaged consistent with national definitions.
4.	Wetlands	The category includes land that is covered or saturated by water for all or part of the year (example: peat land) and that doesn't fall into the forest land, cropland, grassland or settlements categories. The category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub- divisions.
5.	Settlements	This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already include under other categories. This should be consistent with the selection of national definitions.
6.	Other Land	This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

3.1. Water Induced Disaster Management Policy 2072

The government of Nepal has established Water Induced Disaster Management Policy, 2072 since Fiscal Year 2015/16 through Department of Water Induced Disaster Management which covers the river disaster management and landslide disaster management in Nepal. According to this policy, classification of landslide, its description based on area is done and is illustrated in Figure 2 and Table 3. Also, the landslide hazard zone and its land use pattern is described in Table 4. Similarly, land use pattern based on slope degree is tabulated in Table 5.

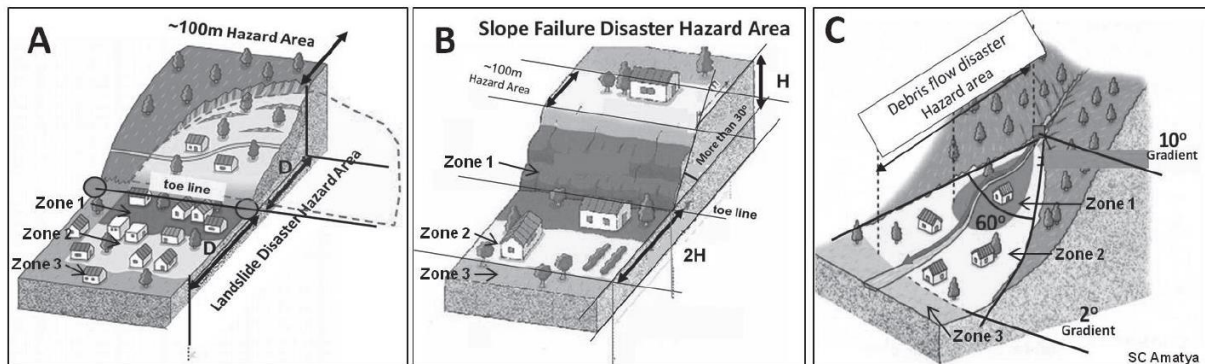


Figure 2: Classification of landslide risk zone. (Source: Water Induced Disaster Management Policy 2072)

Table 3: Classification of landslide types with its area description.

S. No	Types of landslide	Description of landslide area
1.	Landslide	The distance (2D) from the base of landslide to the downstream area is prone to landslide hazard which is equal to the horizontal distance (D) of slow moving landslide from toe point to crown. Also, the E-W and North direction of landslide of about 100 meters is considered as high risk zone (Figure 2 A).
2.	Slope Failure	The horizontal distance (2H) from the base of landslide to the downstream area is prone to landslide hazard which is equal to the vertical height (H) of slope failure hills from toe point to crown of landslide. Also, the E-W and North direction of landslide of about 100 meters is considered as high risk zone (Figure 2 B).
3.	Debris Flow	Regarding the debris flow criteria, the debris flow occurs from 10° to 2° gradient and later flows in the form of fan like structure. So, the area from 10° to 2° debris flow to 60° cone angle of fan is considered as high risk zone (Figure 2 C).

Table 4: Classification of landslide hazard zone and its land use.

S. No	Classification of landslide hazard zone areas	Use of land	Remarks
1.	High Hazard Zone (Zone 1)	New settlement shouldn't be made.	Based on prior notice, high caution should be made.
2.	Medium Hazard Zone (Zone 2)	New settlement shouldn't be made.	Based on prior notice, caution should be made.
3.	Low Hazard Zone (Zone 3)	Based on caution, new settlements and other economic activities like horticulture and animal husbandry can be done.	Based on prior notice, caution shouldn't be made.

Table 5: Landuse pattern based on slope degree.

S. No	Classification of slope	Landuse pattern
1	Slope with 30 degree or less	Can be used for agriculture, farming and human settlements.
2	Slope with 30-45 degree	Can be used for agriculture and animal husbandry
3	Slope with greater than 45 degree	Can be applicable only for forest.
4	Siwalik area (Chure Region)	Can be applicable for economic activities and human settlements.

4. TECHNICAL BACKGROUND ON TYPES OF LANDSLIDES AND LANDSLIDE TRIGGERING EVENTS

A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. Landslides are a type of "mass wasting," which denotes any down-slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses five modes of slope movement: falls, topples, slides, spreads, and flows. These are further subdivided by the type of geologic material

(bedrock, debris, or earth). Debris flows (commonly referred to as mudflows or mudslides) and rock falls are examples of common landslide types. Landslides can be initiated in slopes already on the verge of movement by rainfall, snowmelt, changes in water level, stream erosion, and changes in ground water, earthquakes, volcanic activity, disturbance by human activities, or any combination of these factors. The geomorphological features of landslide is shown in figure 3.

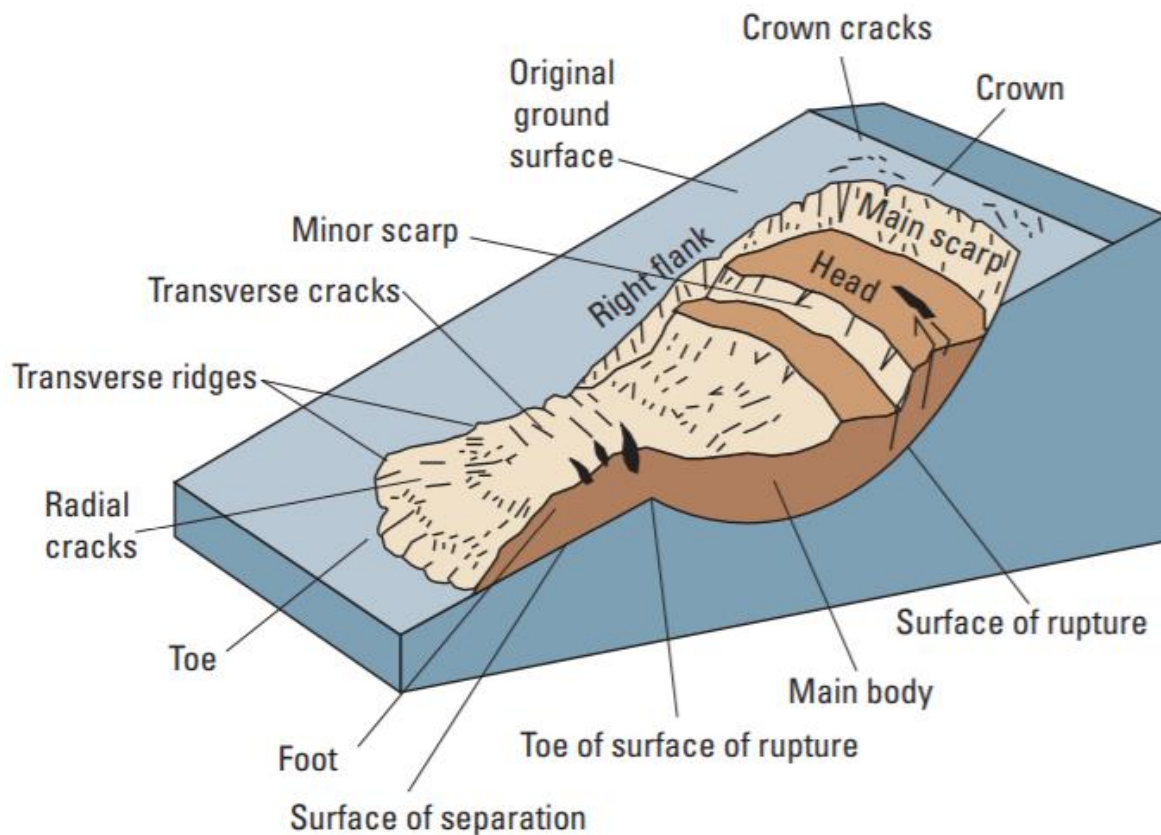


Figure 3: An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a landslide. (Source: USGS, 2004)

4.1. Types of landslides

Landslides are very diverse phenomena in shape and size, movement speed and other characteristics. According to geological structure in which landslides occur, we can distinguish instability in soil and rock mass. Types of landslide are shown in Figure 4.

In soil, following types of instabilities are distinguished: ([Landslide Hazards \(usgs.gov\)](https://www.usgs.gov/landslide-hazards)):

i) Rotational landslide

- ii) Translational landslide
- iii) Debris flow
- iv) Debris avalanche
- v) Earthflow
- vi) Creep
- vii) Lateral spread

Whereas in rock mass, following rock slope failure triggering mechanisms are distinguished:

- i) Block slide
- ii) Rock fall
- iii) Topple

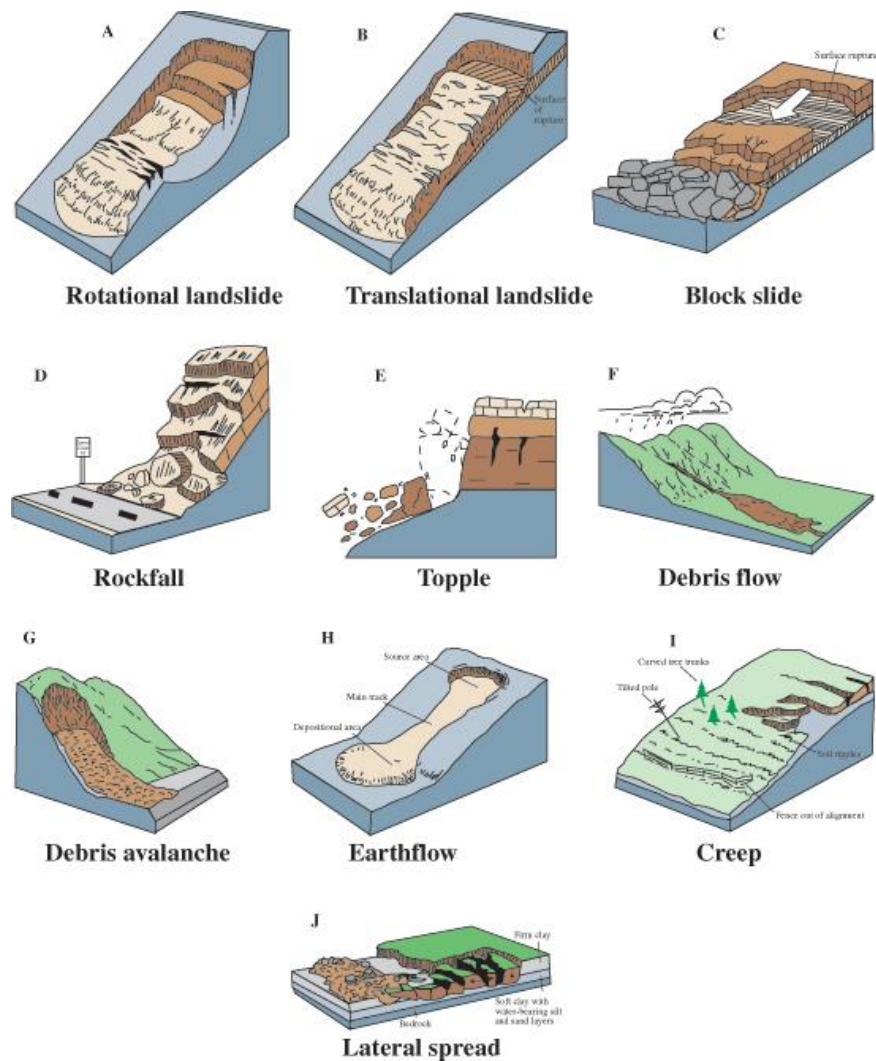


Figure 4: Major types of landslide movement. (Source: USGS, 2004)

4.2. Classification of Mass Movement

There are two types of classifications for the mass movement, i.e. general classification and preventive classification. For the purpose of prevention, internationally adopted scientific classification (Table 6) given by Varnes 1977.i.e. Varne's classification is common but from prevention point of view, the classification used in Japan in the field of disaster prevention is very useful in landslide prevention (Table 7). Outlines of both the classification are described below:

A. Varne's Classification

Table 6: Varne's Classification of Mass Movement.

S. No	Types of movements	Type of material (Before movement)		
		Bed rock	Soil	
			Debris (coarse)	Earth (fine)
1.	Falls	Rock fall	Debris fall	Earth fall
2.	Topples	Rock topple	Debris topple	Earth topple
3.	Slides Rotational Traslational Rock block slides	Rock slump Rock slide	Debris slump Debris slide	Erath slump Earth block slide
4.	Lateral Spread			Earth lateral spread
5.	Flows		Debris flow Debris avalanche	Earth flow Mud flow Sand flow
6.	Complex movement		Rock fall and Debris flow Slump and Topple Rock slide and Rock fall etc.	

B. Preventive Classification

This classification is based on type, speed, dimension of movement and spatial composition. This classification has been established in order to clarify the mechanism of each phenomenon and for the corresponding prevention works. (Figure 5, Table 7).

Table 7: Mechanism of landslide Phenomenon.

Mass Movements		
Slope Failure	Landslide	Debris Flow
Movement of weathered surface soil layer/rock of steep slope. (Small Dimension and rapid movement).	Movement of large sediment block which has clear slide surface. Large dimension, slow and continuous movement mainly affected by ground water.	Movement of deposited or eroded sediment along the stream. Rapid movement including large volume of water through the stream.

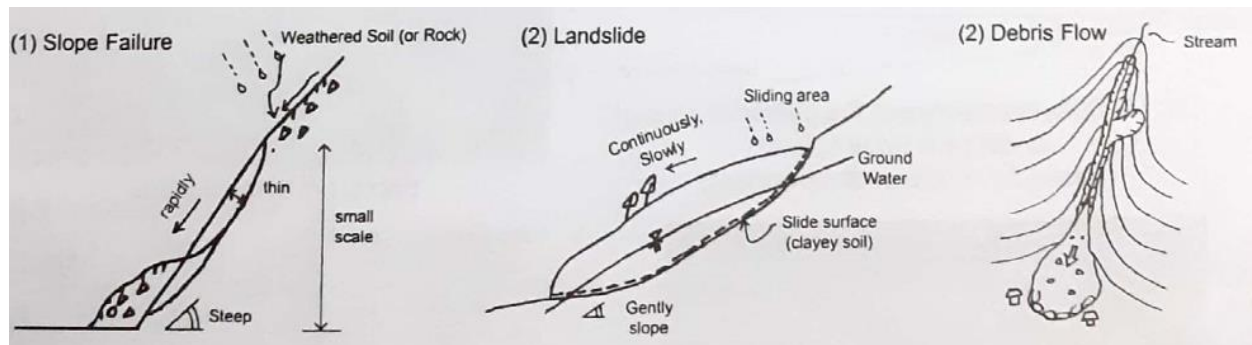


Figure 5: Preventive classification of Mass Movement (Source: Technical Guide on Landslide Mitigation Work, 1999)

4.3. Causes of Landslide ([Landslide Hazards \(usgs.gov\)](https://www.usgs.gov/))

The different causes of landslides are:

1. Geological and Morphological Causes:

i) Geological Causes

- Weak or sensitive materials
- Weathered materials
- Sheared, jointed, or fissured materials
- Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth)
- Contrast in permeability and/or stiffness of materials

ii. Morphological causes

- Tectonic or volcanic uplift
- Glacial rebound
- Fluvial, wave, or glacial erosion of slope toe or lateral margins

- d. Subterranean erosion (solution, piping)
- e. Deposition loading slope or its crest
- f. Vegetation removal (by fire, drought)
- g. Thawing
- h. Freeze-and-thaw weathering
- i. Shrink-and-swell weathering

2. *Human Causes:*

- a. Excavation of slope or its toe
- b. Loading of slope or its crest
- c. Drawdown (of reservoirs)
- d. Deforestation
- e. Irrigation
- f. Mining
- g. Artificial vibration
- h. Water leakage from utilities

Landslide are caused mainly due to two factors: ([Landslide Hazards \(usgs.gov\)](https://www.usgs.gov/land-slide-hazards/))

1. Dynamic Factor

- Slope
- Rainfall Intensity
- Land Use (Mankind Activity)

2. Static Factor

- Soil Type and Geology structure
- Depth of soil column
- Soil permeability
- Soil textures

5. METHODOLOGY

Following methods and methodologies have been adopted to meet the objective of the study:

5.1. Review of Policy, Acts and Institutions

Various reports, documents related to the policies, acts and laws related to the disaster risk reduction from various website and organizations were collected and revised.

5.2. History of landslide evidences in Nepal (2010-2019).

To understand the past landslide history of Nepal, literature review of various articles, reports and documents was done. During the study, the district wise data of landslide was extracted from the website of Ministry of Home Affairs (MoHA). The landslide data of past ten years (2010-2019) were tabulated. The data were further analyzed based on the number of landslide events occurred, number of death occurred, missing number of people, affected family and its estimated loss in each district within year 2010-2019.

5.3. Situation of landslide in Monsoon 2020.

The study of landslide events of Monsoon 2020 was extracted and tabulated from the data source of MoHA and Bipad.gov.np, The data were further analyzed based on the number of landslide events occurred, number of death occurred, missing number of people, affected family and its estimated loss in each district of year 2020 from March –August.

5.4. Landslide inventory mapping on the selected (pilot) watershed.

Landslide inventory map of the selected watershed area of Sindhupalchowk district was prepared for the three years: 2014, 2015 and 2016. Landslide inventory map of year 2014 and 2016 was made from the Google Earth while the Landslide inventory map of 2015 was made from the secondary data from the Japan-Nepal Urgent Collaborative Projects regarding the April 2015 Nepal Earthquake within the J-RAPID Program. These secondary data were the data extracted from remote sensing.

5.5 Case study of selected watershed area for landslide susceptibility mapping.

A landslide susceptibility map identifies an area which are subject to landslides and is measured from low to high. The landslide susceptibility map indicates the area where the landslides had occurred and what causes them to occur. For example: slope, soil type and the impact of the flow of water in an area, elevation of the area are known from the map. Many of the areas with the highest potential for landslide activity are found in steep mountain ranges, including the Himalayas, Andes, and Alps.

Following two methods were conducted during the study of landslide susceptibility mapping.

i) Calculation of the causative factors of the landslide and its map preparations

In landslide studies, causative factors are usually selected based on the analysis of the landslide types and the characteristics of the study area. Commonly used causative factors are elevation, slope angle, slope aspect, plan curvature, and distance to drainage networks (Dou, Jie et al., 2015). Landslide data were used as dependent variable of eight causal factors including slope, curvature, aspect, distance from fault, distance from road, distance from river, lithology and land use pattern which were selected as independent variables for the landslide susceptibility mapping (Budimir et al. 2015). All of these data are commonly used in landslide susceptibility mapping. Budimir et al. (2015) mentioned that in a total of 37 parameters usually used slope, aspect, and lithology, are significantly used particularly on studies related to rainfall-induced landslides. In fact, the relevance of the spatial data combination used in the prediction became an important issue in landslide susceptibility mapping (Dewitte et al. 2010).

Hence, based on literature review, there are many causative factors for the landslide study and landslide susceptibility map preparation. Among which Slope, Aspect, Elevation, Curvature, Distance to river, Distance to road, Geology and Landuse were taken during our study. The respective maps of all those causative factors were prepared in GIS for the further study and analysis.

ii) Application of the frequency ratio method for the preparation of landslide susceptibility map.

After the preparation of the maps of all the causative factors, the raster calculation of all the database was done using the frequency ratio method for the preparation of the landslide susceptibility map.

Landslide Susceptibility Mapping

Landslide susceptibility maps are one of the most significant geology-based maps (Yalçın 2007) which provides information about sensitive areas for landslides in the future and the tendency of an area towards possible landslides (Dağdelenler 2013). For landslide evaluation tasks, different types of maps that contain diverse information are prepared by conducting field and laboratory studies for the geological and the geotechnical purposes. These maps are used for various tasks such as choosing settlement areas, infrastructure works, the construction facilities of other engineering structures, etc. (Kılıçoğlu et.al, 2017). Hence, landslide susceptibility maps plays valuable input during the preliminary landuse planning and for hazard mitigation purposes.

The basic difference in between the various terminologies used in landslide study are:

Landslide Inventory Maps	Landslide Susceptibility Maps	Landslide Hazard Maps	Landslide Risk Maps
➤ It shows locations of landslide with its dimensions and geographical extent of each landslide. ➤ It can be used as a clue to the location of future land sliding from the distribution of past movement, so maps that show the location and size of landslides are helpful in predicting the hazard for an area.	➤ It describes the relative likelihood of future land sliding based solely on the intrinsic properties (slope, elevation, aspect, curvature, geology) of a locale or site. ➤ It is also known as “landslide potential map”.	➤ It indicates the possibility of landslides occurring throughout a given area. ➤ An ideal landslide hazard map shows not only the chances that a landslide might form at a particular place, but also the chance that it might travel downslope a given distance.	➤ It shows landslide potential along with the expected losses to life and properties. ➤ Risk maps combine the probability information from a landslide hazard map with an analysis of all possible consequences (property damage, causative ties, and loss of services).

Frequency Ratio

The relationship between the landslide occurrence area and the landslide causative factors can be done from the relationship between areas where landslides had not occurred and the landslide causative factors. In order to identify the closeness of their relationship, a simple statistical technique is used as a frequency ratio (FR) approach (Rasyid et.al. 2016). FR model became valuable in ranking the preferred causative factors based upon their ability to control a landslide incident (Kannan et al. 2013), because FR can clearly describe the difference of each score between landslides causal factors in class and landslide occurrence. The number of landslide occurred pixels on the area must be combined between causal factors (Rasyid et.al. 2016) for the landslide study. Then the ratio for each factors are calculated by dividing the landslide occurrence ratio with the ratio of each class in causal factors (Lee and Thalib 2005). A ratio value in each class shows the level of relationship, the given factors attribute between landslide occurrences and when the ratio more than one means a stronger correlation then a lower ratio than one suggest a lower correlation (Lee and Pradhan 2006).

The frequency ratio value can be calculated in the following manner:

$$FR = \frac{(ij) / \sum PixL}{P(ij) / \sum Pix}$$

Where, (Where, PixcL(ij) number of pixel with landslide within class i of j parameter,

Pixcl (ij) Number of pixel in class i of j parameter,

$\sum PixL$ total pixel of j parameter, and $\sum Pix$ total pixel of the area). (Abdul et.al. 2016).

Hence, Frequency ratio method was chosen for this study too since it was widely used in the literature, which consist of understandable and simple statistical model and provide accurate result and also can be easily applied. The final landslide susceptibility map was prepared by summing the weight parameter values from frequency ratio model and for the analysis of FR values, Microsoft Excel was used.

6. ANALYSIS AND OUTPUT

6.1 Review of Policy, Acts and Institutions

The Government of Nepal has developed various legal and institutional arrangements to plan and manage the Disaster Risk Reduction and Management activities. In this context, Natural Calamity (relief) Act 1982; Local Self Governance Act 1998; Building Act 1998; National Building Code 2004; National Strategy for Disaster Risk Management 2009, Climate Change Policy 2011, Land Use Policy 2012, Water Induced Disaster Management Policy 2015; National Reconstruction and Rehabilitation Policy 2015; National Disaster Response Framework 2013, Basic Guideline related to Settlement Development, Urban Planning and Building Construction 2016; National Urban Development Strategy 2016 are important legal and policy framework.

Similarly, Constitution of Nepal 2015, Local Government Operation Act 2017 and Disaster Risk Reduction and Management Act 2017, are the latest major legal arrangements. The National Council, Executive Committee, National Disaster Risk Reduction and Management Authority and Disaster Management Committees at Province, District and Local levels are new institutional arrangements as per the Disaster Risk Reduction and Management Act 2017.

6.1.1 National Policy

I. Act No. 20 of the Year 2039 B.S. (1982)

This Act is called the "Natural Calamity (Relief) Act. 2039 B.S. (1982)". In this act, "Disaster area" means the area declared as Disaster area pursuant to Section 3. "Natural Calamity Relief

Work" means any relief work to be carried out in the area affected or likely to be affected by the natural calamity in order to remove the grief and inconvenience caused to the people to rehabilitate the victims of the Natural Calamity and to protect the public property and life and property of the people in general to control and prevent Natural Calamity and to make its advance preparation.

Natural Calamity Relief Act 1982 has given the responsibility of disaster management to the Government of Nepal which is the basis for formation of SAR team in the country. Establishment and mobilization of SAR Team has been further backed up by the following existing legal provisions:

- National Strategy for Disaster Risk Management 2066
- District Disaster Preparedness and Response Plans
- Five Flagship Program
- National Disaster Response Framework 2070
- Guiding Notes on Disaster Preparedness and Response Planning 2067
- Disaster Rescue and Relief Standard 2064
- Nepal Police Act 2052 and bylaws
- Local Administration Act 2028
- Armed Police Force Act 2058 and bylaws
- Military Act 2063

To make the disaster relief and rescue activity more effective, there was a need for amendment and upgrading of existing Disaster Response Act 2039, Military Act 2063, Nepal Police Act 2052 and Armed Police Force Act 2058 to make the disaster response activity more professional.

II. National Policy for Disaster Risk Reduction 2018

The main objective of this policy was to substantially reduce the natural and non-natural disaster losses in lives and properties of persons, health, means of livelihood and production, physical and social infrastructures, cultural and environmental assets. The other objectives of the policy are :

1. To increase understanding on disaster risk and ensure the access of information related to the disaster risk at all levels.
2. To strengthen disaster risk governance for disaster risk reduction and management.
3. To mainstream disaster risk reduction in all development processes by integrating it with climate change adaptation activities.

4. To enhance disaster resilience by increasing public and private investment in disaster risk reduction.
5. To make disaster preparedness and response effective by improving disaster information management system and developing and expanding multi-hazard early warning system.
6. To ensure “Build Back Better” approach for post-disaster recovery, rehabilitation and reconstruction.

According to this policy, disaster risk reduction national policy is based on the following concept:

1. As per the Constitution of Nepal, to adopt the principle of coordination and cooperation among local, provincial and federal government in the disaster risk reduction, prevention and management.
2. As per the disaster risk governance principle, to pursue the involvement and partnership of all stakeholders of the society, and gender and social inclusion by embracing the principle of participation, accountability and transparency.
3. To pursue the concept of risk sensitive development.
4. To pursue the concept of multi-hazards disaster risk management.
5. To pursue the use of science and technology based on local characteristics and optimum utilization of local means, resources, knowledge and skills.

III. National Strategic Action Plan on Search and Rescue 2013

Trained personnel from the Security forces namely Nepal Army, Nepal Police and Armed Police Force are working as search and rescue team in Nepal since Nepal does not have specialized unified SAR force till the date. The government of Nepal, Ministry of Home Affairs (MoHA), supports from national and international organizations, has developed a minimum level of Search and Rescue (SAR) capacity within the security forces.

Based on the National Strategy for Disaster Risk Reduction (NSDRM)-2066, priority-two of the Nepal Risk Reduction Consortium (NRRC), suggestions received from International Search and Rescue Advisory Group (INSARAG) in 2011, National Disaster Response Framework (NDRF) and Disaster Preparedness and Response Planning documents, the government of Nepal has prioritized the formation of integrated search and rescue capacity in the country. The development of Strategic Action Plan on Search and Rescue Capacity is based on the USAR Response

Framework of the INSARAG Guidelines Chapter G on “Building an Urban Search and Rescue Capacity” and the national scenarios.

All structured SAR teams, irrespective of their capacity and operational involvement, should comprise the following components:

- a) Management
- b) Logistics
- c) Search
- d) Rescue
- e) Medical
- f) Fire services

The purpose of National Strategic Action Plan on Search and Rescue Capacity was to elucidate the exact scope wherein search and rescue capacity is organized and guiding its development and operational function. The Action Plan intends to provide a single framework and enable environment for the Government and other stakeholders to address the challenges inherent in the field of search and rescue after disaster incidents. A strategic vision was to develop a professionally and technically sound Urban Search and Rescue capacity in Nepal as per the INSARAG Guidelines and National Disaster Response Framework (NDRF).

IV. National Strategy for Disaster Risk Management in Nepal (NSDRMN)

The National Strategy for Disaster Risk Management in Nepal (NSDRMN) endeavors to facilitate the required change in order to achieve the goal of disaster resilient Nepal by providing guidance for improving the policy and legal environment by prioritizing the strategic interventions. The strategy as well as the elaborate process of its development addresses Nepal’s long-felt need to come up with a long term policy document and build on the enormous amount of disaster reduction planning and implementation works that have been carried out in the country in the past, especially after the commencement of the International Decade for Natural Disaster Reduction (1990-1999). The main content of this section is the statement on Priority Strategic Actions which includes following policies:

1. To ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation.
2. Identify, assess and monitor disaster risks and enhance early warning.
3. Better knowledge management for building a culture of safety.

4. Reducing the underlying risk factors.
5. Enhance preparedness for effective response

The sector-specific strategies are focused on addressing the identified gaps in following sectors:

- Agriculture and Food security
- Health
- Education
- Shelter, Infrastructure and Physical Planning
- Livelihood Protection
- Water and Sanitation
- Information, Communication, Coordination and Logistics
- Search and Rescue, and Damage and Needs Assessment

6.1.2 International and National DRR Initiatives

There was always need and importance of international cooperation, coordination and collaboration in the field of disaster risk reduction and management activities in Nepal. So, Nepal has also actively participated and contributed in various international DRR activities. Nepal is one of the active members of international DRR community and has adopted the major decisions.

Some of the national and international DRR instruments as well as major legislative and institutional initiatives taken by Nepal in the recent, past and present to reduce the disaster vulnerability are discussed briefly below:

I. International Initiatives

1. Yokohama Strategy, Japan (1994)

The first world conference on disaster risk reduction was held in Yokohama, Japan in 1994 where Nepal participated and presented a national action plan on disaster management. Government of Nepal had prepared "National Action Plan on Disaster Management in 1996" incorporating all disaster management cycle and the Yokohama Strategy.

2. Hyogo Framework of Action (HFA) (2005-2015)

The second world conference on disaster risk reduction was held in Kobe, Hyogo, Japan in 2005 where Nepal participated and endorsed the goals and 5 priorities for action between 2005 and 2015. Integration of DRR into sustainable development, develop and strengthen institutions to

build resilience to hazards and emergency preparedness, response and recovery programs were the major goals of HFA.

3 Sendai Framework for Disaster Risk Reduction (2015-2030)

The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 was adopted in Sendai, Japan, on March 18, 2015. The SFDRR's four priorities for action were targeted to achieve by 2030. Afterwards, the government of Nepal prepared Disaster Risk Reduction National Strategic Action Plan (NSAP) (2018-2030) in which DRR activities were prioritized corresponding to the four priorities of the SFDRR.

i) The Sustainable Development Goals

The 17 Sustainable Development Goals (SDGs) were adopted by the world leaders in September 2015 at an historic UN Summit and it came into force on 1 January 2016. Afterwards, government of Nepal prepared and implemented a fifteen-year Sustainable Development Agenda of Nepal (2015-2030), in which DRM has been prioritized.

ii) The Global Platform 2017

The Fifth Session of the Global Platform for Disaster Risk Reduction (GP2017) took place from 24 to 26 May 2017 in Cancun, Mexico. It was the first one to take place after the adoption of the Sendai Framework for Disaster Risk Reduction (2015-2030), as well as the adoption of the 2030 Agenda for Sustainable Development Goals and the Paris Climate Change agreement.

iii) The Paris Agreement on Climate Change

The 2015 United Nations Climate Change Conference, COP 21 or CMP 11 was held in Paris, France, from 30 November to 12 December 2015. On 12 December 2015, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future.

iv) Addis Ababa Action Agenda (AAAA)

Addis Ababa Action Agenda of the Third International Conference on Financing for Development (Addis Ababa Action Agenda) took place in Addis Ababa, Ethiopia from 13–16 July 2015. The Heads of State and Government and High Level Representatives confirmed their strong political commitment to address the challenge of financing and creating an enabling environment at all levels for sustainable development in the spirit of global partnership and solidarity.

v) The Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) 2016

The 2016 Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) was held in New Delhi, India from 3-5 November 2016. It endorsed the Asian Regional Plan for the implementation of the SFDRR for 15 years (2016 – 2030) with specific targets and be achieved by 2016, 2018, 2020, 2022 and 2030. The regional plan will be monitored in every two years period at regional level.

vi) The Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) 2018

Governments and other stakeholders from the world's most disaster-prone region meet in Mongolia in July 2018 to discuss acceleration of efforts vital for the sustainable future of the region including how to prevent disasters and tackle climate change while reviewing progress in reducing disaster losses. The Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) is being organized in every two years' time. The theme of the AMCDRR 2018 'Preventing Disaster Risk: Protecting Sustainable Development' reflects the spirit of the Sendai Framework. This theme is associated with the theme of the 2018 High-level Political Forum on Sustainable Development that focuses on 'Transformation towards sustainable and resilient societies'.

The basic differences between Hyogo Framework and Sendai Framework are:

1. The Sendai Framework (2015-30) is the successor instrument to the Hyogo Framework for Action (2005-15).
2. The Hyogo framework was the first plan which explained, described and detailed the work that is required from all different sectors and actors to reduce disaster losses.
3. Sendai framework recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government, the private sector and other stakeholders.
4. The Hyogo Framework sets five priorities for action, the first two being: governance and risk identification.
5. The Sendai Framework sets four priorities for action to be implemented at national & local levels and at global & regional levels-
 - i. Understanding disaster risk.
 - ii. Strengthening disaster risk governance to manage disaster risk.
 - iii. Investing in disaster risk reduction for resilience.
 - iv. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

II. National Initiatives

Nepal has achieved notable progress in Disaster and Climate Risk Management (DRM/CRM) during the last few decades. A number of legal, institutional and policy frameworks are in place. The New Constitution of Nepal has made provisions of disaster management in different levels of governments. The formulation of policy and legislative procedures on disaster issues in Nepal dates back in early 1980s when Natural Calamity (Relief) Act, 1982 was enacted. Prior to 1982, rescue, relief as well as recovery works were carried out in an ad-hoc basis, primarily as a social work.

The Natural Calamity (Relief) Act, 1982 performed a mission to formalize disaster response as a responsibility of the government to provide relief to the victims of the disaster-events, and it designated authorities at the central, regional and district levels to coordinate the rescue and relief efforts of various response agencies. The Parliament of Nepal endorsed the Disaster Risk Reduction and Management (DRRM) Act, 2017 that formally replaced the Natural Calamity (Relief) Act 1982. This was more comprehensive which had addressed the complex dynamics of all phases of disaster management.

The major legal tools developed by the Nepal government are as following:

1. Disaster Management in Nepal's Constitution, 2015

The Constitution of Nepal has clearly stipulated that DRM is a shared responsibility at all levels of government. The Constitution states that the responsibility of disaster management falls under the jurisdiction of federal, provincial and local government. Among 22 tasks assigned to local level, DRM is one of them (Schedule 8). In the list of concurrent powers of federal, provincial and local level, DRM is kept as one of the subjects (Schedule 9) stating that DRM is a shared responsibility of every layer of governance system, but more should be at the lower level. Article 51 stipulates the policies to be pursued by the state. The sub article G relates to “policies relating to protection, promotion and use of natural resources,” mentions that the state shall formulate policies on development of sustainable and reliable irrigation by controlling water-induced disasters and expediting river management. Article 51(G) (9) of the Constitution states that the state shall pursue policies among several other issues, protection, promotion and use of natural resources.

Sub-article 51(G) (9) allows government to make policies related to “advance warning, preparedness, rescue, relief and rehabilitation in order to mitigate risks from natural disasters.”

The Constitution in Article 267 says, 'the Government of Nepal may also mobilize the Nepal Army in, among other things, the disaster management works, as provided for in the Federal law.' Article 273 of the Constitution gives the President several emergency powers. Article 273 (2) states, "if there arises a grave emergency in a State because of a natural calamity or epidemic, the concerned state government may request the Government of Nepal to declare a state of emergency in respect of the whole of the State or of any specified part thereof."

2. Disaster Risk Reduction and Management Act, 2017

Disaster Management Bill and Policy were drafted in 2017 after nationwide consultation. After long discussions and homework among the government and nongovernment DRR stakeholders from time to time, the Constituent Assembly Members and Parliament Members were informed and consulted about the need and importance of the DM Policy and Act. Disaster Risk Reduction and Management Act (DRRMA), 2017 was then endorsed by the Parliament.

This act has made the provision of a National Council for Disaster Risks Reduction and Management (NCDRRM) upon the chairmanship of the Prime Minister. The government is in the process of establishing a National Risks Reduction and Management Authority (NRRMA) under the Ministry of Home Affairs. The Authority shall work under direct oversight and control of the Executive Committee (EC). The EC shall be chaired by the Home Minister. The NRRMA will look after all phases of disaster management in close cooperation and coordination with all DRR stakeholders as and when necessary. Currently, the government is going to finalize the Disaster Risk Reduction and Management Regulations (DRRMR) to back up the Act. All these activities and output can be considered as exemplary steps taken by the government of Nepal to show its seriousness towards disaster risk reduction in Nepal.

3. Endorsement of Disaster Risk Reduction National Policy 2018 and Disaster Risk Reduction National Strategic Action Plan (2018-2030)

The first meeting of National Council for Disaster Risks Reduction and Management (NCDRRM) was held on 18 June 2018 upon the Chairmanship of the Prime Minister. The meeting endorsed the long awaited Disaster Risk Reduction National Policy 2018 and Disaster Risk Reduction National Strategic Action Plan (2018-2030). The National Strategic Action Plan is in line with the Sendai Framework for Disaster Risk Reduction.

4. Local Government Operation (LGO) Act, 2017

The Local Government Operation Act, 2017 outlines the roles and responsibilities of Urban and Rural Municipalities, District Councils/District Coordination Committees, and Provincial Coordination Councils. This Act entrusts the local level units with the responsibilities of formulating their own laws, by-laws, regulations; levying taxes; and raising funds, in addition to the judiciary responsibilities. This new Act replaces the Local Self Governance Act, 1999 that helped institutionalize the concept of local-self-governance under decentralization framework and empowered the local bodies for sustainable development.

5. National Strategy for Disaster Risk Management in Nepal (NSDRM) 2009

The National Strategy for Disaster Risk Management (NSDRM) 2009 was developed in line with HFA in consultation with the relevant stakeholders across all levels. The Hyogo Framework for Action 2005- 2015 (HFA) was made not only because it recommends what every country should do for disaster reduction, but also because Government of Nepal had taken part in developing this framework and had made commitments to implement it. Hence, streamlining the National Strategy in line with the HFA was regarded as the most important approach to be adopted. The strategy was based on the ground realities and identified needs of Nepal. It tried to capture the opportunities of Disaster Risk Management (DRM) in Nepal in line with the international understanding, scientific progress and regional initiatives. Now, NSDRM has been replaced by Disaster Risk Reduction National Strategic Action Plan (2018-2030).

6. National Building Code (NBC)

The government of Nepal formulated and implemented National Building Code (NBC) in 1993. The Building Act, Building Regulations and the Building Code outline the building construction legal obligations to be followed by the builders or owners through the local government. The Gorkha earthquake 2015 underlined further the importance of the code and is now being implemented throughout the country. The code is also under review and revision process incorporating the learning from the Gorkha earthquake.

7. National Disaster Response Framework (NDRF)

The National Disaster Response Framework (NDRF) has been prepared for the effective coordination and implementation of disaster preparedness and response activities by developing a National Disaster Response Plan that clarifies the role and responsibilities of the government and non-government agencies involved in disaster risk management in Nepal. The main purpose of

this framework is to develop a clear, concise and comprehensive national disaster response framework for Nepal that can guide a more effective and coordinated national response in case of a large scale disaster. The national disaster response plan includes actions to be taken before, during and after the disasters.

8. National Adaptation Programme of Action (NAPA)

The National Adaptation Programme of Action (NAPA) represents the country's notable effort to assess and prioritize immediate and urgent needs to address climate change risks through a broad consultative process. According to NAPA, the effects of climate change have been observed, while some parts of Nepal show increasing erratic and intense rains, and such climatic trends combined with fragile topography, deforestation and eroded soils are leading to landslides and flash flood hazards. It has also been projected that rainfall intensity will increase across many areas of Nepal due to climate change and, therefore, vulnerable communities will have to increase their adaptive capacity to cope with climatic hazards.

9. Framework for Local Adaptation Plan of Action (LAPA)

The Local Adaptation Plan for Action (LAPA) provides guidelines for the disbursement of at least 80 per cent of adaptation funds on the implementation at the local level. To support implementation, the Government of Nepal has developed a national framework for LAPA, which aims to make adaptation planning a bottom-up, inclusive, responsive and flexible processes that will identify the most climate vulnerable people and allow them to make informed decisions on priority adaptation actions. It provides an opportunity for undertaking developmental activities that are climate resilient with strong co-benefits for poverty reduction. The integration of local level Climate and Energy Plans with the LAPA could facilitate some triple wins and produce low carbon climate resilient development.

10. Local Disaster Risk Management Planning (LDRMP) Guidelines, 2011

Keeping in view the need to develop disaster risk management from the central to local level and mainstream it with development plan, policy and programmes at all levels, and also in order to ensure the notion of sustainable development, the "Local Disaster Risk Management Planning Guideline, 2011" has been approved and put into effect. The major goals of the guidelines are to make disaster management participatory, transparent, accountable, inclusive and responsible by optimally mobilizing local resources and capabilities, and by ascertaining the access and ownership of all affected communities and people.

11. Disaster Preparedness and Response Plan (DPRP)

The national workshop on DRR in 2010 recommended 21 points which was approved by the Central Natural Disaster Relief Committee (CNDRC) for an effective disaster preparedness initiative at district, regional and national levels. One of the recommendations was to create District Lead Support Agencies (DLSA) in 75 districts among the national and international agencies to support District Disaster Relief Committee for preparing District Disaster Preparedness and Response Plan. It resulted into very positive feedbacks from all the DRR actors. As a result, so far, almost all districts have the DPRP.

12. Dead Body Management Guidelines (DBMG)

The Government of Nepal has formulated and implemented Dead Body Management Guidelines with the objectives to be considerate of the dignity of the dead; be considerate towards the religion, culture and customs; be respectful of the bereaved; be realistic about logistical and human resource constraints; and ensure the identification of the dead bodies affected due to the occurrence of natural calamities.

13. Nepal Risk Reduction Consortium (NRRC)

In 2009, the NRRC2 was created to bring together lead actors from the government, major donors, UN agencies, the Red Cross, INGOs and NGOs to reduce Nepal's vulnerability to disasters through the 5 flagship areas (School and hospital safety; Emergency preparedness and response capacity; Flood management in the Koshi River basin; Integrated community-based risk reduction; and Policy/institutional support for disaster risk management) for sustainable disaster risk management. The 5 flagship areas were in line with the HFA 5 priority areas. For each area, the lead role was assigned to a government <http://un.org.np/coordinationmechanism/nrrc>. NRRC started in 2009. Nine characteristics have been defined to describe the essential components for resilient communities along with indicators for monitoring progress ministry while an international agency was designated as coordinator to support the concerned government lead.

14. National Emergency Operation Centre (NEOC)

The National Emergency Operations Centre (NEOC) started on the 17 December 2010 under the Ministry of Home Affairs. The objectives of the NEOC are to work as a coordination and communication point for disaster information across the country, including government agencies and other response and recovery stakeholders such as Nepal Red Cross Society, UN agencies, INGOS and NGOs. Likewise, Ministry of Health has established the Health Emergency Operation

Centre, which is well connected with the NEOC, MoHA. As part of MoHA's strategy to further develop Nepal's emergency preparedness and response capacity, it is planning to establish district emergency operation centers (DEOCs) in all 77 districts of Nepal in three phases.

15. National Platform for DRR (NDRRP)

National Platform for DRR in Nepal was established in 2009. National Platform for Disaster Risk Reduction is a national mechanism for coordination and policy guidance on disaster risk reduction that is multi-sectoral and inter-disciplinary in nature, which includes representatives from all stakeholders involved, such as government, international organizations, NGOs, academic institutions, private sector and the media. All NGOs, INGOs, UN agencies, media and private sector of Nepal that are working in the field of DRR are the member in this Platform.

The Disaster Risk Reduction (DRR) report provides a snapshot of the latest DRR progress Nepal has achieved under the four priorities of the Sendai Framework. It also highlights some of the key challenges surrounding the issue of creating coherence among the key global frameworks at the country level; and makes recommendations for strengthening the overall Disaster Risk Management (DRM) governance by government institutions and other stakeholders at national, sub-national, and local levels.

16. National Reconstruction Authority (NRA)

National Reconstruction Authority (NRA) was established in 25 December 2015 for five years to lead and manage the reconstruction and recovery of the earthquake. The overall goal of NRA is to promptly complete the reconstruction works damaged by the earthquake, and to promote national Build Back Better (BBB) interest. NRA has formulated a Post Disaster Recovery Framework (PDRF) (2016-2020) on the basis of Post Disaster Need Assessment (PDNA) report. The government has allocated adequate budget for reconstruction and recovery activities. Similarly, almost all of the affected families have received the first instalment of the grant and recovery activities have been further expedited. So far, National Reconstruction Authority (NRA) has reconstructed 160, 978 individual houses, 220 government buildings, 3636 school buildings, 106 cultural and heritage sites, 643 health facilities, 79 security forces facilities and 581 water supply schemes.

17. BIPAD: Building Information Platform against Disaster

BIPAD is built at a time when disaster governance in Nepal was changing on account of federal restructuring of the country. However, disaster data/information was still scattered, insufficient

and not fully harmonized. On this backdrop, BIPAD was developed by pooling all credible digital and spatial data that are available within different government bodies, non-governmental organizations, academic institutions and research organizations on a single platform. The platform has six modules in the portal that has the potential to: enhance preparedness and early warning, strengthen disaster communication, strengthen emergency response, enhance coordination post-incident and evidence-based planning, decision making and policy making.

The focus of the system was on bottom up approach of data collection, targeting the Provincial and Municipal governments to engage in verifying and collecting data. BIPAD was targeted for Emergency Operation Centers at National, Provincial and Municipal tiers of the government, and Nepal Police, who is the first responder to disaster. Other users of this system are the line ministries at National and Provincial tiers working in disaster management division and departments, Nepal Army, Armed Police Force, non-governmental organizations, research institutions and the general public. The features in BIPAD inform the users about the details of an incident for both natural and non-natural hazards for response and for historical analysis of loss and damage.

6.2 History of landslide evidences in Nepal

1. History of landslide events in Nepal (2010-2019)

According to the report “Nepal Disaster Report, 2011: Policies, Practices and Lessons”, the disaster statistics for Nepal during 1971-2010, landslide is considered as the second hazard with high loss of life after epidemics in Nepal. There was death of 67 people in the year 2010 due to landslide. The report also states that there was record of 2,705 number of landslide events with 4,327 human deaths. These had affected 5,55,607 human population where 1,446 were highly injured due to the landslide.

Based on the data extracted from MoHA, the distribution of landslide in different districts of Nepal in different years from 2010-2019 were analyzed. During the 10 years data analysis, highly affected districts with maximum number of landslide occurred are: Nuwakot, Sankhuwasabha, Baglung and Taplejung having 76, 73, 70 and 55 respectively (Figure 6). Similarly, Sindhupalchowk, Pyuthan, Taplejung and Kaski has the highest number of human casualties due to landslide events on past 10 years are: 57, 56, 56 and 50 respectively (Figure 7). The detail information of each district with the number of number of death, missing people, affected family, estimated loss (NRs) and the number of landslide events that occurred in (2010-2019) are summarized in Table 8.

Number of human casualties with affected family and estimated loss in Nepal due to landslide (2010-2019)

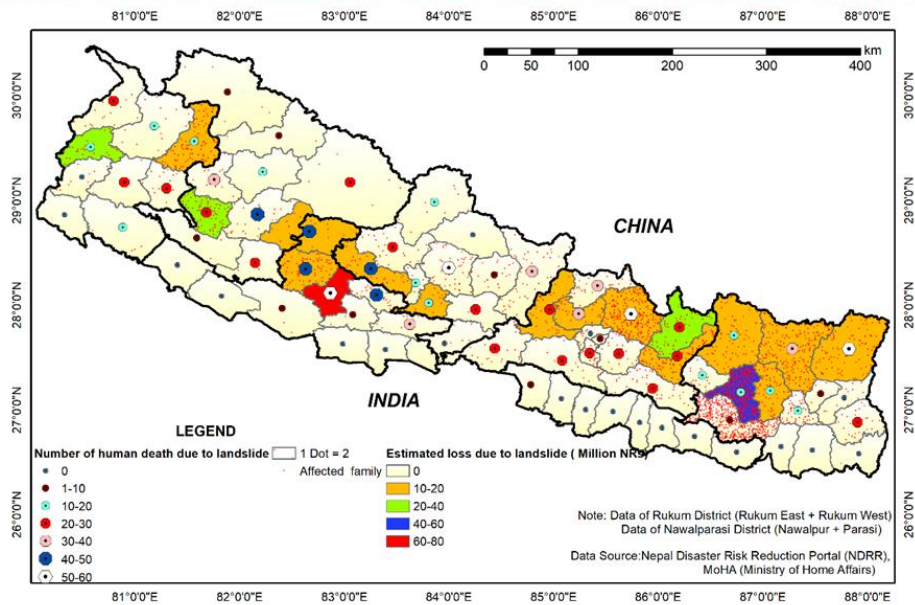


Figure 6: Number of human casualties with affected family and estimated loss in Nepal due to landslide (2010-2019). (Source: NDRR, MoHA)

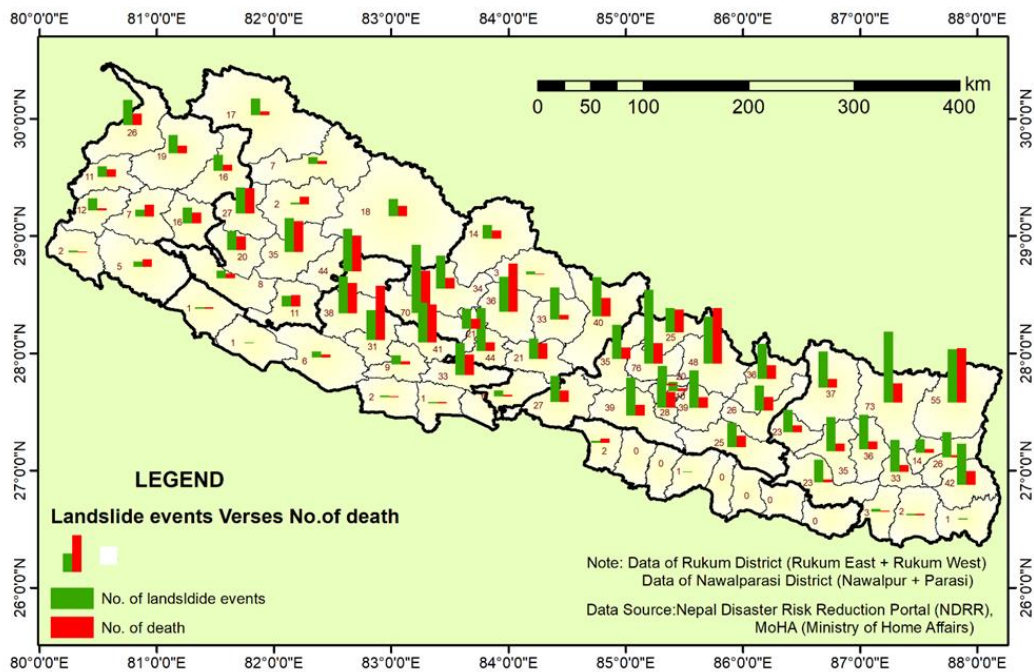


Figure 7: Landslide events Verses Human Death in Nepal (2010-2019) (Source: NDRR, MoHA).

6.3. Status of landslides in the Monsoon of 2020 (01/03/2020-30/08/2020)

Landslide data of past six months (March- August), 2020 has been collected from the data source of MoHA, DRR portal and Bipad gov.np. Based on data, it was found that the highest number of landslide incidents has occurred in Palpa, Lamjung and Kalikot district with 26, 15 and 14 respectively while the number of death is highest in Myagdi and Kalikot district of 30 and 29 respectively (Figure 8). Similarly, the highest number of people missing due to the landslide is 21 and 11 respectively in Sindhupalchowk and Sankhuwasabha district. Also, the highest number of family affected due to landslide is in Myagdi and Sindhupalchowk of 43 and 41 families respectively. Similarly, the largest economic loss has occurred in the Myagdi district of NRs 40, 75,000. The detail information of each district with the number of death, missing people, affected family, estimated loss (NRs) and the number of landslide events of monsoon 2020 (March – August) are summarized in Table 9.

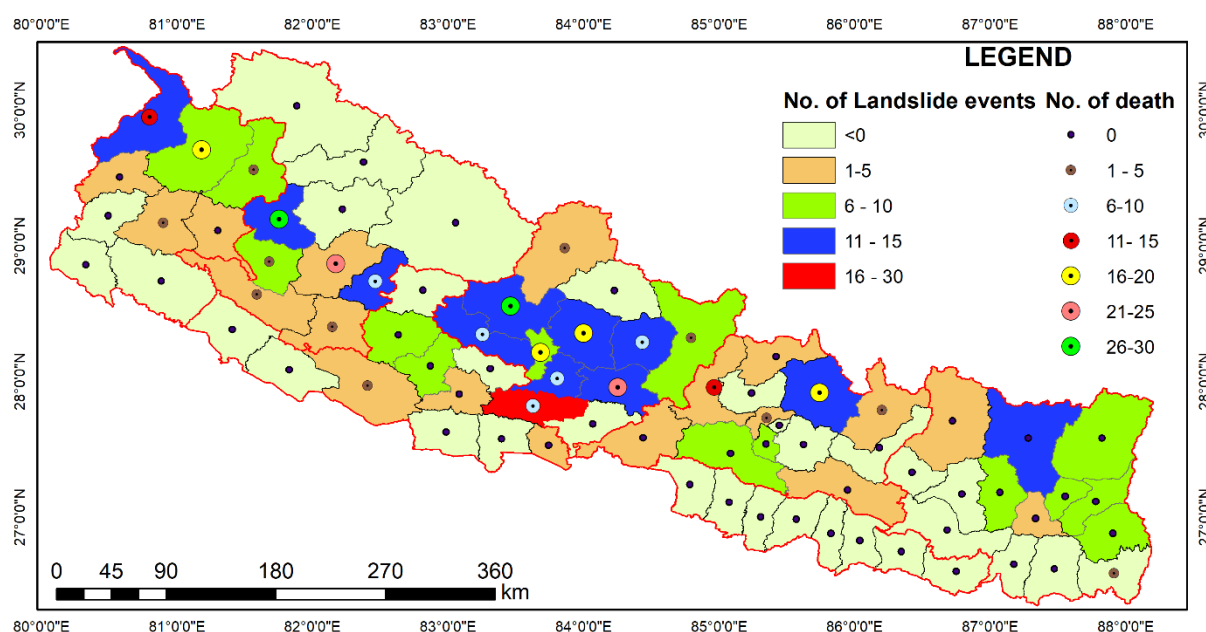


Figure 8: Status of landslide events in Monsson 2020 (01/03/2020-30/08/2020). (Source: Bipad.gov.np)

6.4. Case Study of Selected Watershed of Sindhupalchowk

Based on the literature review and the collected data, in Monsoon 2020, the Sindhupalchowk district of Bagmati zone was found to be the hot spot with highest number of family affected and people missing due to landslide in Monsoon 2020 of past six months (March- August) in Nepal.

Sindhupalchowk district consist of 11 different landside events with the loss of estimated 7 lakh NRP along with missing 21 people and affecting 43 families within the past six months (March – August 2020). Hence, the district comprises of maximum human causalties on past months. The latest devastating landslide that occurred in Lidi Village of Jugal Rural Municipality-2 on 14th August, 2020 had caused maximum human death of 37 people.

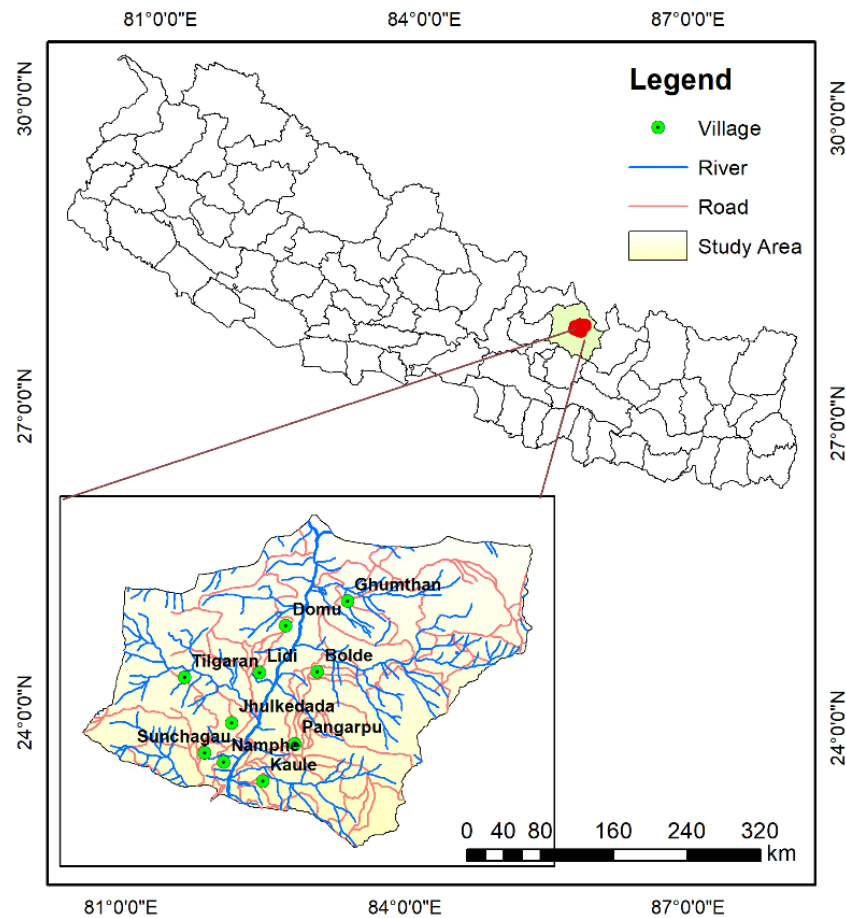


Figure 9: Location map of the study area.

The study area around Jugal Rural municipality was selected as a small catchment area of Balephi river of Sindhupalchowk district, Central Nepal as a pilot area of this study. The catchment area of selected watershed area is of around 100 km². The location map of the study area is shown in Figure 9.

6.4.1 Preparation of Landslide Inventory Maps.

i) Landslide Inventory Map of Study Area of year 2015

The landslide inventory map (Figure 10) shows the distribution of occurrence of all landslides throughout the selected watershed area after Gorkha Earthquake 2015. The landslide data used for this map preparation were the secondary data collected from the use of remote sensing (Source: Final Report: J-RAPID Program)

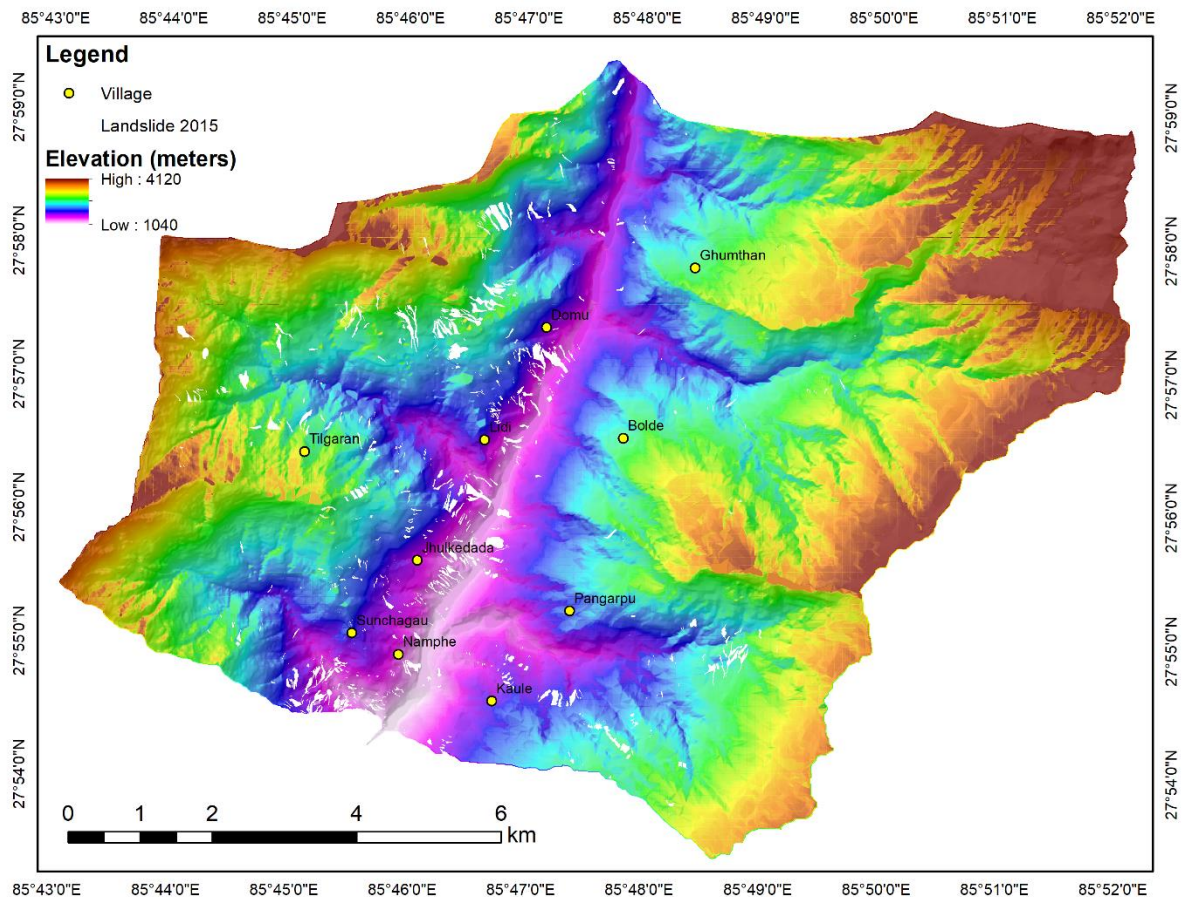


Figure 10: Landslide inventory map of study area. Source: Final Report: J-RAPID Program)

ii) Landslide Inventory Map of Study Area of year 2016 and 2014

The landslide inventory map of the study area of year 2014 and 2016 is prepared from the Google Earth Images (Figure 11). The individual landslide were identified and digitized in GIS for the preparation of landslide inventory maps. Year 2016 shows total number of 87 landslides while year 2014 shows 17 landslides occurred in the area. The location and landslide types of the

respective year 2014 and 2016 is shown in table 10 and table 11, respectively. All the types of landslides is of slope failure pattern.

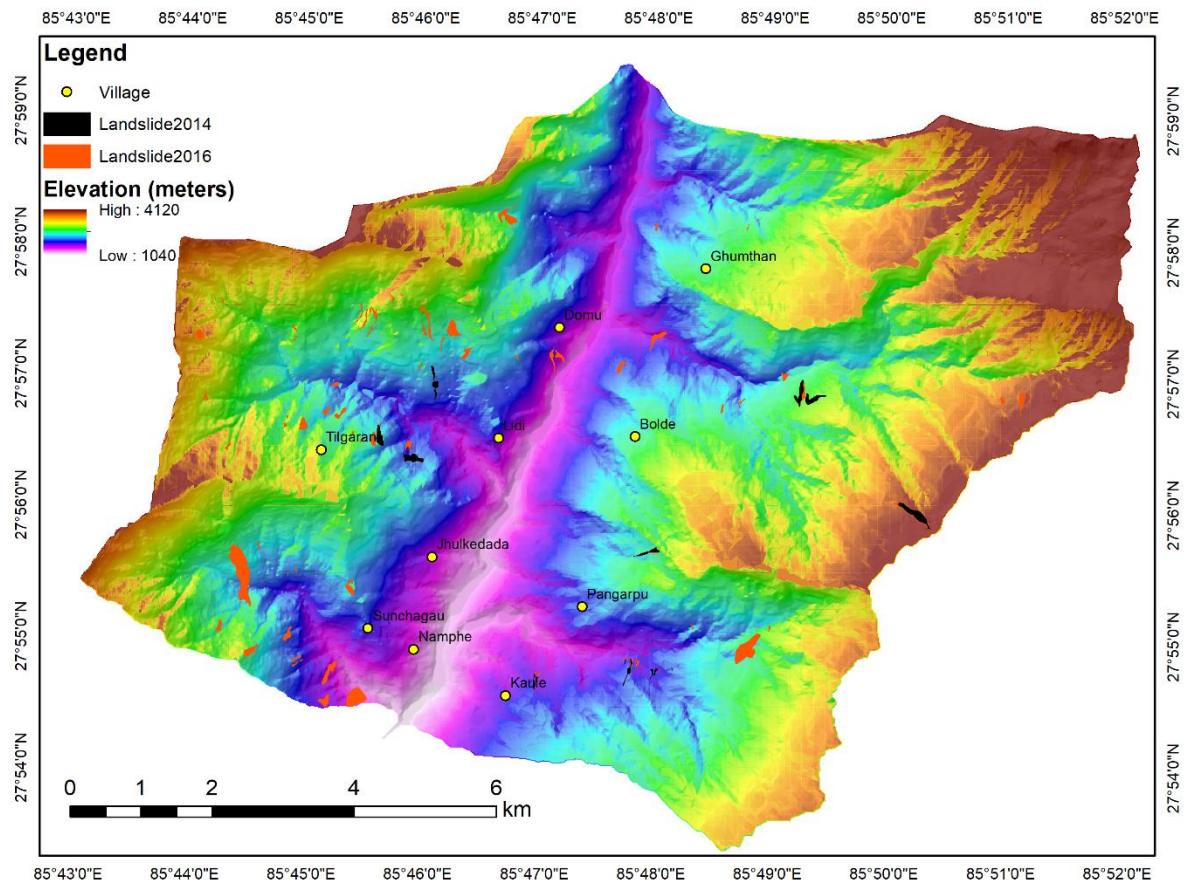


Figure 11: Landslide inventory map of study area in 2014 and 2016 after Gorkha Earthquake. (Source: Google Earth)

6.4.2 Preparation of Landslide Susceptibility Maps

The landslide susceptibility map (Figure 20) of the selected watershed area was prepared using the eight different landslide causative factors. Slope, Aspect, Elevation, Curvature, Distance to road, Distance to river, Geology and Landuse were used as an input parameter for the susceptibility mapping. The topographic data used in the analysis include slope, aspect, curvature and elevation. These data were derived from DEM with a spatial resolution of 10m using arc toolbox raster surface in ArcGIS. The map of all the respective landslide causative factors is shown (Figure 12- Figure 19).

1. During the calculation of landslide causative factors, eight different factors were taken for the study. Each factors are described briefly below:

i. Slope

The gravity is the force that causes the material to move downward. The steeper the slope, higher is the shear induced by gravity and the more risk of landslide. Hence, slope is the principle factor affecting the landslide occurrence. On a slope of uniform isotropic material, increased slope correlates with increased likelihood of failure (Rasyid et.al. 2016). The slope map of the study area is shown in Figure 12. Five different classes of slopes were classified as:

Slope Degree	0-15
	15-30
	30-45
	45-60
	>60

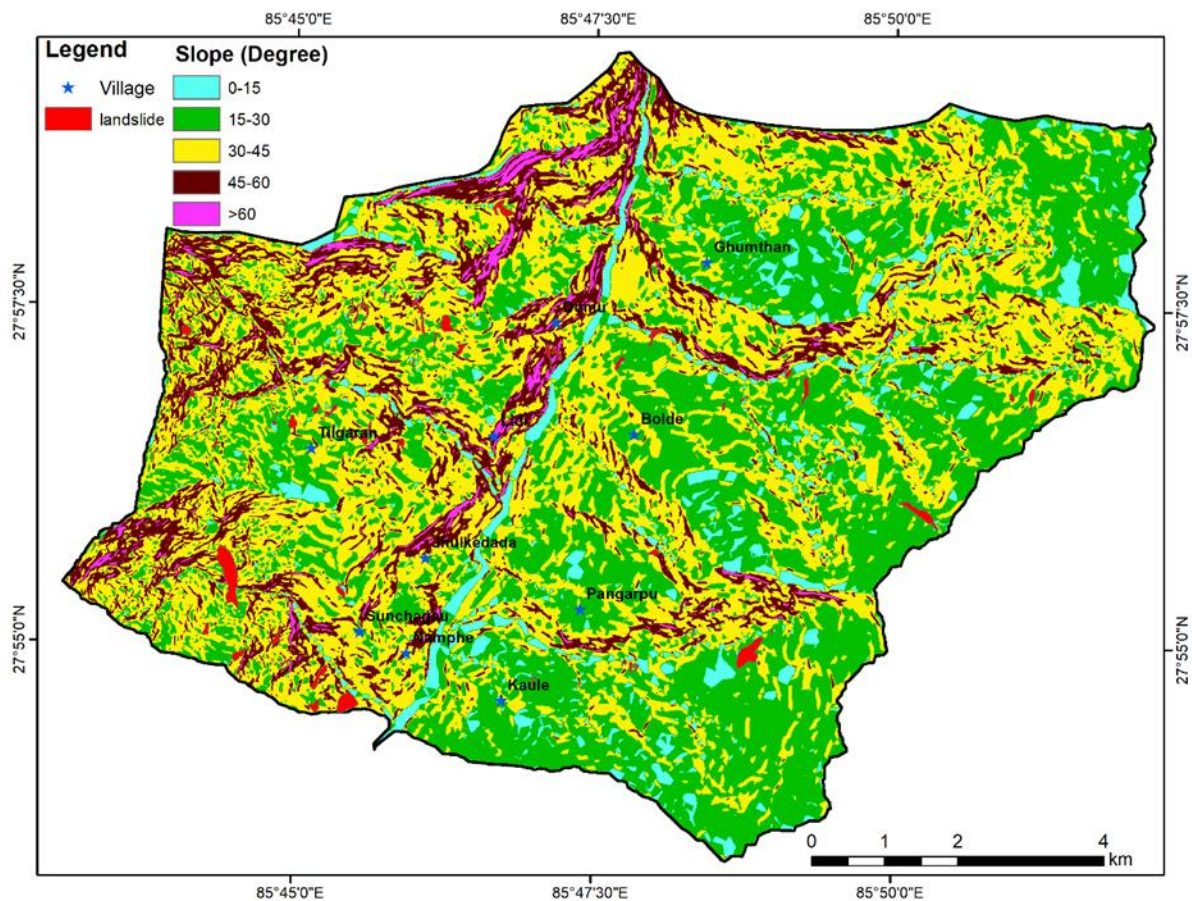


Figure 12: Slope map of the study area.

ii. Aspect

The effect of the slope aspect on the landslide occurrence may be direct or the indirect. The slope aspect determines the amount of the soil moisture content in different direction or aspect of the hill slope of same region. Slope aspect strongly affects hydrologic processes by the process of the evapotranspiration and affects the weathering processes and vegetation root development. Ten different aspects were classified as:

Aspect	Flat (-1)
	North (0-22.5)
	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)
	NorthWest (292.5-337.5)
	North (337.5-360)

The aspect map of the study area is shown in Figure 13.

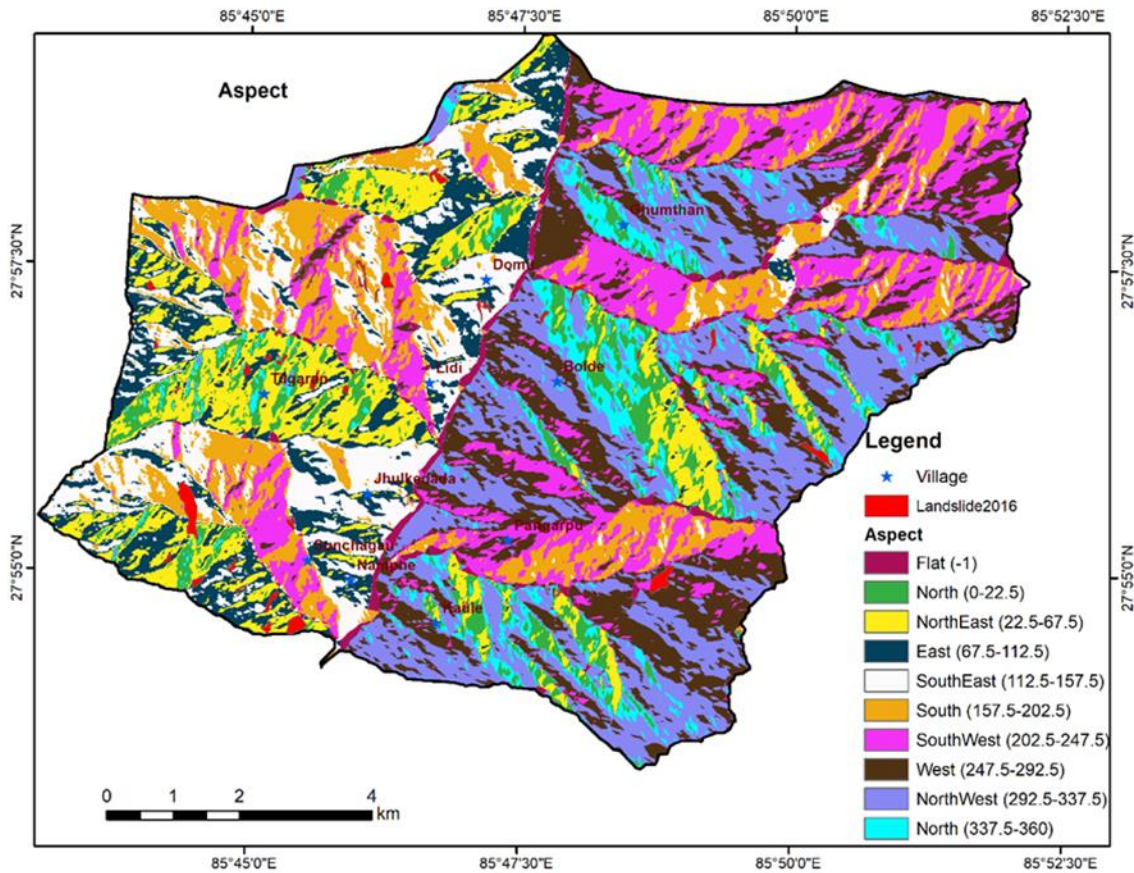


Figure 13: Aspect map of the study area.

iii. Curvature

The shape of the hill slope controls the distribution of the surface and subsurface water on the slope. In general, the convex shape of the slope or the divergent landform is most stable in the steep terrain, followed by the planar or flat shape of the slope. In most of the cases the concave shape of the slope or the convergent hill slope are least stable. This is due to the concentration or the dispersion of the surface and the subsurface water on the hillslope. Concave shape of the slope tend to concentrate the water into the small area of the hillslope and thereby generating the relatively high pore water pressure which increases the driving force that causes the slope to failure. So, curvature is classified into three classes as: Concave, Flat and Convex. The curvature map of the study area is shown in Figure 14.

Plan Curvature	Concave
	Flat
	Convex

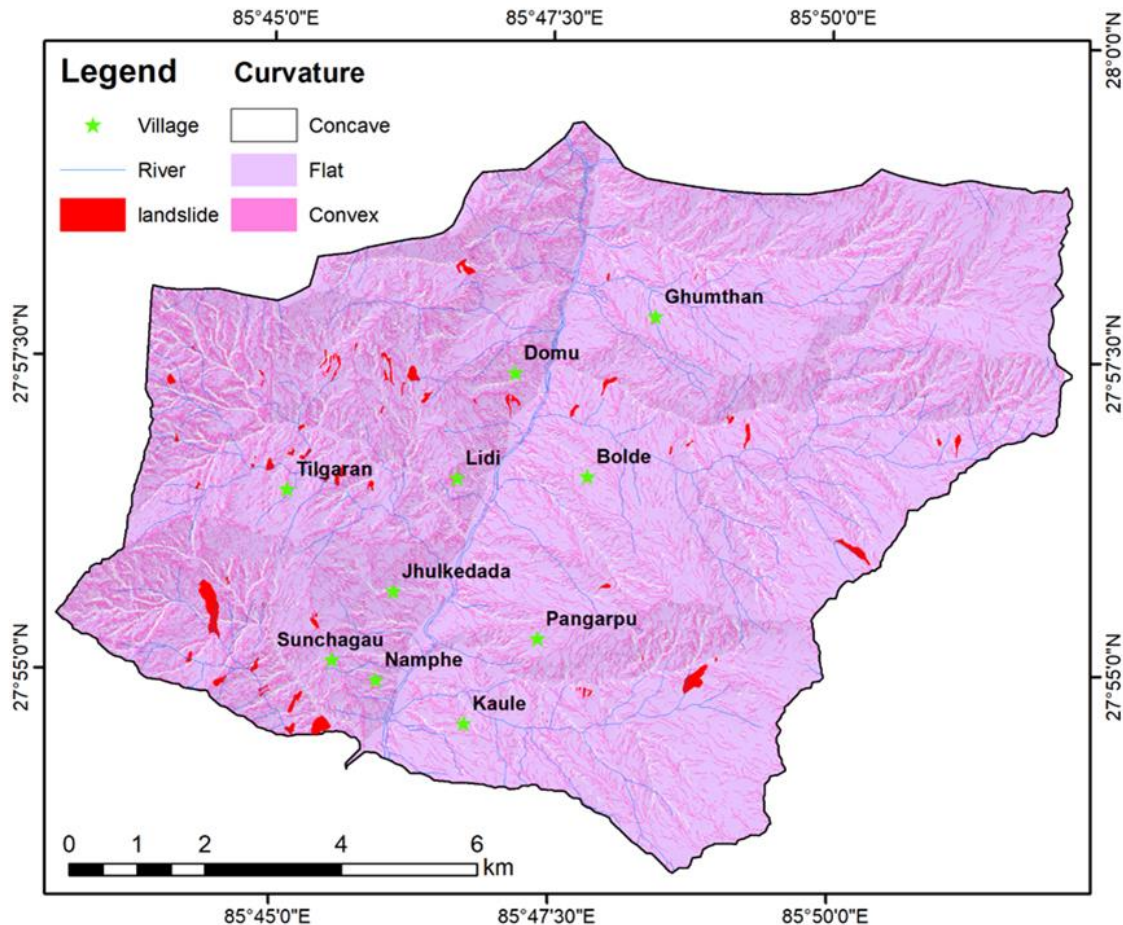


Figure 14: Curvature map of the study area.

iv. Elevation

The relationship between the influences of the elevation on the landslide occurrence is considered as the indirect relation or by means of other factors.

The elevation map of the study area is shown in Figure 15.

Elevation is classified into seven different classes as:

Elevation	<1500 m
	(1500-2000)m
	(2000-2500)m
	(2500-3000)m
	(3000-3500)m
	(3500-4000)m
	>4000m

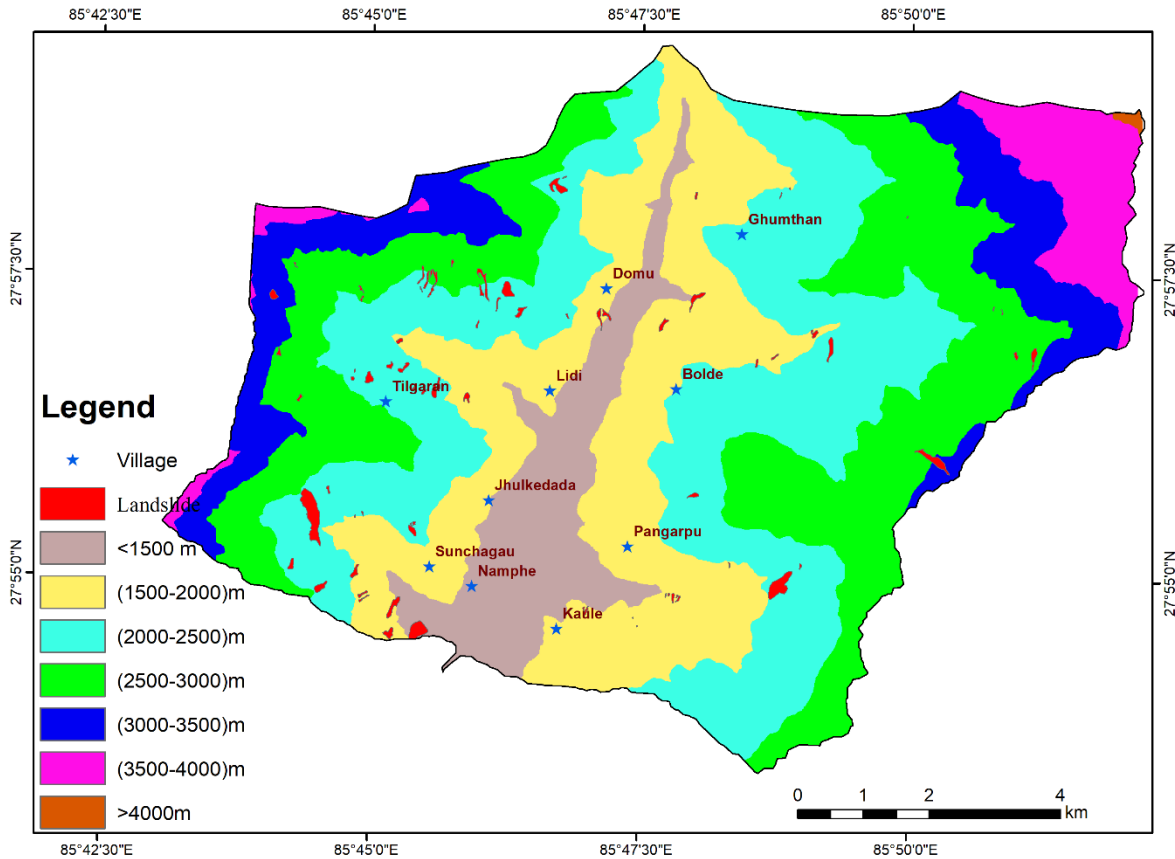


Figure 15: Elevation Map of the study area.

v. Distance to River

Proximity to the drainage and the river cut or the erosion process are important in terms of the landslide occurrence. Hence, in order to model the influence of runoff on land sliding, the distance to river parameter is taken in the study. The distance to river map of the study area is shown in Figure 16. Distance to river is classified as:

Distance to River	0-50m
	50-100m
	100-150m
	150-200m
	>200m

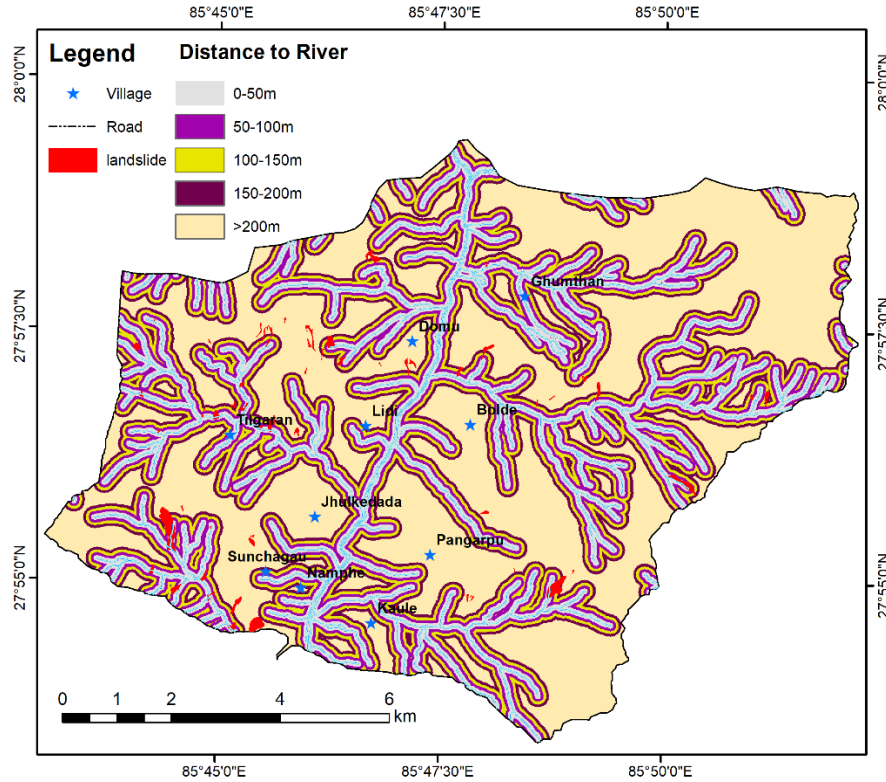


Figure 16: Distance to river map of the study area.

vi. Distance to Road

The landslide may occur on the road and on the side of the slopes affected by roads. Thus, a distance from road map was prepared in Arc GIS assuming that the landslide occurs more frequent along road. The distance to road map of the study area is shown in Figure 17.

Distance to road is classified as:

Distance to Road	0-100m
	100-200m
	200-300m
	300-400m
	>400m

vii. Geology

Geology plays an important role in landslide susceptibility and hazard studies because different geological units have different susceptibilities to active geomorphological processes of the Himalaya (Pardhan et al. 2006). It is clear that the geological factor is the most influencing parameters in the landslide occurrence and the

Geology	Augen Gneisses
	Banded Gneisses
	Ulleri Formation
	Himal Gneiss
	Lakharpata Formation
	Galyang Formation

slope instability phenomena (Sidle and Ochai 2006). Geological map of the study area is shown in Figure18. Geology of the study area is categorized as:

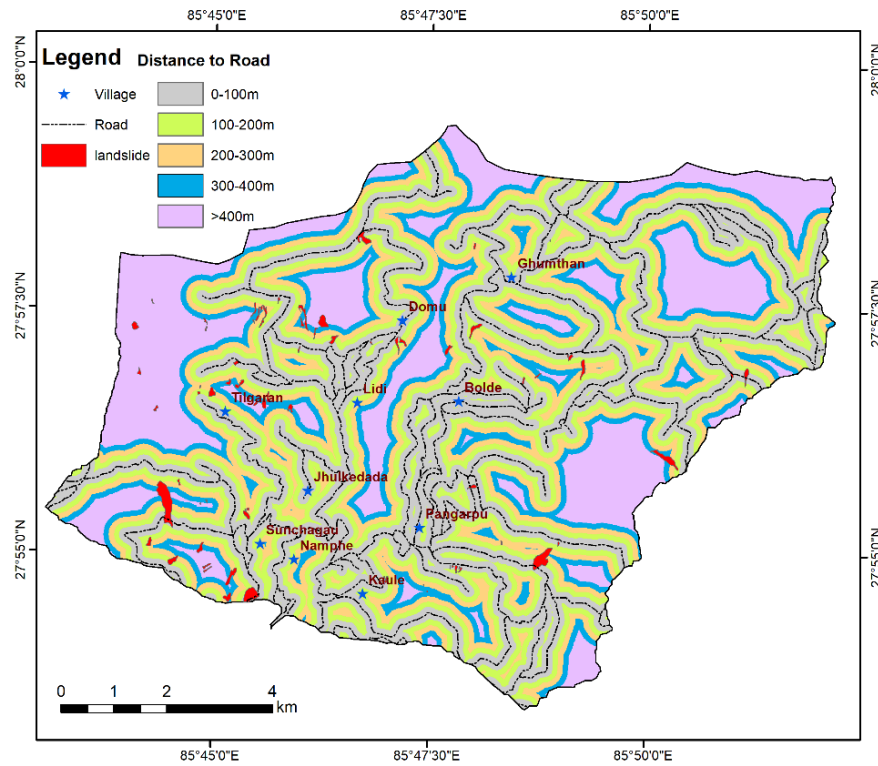


Figure 17: Distance to road map of the study area.

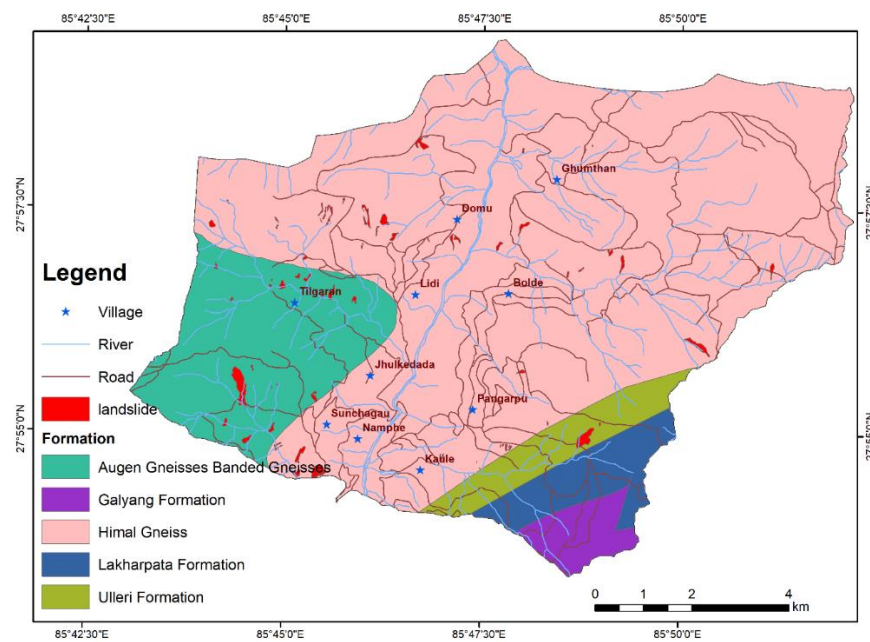


Figure 18: Geological map of the study area.

viii. LandUse

The top of the earth's crust provides the surface for the different activities and landslide occurrence depends on the use of the land for the several purposes. Vegetation plays a very important role in landslide mechanisms by holding the soil and changing the rainfall infiltration amount. Roots of the plant may develop the cracks on the underlying material and may enhance the landslide occurrence. There is the high risk of the landslides in the bare soil. Landuse map of the study area is shown in Figure 19. Landuse of the study area is classified according to landuse classification 2010 which is as:

LandUse	Forest
	Shrubland
	Grassland
	Agriculture Land
	Water bodies

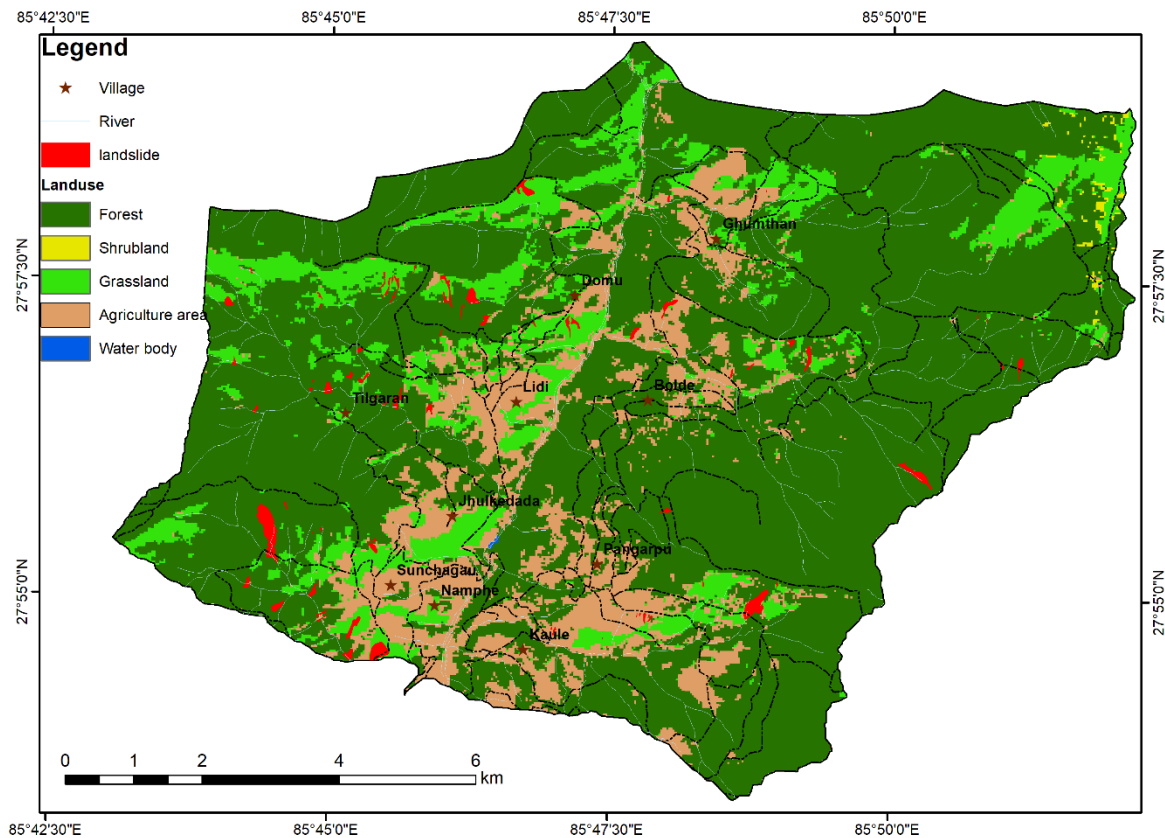


Figure 19: Landuse map of the study area.

2. After the calculation of all eight landslide causative factors, class pixels and landslide pixels on each causative factors were individually calculated. (<https://youtu.be/zc9FHIqfhK0>).
3. Frequency Ratio (FR) was calculated on each class of individual landslide causative factors.

FR= Landslide Pixels / Class Pixels.

4. Relative Frequency (RF) of each class of individual landslide causative factors was calculated.

RF= FR of each class/ Summation of FR value.

5. RF (non %) is calculated as: RF*100.

6. RF (INT) is calculated.

7. Min RF is calculated.

8. Max RF is calculated.

9. Max-Min RF is calculated.

10. (Max-Min) Min RF is calculated which is the lowest Max-Min RF value.

11. PR (Prediction Rate) is calculated as:

PR= Max-Min RF/ (Max-Min) Min RF

12. PR of all the causative factors of landslide were calculated.

13. To make final map in GIS, the reclass value was replaced by RF (INT) value.

14. The value of PR is taken as a prediction value for individual weightage for all the landslide causative factors during the raster calculation in ArcGIS.

15. Susceptibility map is prepared after the calculation from this all factors from the raster calculator as:

LSI= PR(slope) +PR(aspect) +PR(elevation) + PR(curvature) + PR(Dis_road) + PR(Distance_river) +PR (geology) +PR(landuse)

16. The landslide susceptibility map was prepared with the insertion of landslide polygon in the prepared as landslide susceptibility map (Figure 18).

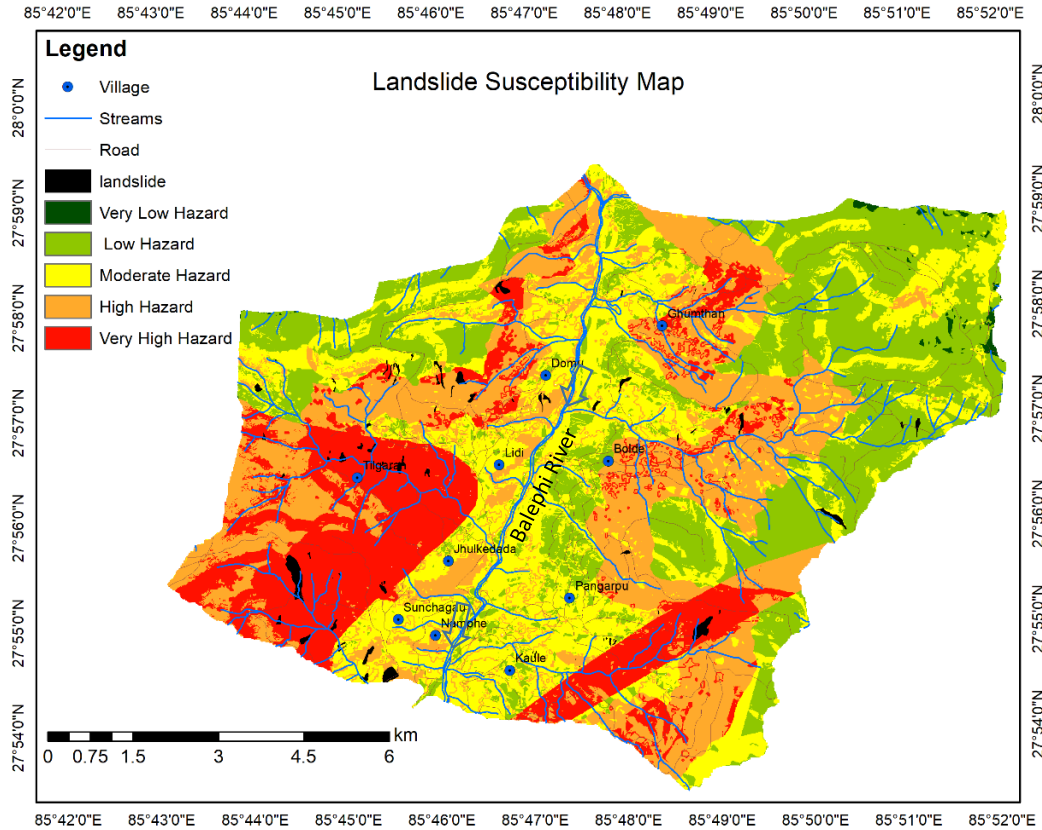


Figure 20: Landslide Susceptibility Map of study area.

The Landslide Susceptibility Index (LSI) value varied between 162 to 817 in our case study with the prediction rate value from 1 to 4.84. If the LSI value is high, it means a higher susceptibility to landslide; a lower value means a lower susceptibility to landslides (Lee and Evangelista, 2005). Subsequently, the LSI was divided into five classes with natural break classification, each representing “very low, low, moderate, high and very high hazard” areas. The susceptibility map with the five hazard zonation is shown in Figure 20.

7. CONCLUSIONS AND DISCUSSIONS

The study has reviewed the plan policies and strategies of various disaster acts being held in Nepal since past years. Sendai framework (2015-2030) is widely used in current phases. The enactment of different bylaws and policies had supported in the management of disaster risk reduction too. Study of past data has summarized the landslide prone districts with highest and lowest fatality rate along with the number of family missing and their economic loss in each districts showing Sindhupalcowk as the most vulnerable district for landslide on this year with maximum number

of human casualties. In every monsoon, the number of landslide events are maximum in the hilly area of Nepal. The rate of landslide increases with the start of rainy season and decreases in start of autumn. The study of past 10 year's data monitoring and analysis has concluded that single district (Sindhupalchowk) has lost 57 human casualties. The risky hillslope of the landslide prone areas has to be identified and the effective scientific slope stability management has to be implemented preparing a suitable landslide hazard risk map of each area. Since, hilly districts like Nuwakot, Baglung, Sankhuwasabha have shown maximum landslide events in past years.

The landslide inventory map of 2015 prepared from secondary data shows maximum occurrence of landslide events after Gorkha earthquake in Nepal. Also, the inventory map of 2014 has comparatively less landslide events than that of 2016. Hence, it also shows that the number of landslide has occurred more in study area after Gorkha earthquake. Those landslide can also be considered as the earthquake induced landslide.

The landslide susceptibility map of the small catchment of Balephi khola of Sindhupalchowk district, Bagmati province was prepared using frequency ratio method. The landslide susceptibility map was classified into five types as “very low, low, moderate, high and very high hazard” areas. After the preparation of landslide susceptibility map using frequency ratio method, insertion of landslide polygon on the map was done. It shows that the maximum landslide has occurred within the high hazard and hazard zone. Hence, the map sets its relevancy for the further study. The map shows that the maximum number of landslide has occurred in between 30 - 45 degree slope at an elevation difference of 2000m to 3000m. The landuse pattern of the area is forest area and grassland where the landslide has occurred. The map shows that the Tilgaran, Ghumthan and Bolde village are in high hazard zone while other villages like Jhulkedada, Pangarpu, Kaule, Namphe, Sanchagau, lidi and Domu villages are in moderate hazard zone. According to the movement of weathered surface soil layer/rock of steep slope, the landslide of this catchment area are of slope failure type.

According to the Water Induced Disaster Management Policy 2072, slope with 30-45 degree has to be used for agriculture and animal husbandry. Similarly in High Hazard Zone (Zone 1) and Medium Hazard Zone (Zone 2), new settlement shouldn't be made. Based on prior notice, high caution should be made in such area.

8. LIMITATIONS/ISSUES

- i. Lack of high resolutions images for the recent landslide events that occurred in Nepal.
- ii. Due to the threat of pandemic COVID-19, field visit was not possible to conduct.
- iii. Lack of geomorphological field data.

9. RECOMMENDATIONS

Further researches can be done on the study area. So, few recommendations are listed as:

- i. The study of landslide on the study area can be further done with the field verification and detail geomorphological mapping.
- ii. The validation of the landslide inventory prepared from the google earth images can be done with the field survey.
- iii. The types of landslide can be differentiated as a rainfall induced landslide and earthquake induced landslide too.

10. REFERENCES

1. Amatya, S.C., 2016. Landslide disaster management in Nepal: a near-future perspective. *Nepal-Japan Friendship Association of Water Induced Disaster (NFAD), Japan Department of Water Induced Disaster Management (DWIDM)*.
2. Budimir, M.E.A., Atkinson, P.M. and Lewis, H.G., 2015. A systematic review of landslide probability mapping using logistic regression. *Landslides*, 12(3), pp.419-436.
3. Dağdelenler G., (2013), *Heyelan Duyarlılık Haritalarının Üretilmesinde Örneklem ve Doğrulama Stratejilerinin Değerlendirilmesi (Gelibolu Yarımadası'nın Doğu Kesimi)*, Doktora Tezi, Hacettepe Üniversitesi, Ankara.
4. Dewitte, O., C.-J. Chung, Y. Cornet, M. Daoudi, and A. Demoulin. 2010. Combining spatial data in landslide reactivation susceptibility mapping: A likelihood ratio-based approach in W Belgium. *Geomorphology* 122: 153–166. doi:10.1016/j.geomorph.2010.06.010.
5. Dou, Jie et al. "Optimization of Causative Factors for Landslide Susceptibility Evaluation Using Remote Sensing and GIS Data in Parts of Niigata, Japan." *PloS one* vol. 10, 7 e0133262. 27 Jul. 2015, doi:10.1371/journal.pone.0133262.
6. El Jazouli, A., Barakat, A. and Khellouk, R., 2019. GIS-multicriteria evaluation using AHP for landslide susceptibility mapping in OumErRbia high basin (Morocco). *Geoenvironmental Disasters*, 6(1), p.3.
7. Forbes, K. and Broadhead, J., 2013. Forests and landslides: The role of trees and forests in the prevention of landslides and rehabilitation of landslide-affected areas in Asia. *Rap Publication*, (2013/02).
8. Javad, M., Baharin, A., Mojaradi, B. and Farshid, S., 2014. Using frequency ratio method for spatial landslide prediction. *Research Journal of Applied Sciences, Engineering and Technology*, 7(15), pp.3174-3180.
9. Kannan, M., E. Saranathan, and R. Anabalagan. 2013. Landslide vulnerability mapping using frequency ratio model: a geospatial approach in Bodi-Bodimettu Ghat section, Theni district, Tamil Nadu, India. *Arabian Journal of Geosciences* 6: 2901–2913. doi: 10.1007/s12517-012-0587-5.
10. Kılıçoğlu, C., Doğan, S. and Akıncı, H., Landslide Susceptibility Mapping of Ilkadam (Samsun) District Using Frequency Ratio Method.
11. Lee S., Evangelista D.G., (2005), *Landslide Susceptibility Mapping using Probability and Statistics Models in Baguio City, Philippines*, ISPRS 31st International Symposium on Remote Sensing of Environment, Saint Petersburg, Russia, 20-24 May 2005.
12. Lee, S. and Pradhan, B., 2006. Probabilistic landslide hazards and risk mapping on Penang Island, Malaysia. *Journal of Earth System Science*, 115(6), pp.661-672.
13. Lee, S. and Pradhan, B., 2007. Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. *Landslides*, 4(1), pp.33-41.
14. Lee S., Talip J.A., (2005), *Probabilistic Landslide Susceptibility and Factor Effect Analysis*, *Environmental Geology*, 47(7), 982-990.

15. National Level Forests and Land Cover Analysis of Nepal using Google Earth Images. Ministry of Forests and Environment Forest Research and Training Centre Kathmandu, Nepal January, 2019.
16. Nepal Disaster Report, 2011: Policies, Practices and Lessons. Government of Nepal. Ministry of Home Affairs.
17. Paudel, P.P., Omura, H., Kubota, T. and Morita, K., 2003. Landslide damage and disaster management system in Nepal. *Disaster Prevention and Management: An International Journal*.
18. Petley, D.N., Hearn, G.J., Hart, A., Rosser, N.J., Dunning, S.A., Owen, K. and Mitchell, W.A., 2007. Trends in landslide occurrence in Nepal. *Natural hazards*, 43(1), pp.23-44.
19. Pradhan, A.M.S., Dawadi, A. and Kim, Y.T., 2012. Use of different bivariate statistical landslide susceptibility methods: A case study of Khulekhani watershed, Nepal. *Journal of Nepal Geological Society*, 44, pp.1-12.
20. Rasyid, A.R., Bhandary, N.P. and Yatabe, R., 2016. Performance of frequency ratio and logistic regression model in creating GIS based landslides susceptibility map at Lompobattang Mountain, Indonesia. *Geoenvironmental Disasters*, 3(1), p.19.
21. Shrestha, B.R., 2019. An Assessment of Disaster Loss and Damage in Nepal. *The Geographic Base*, 6, pp.49-57
22. Solari, L., Del Soldato, M., Raspini, F., Barra, A., Bianchini, S., Confuorto, P., Casagli, N. and Crosetto, M., 2020. Review of Satellite Interferometry for Landslide Detection in Italy. *Remote Sensing*, 12(8), p.1351.
23. Upreti, B.N. and Dhital, M.R., 1996. Landslide studies and management in Nepal.
24. Varnes, D.J., 1978. Slope movement types and processes. *Special report*, 176, pp.11-33.
25. Yalçın A., (2007), *Heyelan Duyarlılık Haritalarının Üretilmesinde Analitik Hiyerarşi Yönteminin ve CBS'nin Kullanımı*, Selçuk Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 22(3), 1–14.
26. Retrieved from (<http://therisingnepal.org.np/news/34254>).
27. Retrieved from <https://www.thethirdpole.net/2020/09/14/why-are-landslides-so-deadly-in-nepal/>
28. Retrieved from <http://drrportal.gov.np/uploads/document/1321.pdf>
29. Retrieved from <https://bipad.gov.np/>
30. Retrieved from <https://www.moha.gov.np/>
31. Retrieved from <http://drrportal.gov.np/>
32. Retrieved from <https://youtu.be/X5ho-1Iqn6E>
33. Retrieved from <https://youtu.be/zc9FHIqfhK0>
34. Retrieved from <https://www.youtube.com/watch?v=q94p9UQuBqg>

ANNEXES

Table 8: Landslide Data Analysis (2010-01-1/2019-12-30) Source: MoHA, GoN.

<i>Landslide Data Analysis (2010-01-1/2019-12-30) Source: MoHA , GoN</i>						
S.No	District	No. of death	Number of Missing People	Number of Affected family	Estimated Loss (NRs)	No. of landslide events
1	Dang	3	0	6	800000	6
2	Pyuthan	56	4	499	748685979	31
3	Rolpa	31	17	178	20900000	38
4	Salyan	12	0	8	0	11
5	Rukum	37	0	49	41557000	44
6	Dolpa	11	8	15	1857800	18
7	Mugu	3	1	7	700000	7
8	Humla	4	4	13	3975000	17
9	Jumla	8	1	2	0	2
10	Kalikot	26	2	34	177400	27
11	Jajarkot	32	2	50	800000	35
12	Dailekh	14	5	145	86740000	20
13	Surkhet	5	1	6	2800000	8
14	Bardiya	1	0	0	0	1
15	Banke	0	0	1	0	1
16	Kailali	8	1	9	0	5
17	Doti	12	0	5	70000	7
18	Achhaam	11	0	34	954000	16
19	Bajura	6	0	233	19500000	16
20	Bajhang	8	4	31	1632200	19
21	Darchula	12	0	45	280000	26

22	Baitadi	8	0	67	63031458	11
23	Dadeldhura	2	0	23	300000	12
24	Kanchanpur	1	0	0	150000	2
25	Parbat	10	1	17	3300000	21
26	Baglung	43	0	86	30757000	70
27	Myagdi	11	4	57	1918000	34
28	Mustang	8	1	22	0	14
29	Manang	1	0	0	0	3
30	Kaski	50	3	103	1450000	36
31	Lamjung	5	1	46	2300000	33
32	Gorkha	19	2	98	3202000	40
33	Tanahu	16	0	4	0	21
34	Shyanja	9	0	32	16973000	44
35	Gulmi	39	0	67	1003000	41
36	Arghakhanchi	3	0	7	2700000	9
37	Palpa	21	0	33	340000	33
38	Kapilbastu	1	0	1	0	2
39	Rupandehi	1	0	0	0	1
40	Nawalparasi	2	3	22	0	6
41	Chitawan	12	1	39	30000	27
42	Parsa	4	0	0	0	2
43	Makawanpur	11	6	31	2550000	39
44	Kavrepalanchow k	11	0	48	9410000	39
45	Bhaktapur	3	0	8	1167500	10
46	Lalitpur	16	0	37	1700000	28
47	Kathmandu	2	0	23	1000000	20
48	Dhading	12	0	73	20772000	35
49	Nuwakot	21	0	87	22537500	76
50	Sindhupalchowk	57	123	554	31784000	48

51	Rasuwa	23	0	74	900000	25
52	Dolakha	14	13	109	71292000	36
53	Ramechhap	14	0	203	18795000	26
54	Sindhuli	12	1	86	300000	25
55	Sarlahi	0	0	0	200000	1
56	Udayapur	3	0	1090	700000	23
57	Okhaldhunga	7	1	39	2200000	23
58	Khotang	8	2	1080	272978000	35
59	Solukhumbu	9	1	161	40230000	37
60	Shankhuwasabha	20	6	409	29337000	73
61	Bhojpur	8	0	142	15871000	36
62	Terhathum	4	0	13	5750000	14
63	Dhankuta	7	0	131	8270000	33
64	Sunsari	1	0	1	0	3
65	Morang	2	0	1	0	2
66	Jhapa	0	0	3	0	1
67	Ilam	14	4	67	12832000	42
68	Panchthar	2	3	31	3156000	26
69	Taplejung	56	6	198	34434500	55
70	Siraha	No data	No data	No data	No data	No data
71	Saptari	No data	No data	No data	No data	No data
72	Dhanusha	No data	No data	No data	No data	No data
73	Mahottari	No data	No data	No data	No data	No data
74	Rautahat	No data	No data	No data	No data	No data

75	Bara	No data	No data	No data	No data	No data
----	------	---------	---------	---------	---------	---------

Table 9: Landslide Data Analysis (2020-03-01 - 2020-08-30) Source: MoHA, GoN.

S.No	District	No. of landslide events	No. of death	No. of Missing People	No. of Affected family	Estimated Loss (NRs)
1	Achham	3	0	0	2	500000
2	Arghakhanchi	5	0	0	2	0
3	Baglung	13	5	1	20	305000
4	Baitadi	4	0	0	4	0
5	Bajhang	7	9	1	23	0
6	Bajura	8	3	0	12	200000
7	Banke	0	0	0	0	0
8	Bara	0	0	0	0	0
9	Bardiya	0	0	0	0	0
10	Bhaktapur	1	0	0	2	250000
11	Bhojpur	9	0	0	4	741000
12	Chitawan	3	0	0	0	0
13	Dadeldhura	0	0	0	0	0
14	Dailekh	7	1	0	4	0
15	Dang	4	2	0	1	0
16	Darchula	13	7	0	15	0
17	Dhading	5	6	0	9	0
18	Dhankuta	5	0	0	6	425000
19	Dhanusha	0	0	0	0	0
20	Dolakha	4	1	0	3	0
21	Dolpa	0	0	0	0	0
22	Doti	4	1	0	4	0

23	Gorkha	7	2	0	9	1750000
24	Gulmi	0	0	0	0	0
25	Humla	1	0	0	0	0
26	Ilam	8	0	0	14	2647000
27	Jajarkot	3	11	1	5	0
28	Jhapa	1	1	0	2	0
29	Jumla	0	0	0	0	0
30	Kabhrepalanchok	1	0	1	1	0
31	Kailali	0	0	0	0	0
32	Kalikot	14	29	3	24	0
33	Kanchanpur	0	0	0	0	0
34	Kapilbastu	0	0	0	0	0
35	Kaski	13	10	0	30	0
36	Kathmandu	3	3	0	3	300000
37	Khotang	1	0	0	0	0
38	Lalitpur	7	0	0	2	2115000
39	Lamjung	15	4	0	22	0
40	Mahottari	1	0	0	1	150000
41	Makawanpur	9	0	0	1	150000
42	Manang	2	0	0	1	0
43	Morang	1	0	0	1	600000
44	Mugu	0	0	0	0	0
45	Mustang	3	1	0	2	0
46	Myagdi	11	30	4	43	0
47	Nawalparasi_E	0	0	0	0	0
48	Nawalparasi_W	5	0	0	3	60000
49	Nuwakot	2	0	0	6	60000
50	Okhaldhunga	0	0	0	0	0
51	Palpa	26	5	0	20	4075000
52	Panchthar	6	0	0	7	1500000

53	Parbat	10	9	0	5	760000
54	Parsa	0	0	0	0	0
55	Pyuthan	6	0	0	1	80000
56	Ramechhap	0	0	0	0	0
57	Rasuwa	5	0	0	0	0
58	Rautahat	0	0	0	0	0
59	Rolpa	7	0	0	8	70000
60	Rukum_E	1	0	0	1	0
61	Rukum_W	13	5	0	18	1380000
62	Rupandehi	1	0	0	2	0
63	Salyan	3	1	0	3	0
64	Sankhuwasabha	13	0	11	18	660000
65	Saptari	0	0	0	0	0
66	Sarlahi	0	0	0	0	0
67	Sindhuli	5	0	0	0	0
68	Sindhupalchok	11	8	21	41	700000
69	Siraha	0	0	0	0	0
70	Solukhumbu	5	0	0	6	2700000
71	Sunsari	1	0	0	0	0
72	Surkhet	4	2	0	6	0
73	Syangja	11	5	1	15	314500
74	Tanahu	13	13	1	26	2600000
75	Taplejung	9	0	0	11	2000000
76	Terhathum	9	0	0	11	2000000
77	Udayapur	2	0	0	2	0

Table 10: : Landslide details of selected watershed of year 2014

S.No	Lat_Long	Landslide Types
0	85.762872 27.942194	Slope Failure
1	85.760763 27.904923	Slope Failure

2	85.783405 27.893249	Slope Failure
3	85.799108 27.912942	Slope Failure
4	85.837880 27.934038	Slope Failure
5	85.825387 27.947667	Slope Failure
6	85.823347 27.949159	Slope Failure
7	85.767420 27.939594	Slope Failure
8	85.770536 27.950984	Slope Failure
9	85.770911 27.948834	Slope Failure
10	85.802153 27.928075	Slope Failure
11	85.802345 27.912950	Slope Failure
12	85.802950 27.912969	Slope Failure
13	85.805162 27.913234	Slope Failure
14	85.798561 27.914161	Slope Failure
15	85.785782 27.911671	Slope Failure
16	85.785537 27.912152	Slope Failure

Table 11: Landslide details of selected watershed of year 2016.

S.No	Lat_long	Lanslide Type
0	85.737122 27.955065	Slope Failure
1	85.750627 27.956041	Slope Failure
2	85.750970 27.954738	Slope Failure
3	85.756905 27.949046	Slope Failure
4	85.752079 27.944412	Slope Failure
5	85.749931 27.944788	Slope Failure
6	85.749538 27.943624	Slope Failure
7	85.755431 27.945371	Slope Failure
8	85.767188 27.941188	Slope Failure
9	85.762880 27.942811	Slope Failure
10	85.762155 27.942056	Slope Failure
11	85.760466 27.941748	Slope Failure
12	85.759262 27.942607	Slope Failure
13	85.757822 27.945385	Slope Failure
14	85.742787 27.927016	Slope Failure
15	85.745884 27.928494	Slope Failure
16	85.751218 27.925217	Slope Failure

17	85.750150 27.924768	Slope Failure
18	85.758962 27.922936	Slope Failure
19	85.758758 27.923724	Slope Failure
20	85.759244 27.923884	Slope Failure
21	85.740513 27.918411	Slope Failure
22	85.744710 27.914676	Slope Failure
23	85.750360 27.917308	Slope Failure
24	85.760486 27.909466	Slope Failure
25	85.754041 27.906893	Slope Failure
26	85.755637 27.908680	Slope Failure
27	85.756578 27.912991	Slope Failure
28	85.752170 27.913767	Slope Failure
29	85.751690 27.914146	Slope Failure
30	85.785629 27.912392	Slope Failure
31	85.785905 27.911797	Slope Failure
32	85.793907 27.909975	Slope Failure
33	85.793252 27.911090	Slope Failure
34	85.816750 27.916635	Slope Failure
35	85.819087 27.918430	Slope Failure
36	85.808097 27.918547	Slope Failure
37	85.777019 27.893924	Slope Failure
38	85.783719 27.893639	Slope Failure
39	85.780785 27.894044	Slope Failure
40	85.781429 27.893429	Slope Failure
41	85.779908 27.894591	Slope Failure
42	85.802477 27.928016	Slope Failure
43	85.812103 27.946646	Slope Failure
44	85.815244 27.947452	Slope Failure
45	85.821191 27.950440	Slope Failure
46	85.820550 27.950695	Slope Failure
47	85.760206 27.958742	Slope Failure
48	85.761901 27.958317	Slope Failure
49	85.761769 27.955920	Slope Failure
50	85.759902 27.956098	Slope Failure
51	85.760956 27.957476	Slope Failure
52	85.761513 27.958416	Slope Failure

53	85.764823 27.959845	Slope Failure
54	85.768984 27.958480	Slope Failure
55	85.769116 27.956234	Slope Failure
56	85.738077 27.946954	Slope Failure
57	85.741529 27.941168	Slope Failure
58	85.854838 27.948020	Slope Failure
59	85.851996 27.947792	Slope Failure
60	85.769008 27.951545	Slope Failure
61	85.771958 27.954722	Slope Failure
62	85.775681 27.953218	Slope Failure
63	85.782552 27.952582	Slope Failure
64	85.787384 27.952832	Slope Failure
65	85.788645 27.952799	Slope Failure
66	85.797677 27.951771	Slope Failure
67	85.803017 27.955290	Slope Failure
68	85.823399 27.949388	Slope Failure
69	85.802444 27.969519	Slope Failure
70	85.815602 27.969536	Slope Failure
71	85.816953 27.970227	Slope Failure
72	85.835177 27.966464	Slope Failure
73	85.848615 27.954094	Slope Failure
74	85.849775 27.953825	Slope Failure
75	85.740445 27.959318	Slope Failure
76	85.773291 27.955909	Slope Failure
77	85.780854 27.970269	Slope Failure
78	85.782235 27.971575	Slope Failure
79	85.781880 27.971421	Slope Failure
80	85.799456 27.914243	Slope Failure
81	85.800079 27.914189	Slope Failure
82	85.800341 27.913880	Slope Failure
83	85.798327 27.914346	Slope Failure
84	85.798781 27.914424	Slope Failure
85	85.838092 27.933890	Slope Failure
86	85.737258 27.955082	Slope Failure

Table 12: Calculation of landslide prediction rate using frequency ratio method.

S.N	Data Layers	Class	Class Pixels	Landslide Pixels	FR	RF	RF (non%)	RF (INT)	Min RF	Max RF	Max-Min RF	(Max-Min) Min RF	PR
1.	Slope Degree	0-15	60597	148	0.00244	0.07994	7.99359	7					
		15-30	386733	2859	0.00739	0.24195	24.1955	24					
		30-45	393091	3222	0.0082	0.26826	26.8265	26					
		45-60	132344	1067	0.00806	0.26387	26.3871	26					
		>60	17040	76	0.00446	0.14597	14.5974	14					
	Total				0.03055	1	100		0.07994	0.268265	0.1883289	0.090593689	2.07883
2.	Aspect	Flat (-1)	20993	27	0.00129	0.01711	1.71127	1					
		North (0-22.5)	56061	394	0.00703	0.09351	9.35112	9					
		NorthEast (22.5-67.5)	94754	1491	0.01574	0.20937	20.9367	20					
		East (67.5-112.5)	81801	1074	0.01313	0.17469	17.4692	17					
		SouthEast (112.5-157.5)	104838	918	0.00876	0.11651	11.6507	11					
		South (157.5-202.5)	122951	1056	0.00859	0.11428	11.4277	11					
		SouthWest (202.5-247.5)	138121	653	0.00473	0.0629	6.29045	6					

		West (247.5- 292.5)	148945	941	0.00632	0.08406	8.40605	8					
		NorthWest (292.5- 337.5)	174889	536	0.00306	0.04078	4.07784	4					
		North (337.5- 360)	46452	303	0.00652	0.08679	8.67893	8					
	Total				0.07516	1	100		0.01711	0.209367	0.1922543	0.090593689	2.12216
3.	Plan Curvature	Concave	50313	391	0.00777	0.32545	32.5451	32					
		Flat	730632	5094	0.00697	0.29198	29.1978	29					
		Convex	208860	1908	0.00914	0.38257	38.2571	38					
	Total				0.02388	1	100		0.29198	0.382571	0.0905937	0.090593689	1
4.	Elevation	<1500 m	88357	646	0.00731	0.20904	20.9037	20					
		(1500- 2000)m	224128	1260	0.00562	0.16073	16.0733	16					
		(2000- 2500)m	292309	4319	0.01478	0.42245	42.2447	42					
		(2500- 3000)m	238429	792	0.00332	0.09497	9.49723	9					
		(3000- 3500)m	95294	376	0.00395	0.11281	11.2811	11					
		(3500- 4000)m	50445	0	0	0	0	0					
		>4000m	843	0	0	0	0	0					
	Total				0.03498	1	100		0	0.422447	0.4224466	0.090593689	4.66309
5.	Distance to River	0-50m	181063	2006	0.01108	0.28296	28.2956	28					
		50-100m	145280	1115	0.00767	0.19601	19.6014	19					
		100-150m	127769	885	0.00693	0.1769	17.6903	17					
		150-200m	108682	808	0.00743	0.18988	18.9876	18					

		>200m	427011	2579	0.00604	0.15425	15.4252	15					
	Total				0.03915	1	100		0.15425	0.282956	0.1287041	0.090593689	1.42067
6.	Distance to Road	0-100m	312812	1681	0.00537	0.12725	12.7253	12					
		100-200m	207082	1447	0.00699	0.16547	16.5467	16					
		200-300m	156820	1754	0.01118	0.26486	26.4858	26					
		300-400m	110599	1532	0.01385	0.32801	32.8014	32					
		>400m	202633	979	0.00483	0.11441	11.4408	11					
	Total				0.04223	1	100		0.11441	0.328014	0.2136057	0.090593689	2.35784
7.	Geology	Augen Gneisses Banded Gneisses	142554	2538	0.0178	0.42816	42.8164	42					
		Ulleri Formation	39913	728	0.01824	0.43865	43.8646	43					
		Himal Gneiss	743916	4120	0.00554	0.13319	13.319	13					
		Lakharpata Formation	29910	0	0	0	0	0					
		Galyang Formation	33691	0	0	0	0	0					
	Total				0.04158	1	100		0	0.438646	0.4386465	0.090593689	4.84191
8.	LandUse	Forest	702800	3903	0.00555	0.16204	16.2041	16					
		Shrubland	175937	2361	0.01342	0.39156	39.1558	39					
		Grassland	111172	764	0.00687	0.20052	20.0519	20					
		Agriculture Land	356	3	0.00843	0.24588	24.5883	25					
		Water bodies	57	0	0	0	0	0					
	Total				0.03427	1	100		0	0.391558	0.3915578	0.090593689	4.32213