

**LANDSLIDE SUSCEPTIBILITY MAPPING AND GEOLOGICAL STUDY IN
KALIGANDAKI RURAL MUNICIPALITY, GULMI,
CENTRAL NEPAL**

Field Report

Submitted to

Kaligandaki Rural Municipality office, Purnighat, 04, Gulmi

Submitted by

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Date –

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Abstract

Landslide is major problem in mountainous region, it occur shallow to deep landslide, caused by rainfall, earthquake and human activity. Monsoon and earthquake are the main causes of landslide in Nepal. The study area is located at highly fragile, crushed and weak geology of hilly region. The main objectives of this study are landslide susceptibility mapping, landslide inventory mapping, and identification of landslide prone area. Desk study, field study, data interpretation and analysis, discussion and conclusion methodology was applied for this study. For landslide susceptibility mapping Frequency ratio method was applied and which was validated by ROC curve. Nine parameters were taken such as Slope, Aspect, Curvature, Relief, Geology, Landuse, Structures, Road, and Stream. The number of landslide is 181. An area under the cure of this study area is 70.10 % i.e. it is validated model. The outcomes of the susceptibility map of the study area is validated by field visit data and the almost these model is valid. The outcome of the data shows that most of the landslide were observed near about distance to structures (Fault, Joints, and Folds), distance to streams, distance to roads, weak geology, and colluvial soil. The main causes of landslides are the highly fragile geology with newly constructed road (without detail study of the geology). For instance Dandagaun phyllite area, colluvial soil, Fault zone along the Urleni, Khamaripata to Nayagau. In addition, anthropogenic, topographic and geological factors are the main responsible for the landside in this area.

Keywords: Frequency ratio, landslide susceptibility, Dem, Geology and landslide inventory.

1 INTRODUCTION

Landslide is major problem in mountainous region, it occur shallow to deep landslide, caused by rainfall, earthquake and human activity. Mostly, landslide occurs during monsoon season and earthquake but human activity also vital role for landslide. Nepal is central zone of Himalaya and it is tectonically more active zone thus, many shallow to large earthquakes occurs. The geomorphic and tectonic history of the Nepal Himalaya largely supports the occurrence of deep and steep river valleys in central Nepal (Hasegawa et al. 2008). Tectonically Nepal is divided into five division such as Siwalik, Lesser Himalaya, Higher Himalaya, and Tethys Himalaya. Landslide is major natural disaster in Nepal, every year many people lost their life and properties. Nowadays, the major problem in hilly area is construction of low budget roads that create lots of shallow to large scale landslide in monsoon season. The construction of roads in hilly area is most challenging job but if we study properly then we can manage natural disaster. Disaster will occur every year but if we diagnosis such kind of disaster then we can manage or save ours live and property. Therefore landslide susceptibility mapping is one of the most useful tools for the identification of landslide prone area and we can use such kind of map for the land use planning, engineering work and urban planning. That map differentiate high, medium, and low susceptibility area.

1.1 Study Area

The study area are assigned for Kaligandaki Rural Municipality, Gulmi district. Kaligandaki rural municipality is located in hilly region. This area also affected by landslide during this monsoon and previous years and many people lost their lives and properties. The study area is located in Lesser Himalaya which is bounded by Main Central Thrust (MCT) in Northern side whereas Main Boundary Thrust (MBT) in southern side. The lowest elevation of this area is 550 m whereas the highest elevation is 1976 m.

Climate in Kaligandaki area is vary from upper tropical bioclimatic zone to upper subtropical bioclimatic zone. The total area under the study area is 101 sq. km and bounded by the coordination of 28° 0' 49.36'' N, 83° 36' 12.84'' E to 28° 4' 3.11'' N, 83° 28' 40.47'' E.

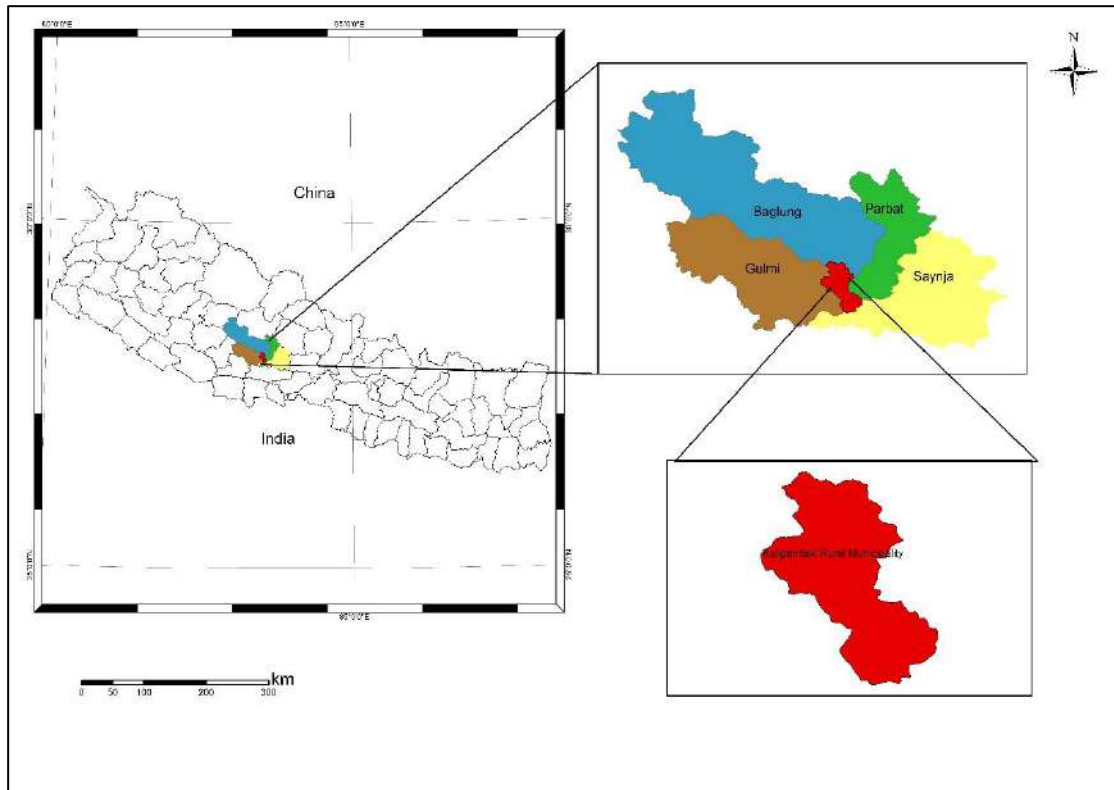


Fig:1 Study Area

1.2 Objectives

The main objective of this project are

- Landslide susceptibility mapping
- Landslide inventory mapping
- To identify landslide prone area

2 METHODOLOGY

In order to carry out the study and arrive at a logical conclusion, the consultant adopted the standard research tools for data collection, interpretation, and analysis. The methodology also taken into account the Terms of Reference Provided by the client. The methodology for various phases of the study has been presented in following sections.

- Desk study
- Field survey and investigation
- Susceptibility mapping
- Data analysis, interpretation
- Discussion and conclusion

2.1 Desk Study

During this phase of the study, the secondary information and data generated by various agencies was done. Topographic map, digital topo data, geological map and satellite image were collected and respective study area related publish and non-published literatures and paper were review. Landslide susceptibility map was prepared based on secondary data collected in desk study. Landslide susceptibility mapping procedure is shown in following flow chart.

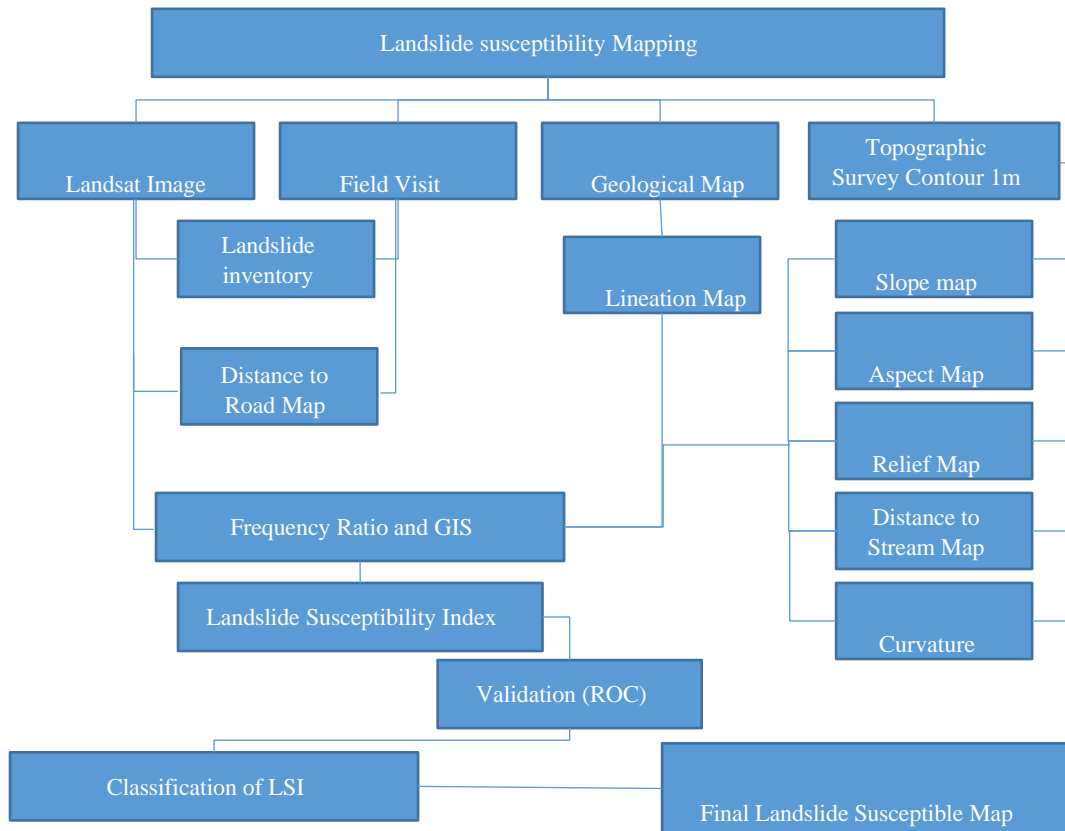


Fig:2 Flow Chart

Landsat image was used to create landslide inventory mapping, landuse cover map, distance to stream, and distance to road mapping. Topographic survey data (Department of survey) was used for preparation of other factor map (slope, aspect, relief, curvature). Geological map was taken from department of mines and geology and prepared studied area of geological map and structures map.

After preparing all 9 factor maps, landslide inventory map was use to cross with the all factor maps and the generated tabulated data was create landslide susceptibility map using frequency ratio method. LSI map so prepared was validated in SPSS using training sample

of landslide of the study area. Finally ROC curve was used to classify the LSI map into stable zone, quasi stable zone and unstable zone and create final landslide susceptibility map of the study area

2.1.1 Frequency Ratio Method

Understanding the area specific, physical conditions and processes for triggering the landslides is of significant importance to evaluate the probability of landslides. Frequency ratio is a quantitative technique for landslide susceptibility assessment using GIS techniques and spatial data (Bonham-Carter, 1994, Lee and Talib, 2005, Chen et al., 2016, Chen et al., 2016, Ding et al., 2017). The frequency ratio (FR) technique is frequently and effectively used for landslide susceptibility mapping (Yilmaz, 2009, Reis et al., 2012, Umar et al., 2014, Chen et al., 2016, Wu et al., 2016, Wang and Li, 2017). It is based on the quantified association between the landslide inventory and the landslide causative factors (Reis et al., 2012). To obtain the frequency ratio (FR) for each class of the causative factors, a combination has been established between the landslide inventory map and factor map using the Eq. (1) (Mondal and Maiti, 2013, Fayez et al., 2018).

$$FR = \frac{Npix(1)/Npix(2)}{\sum Npix(3)/\sum Npix(4)} \dots \dots \dots Eq (1)$$

Where Npix (1) = the number of pixels containing Landslide in a class

Npix (2) = Total number of pixels of each class in whole area.

Npix (3) = Total number of pixels containing landslide.

Npix (4) = Total number of pixels in the study area.

The derived frequency ratio is summed to develop a Landslide Susceptibility Index (LSI) map using Eq. (2) (Lee and Talib, 2005)

$$LSI = FR1 + FR2 + FR3 + FR4 + \dots \dots \dots + FRn \text{ ----- Eq. (2)}$$

2.2 Field Survey and Investigation

The main objective of field work is to verify the data collected during the desk study and identify the major landslide and its impact in the study area. Kaligandaki rural municipality has a seven ward and field visit was carried out through one to seven ward. As the consultation with president of Kaligandaki rural municipality, study was done. Similarly,

with consultation of every ward president, field work was carried out in respective landslide area guided by local people also.

2.2.1 Ward No – One

Geologically this area is located at Dhading dolomite formation and there is rough and steep terrain. Giduwa was the first study area and guided by Mr. Preetam Singh Rana, there is found lots of shallow landslide, had happened during this monsoon. NERA school building is high risk of landslide both upper and lower building because there has already landslide gone and lower building will affect if extension of road. Similarly, backward of upper building had been built some retaining wall but it couldn't stabilized the slope failure. For the protection of this building, we should do proper retaining wall with bioengineering on this area.



Photo:1 School Building

In addition, Tuthum village is another risk area where there is residual silty clay (red soil) soil type and steep terrain, there is high probability of landslide during monsoon because the behavior of silty clay (red soil) is high porosity and less permeability therefore it expanded its volume. In this area a newly constructed road was observed which is quiet good to avoid

the village by road but at the eastern side of the village there is problem of landslide due to the constructed road. There should be more attention for further construction of this road.

2.2.2 Ward No – Two

Janajyoti Primary School, Vayakot is high risk of landslide because forward and backward side of school building was observed landslide. The soil type of this area is silty gravel and colluvial soil. The main causes of landslide is not proper channeling of rain water during monsoon. Similarly, Hira Bahadur Thapa house is high risk of landslide in Vayakot because both backward and forward of this house has gone landslide. The main causes of this landslide are high step of slope and weak soil and geology.



Photo:2 Newly Formed House

Nigare village landslide is man made landslide, causes of landslide is low budget road construction, weak and fragile geology. This track was open without proper knowledge of geology and geomorphology. And another big mistake was track open beyond the DPR. There is high risk of landslide and it directly affects five houses. Geology of this area is highly weathered phyllite and colluvial soil with steep (45 degree) slope. Road constructed as like butchering of the hill and its consequences, there is lots of cut slope failure and crack

developed on depositional, cut slope masses. Another risk factor is large boulder (29 m×28 m×10 m) was observed, has appeared during road construction 200 m above the village and which is high probability of slide during monsoon or earthquake therefore this village is high risk of disaster.



Photo:3 Landslide at Nigare village



Photo:4 Boulder

2.2.3 Ward No - Three

At Lamsarang Mr. Yam Bdr Thapa house is high risk of landslide because there is high angle slope (40 degree) terrain and landslide has occurred on this monsoon and there is lots of crack develop in the top of landslide. The lithology is silty gravel with highly crushed phyllite.



Photo:5 Landslide at Lamsarang

Nayakhani is another vulnerable area where three houses are directly affected by landslide, there is landslide on both sides of the village. Geologically this area is weak and highly weathered phyllite and colluvial soil. At the left side of the village there is a series of landslides. Similarly, just 200 m above the previous slide there is a man-made slide observed, i.e. caused by road construction. Three houses are directly affected by this slide.



Photo:6 Landslide at Nayakhani

2.2.4 Ward No – Four

Saurani village is high risk of landslide because there is three houses are affected and one house had already destroyed. The geology of this area is weathered dolomite and this is the main caused of landslide. Another risk area is Bhangkharka, Mr. Min Bdr Bhandari house is very risk of landslide. In this monsoon there had gone landslide which directly affected newly constructed road and his house. The lithology of this area is weathered phyllite, slate and colluvial soil. The main causes of landslide are construction of road below the landslide and weak geology. There is lots of crack developed in top and right side of the landslide therefore this area is high risk of landslide.



Photo:7 Landslide at Saureni village

Khottrok village is situated large scale passive landslide. Slide was occurred in 2018 BC and affected total village, near about 20 m slip scarp had been appeared on the top of village i.e. detachment of land mass.

Similarly, in Wakin road, depositional material has cracked due to loose overburden material. If crack facilitated to slide it will affects lower Wakin village.

2.2.5 Ward No – Five

At 500 m ahead Danda village, a landslide was observed which affected road and cultivation land below the road i.e. Latitude 28.06757, longitude 83.53634. The main causes of landslide are road construction and failure of depositional material. The lithology of this area is dolomite rock.



Photo:8 Dolomite Rock Slide

Similarly, at 100 m below Litung Mangalsthan Lower Secondary School, Phoksin, a landslide was observed which directly affected three houses. The main causes of landslide are low budget road construction just above the houses and consequently this monsoon flowed debris masses on these houses. The soil type is colluvial soil and weathered phyllite. The coordination of this location is latitude 28.07121, longitude 83.52859.

Three houses are affected by landslide at lamkura village was observed and is caused by low budget road construction. Its location is Latitude 28.05896, longitude 83.53111. The main lithology of this area is phyllite, dolomite, and colluvial soil. In inquiry of local people this road would connect Bali and this area is too steep with fragile geology there should be more attention for construction of further road i.e. needs proper study. If road is construct without detail study, It will be appeared same problem as a like Nigare village.

2.2.6 Ward No – Six

At Dhungrekharka Dhawa, cut slope failure was observed, there is crack developed and that affects seven houses of this village. The main causes of this slide are road construction and above the road there is cultivation land (generally rice plantation). Geologically this area is Dhading dolomite i.e., dolomite rock type and silty gravel soil type.

Backward from the Lung village at Shree Sukra Secondary School a cut slope failure was observed and it directly affected school building. The main cause of landslide is depositional material has filed due to high steep of slope and loose compactness of soil. The main lithology of this area is dolomite and silty gravel. The location of this area is Latitude 28.11617, Longitude 83.54178. For the protection of this building requires gabion/concrete wall.



Photo:9 Landslide at Lung School

Similarly at lower Korang, series of landslide was observed and it directly affects road obstruction. If this landslide occurs as similar way then it will affects cultivation land and some houses above this landslide. The main cause of landslide is weathered and crushed dolomite.



Photo:10 Landslide at Lower Korang

At Janata Bal Kalyn Primary School, cut slope failure was observed and its affects building backward and forward. The main cause of cut slope failure is high steep slope and loose soil compaction during built of wall. Backward of building road depositional material has field. For the mitigation of this slide required benching gabion/concrete wall and channeling rainfall water in proper way.

At Urleni, this area is geologically sensitive area and road are constructed without proper channeling system in the road thus it affect directly and indirectly in our social activities. Without proper planning, low budget road has been constructed and its consequences seven houses are affected by this slope failures. The soil type of this area is colluvial soil and there is high possibility of landslide. This area is highly fragile geology i.e. weak geology and was observed ancient landslide also. The road has been constructed in between the village which is the major problem and its consequences slope failures has occurred. To continue of this road is major challenging for construction by low budget i.e. requires high budget (can do channel, protection wall, gabion, concrete wall etc., as consequently).



Photo:11 Landslide at Urleni Gaun

Similarly, in between Urleni to Ghumaune, this area crosses geological structures (Fault) which created geology more crushed and fragile and which is passed over Khamaripata therefore this area has more prone to landslide. We can observed many landslide over there. In this area Kaligandaki corridor also constructed over the ancient landslide whereas another Urleni to Korang road also constructed. Which is constructed without of study of landslide. Another interesting part is road constructed without channel, during monsoon which helped to initiates the slope instability. Under the observation of this area, we need to construction

of road very carefully i.e. requires channel and stabilization methods during construction phase of the road consequently.

At Baralwa, translational slide was observed which directly affected five houses. The main cause of this landslides is newly constructed low budget road. Small slide creates debris flow above the village. Residual soil (red clay) expanded due to absorption of water during this monsoon and failed.



Photo:12 Landslide at Barlwa

2.2.7 Ward No – Seven

At Dhuwa Khola Kanchane Gaunda, landslide was observed. The main causes of landslide are construction of road and seepage of water during monsoon in between clay layer of this slide. Geologically this area is very weak because there is a fault which affects this area more vulnerable and risk for landslide. The main lithology of this area is crushed dolomite and slate, due to the fault pressure, temperature dolomite and slate became white and black clay.



Photo:13 Landslide at Dhuwa Khola

At Nayagaun village, two landslides were observed: one is a depositional mass that failed during this monsoon, and another is a cracked depositional mass. If this landmass failed, it would affect many houses. The main cause of the landslide is road construction without a proper water channeling system. The soil type in this area is residual silty clay.



Photo:14 Landslide at Nayagaun

2.3 Landslide Susceptibility Mapping

2.3.1 Landslide Inventory

Based on the Landsat image, google earth and field visit, 181 landslides were mapped with a total area of 101 sq. km and inventory map is shown in Figure 3. Most of the landslides are complex landslide triggered by rainfall and earthquake.

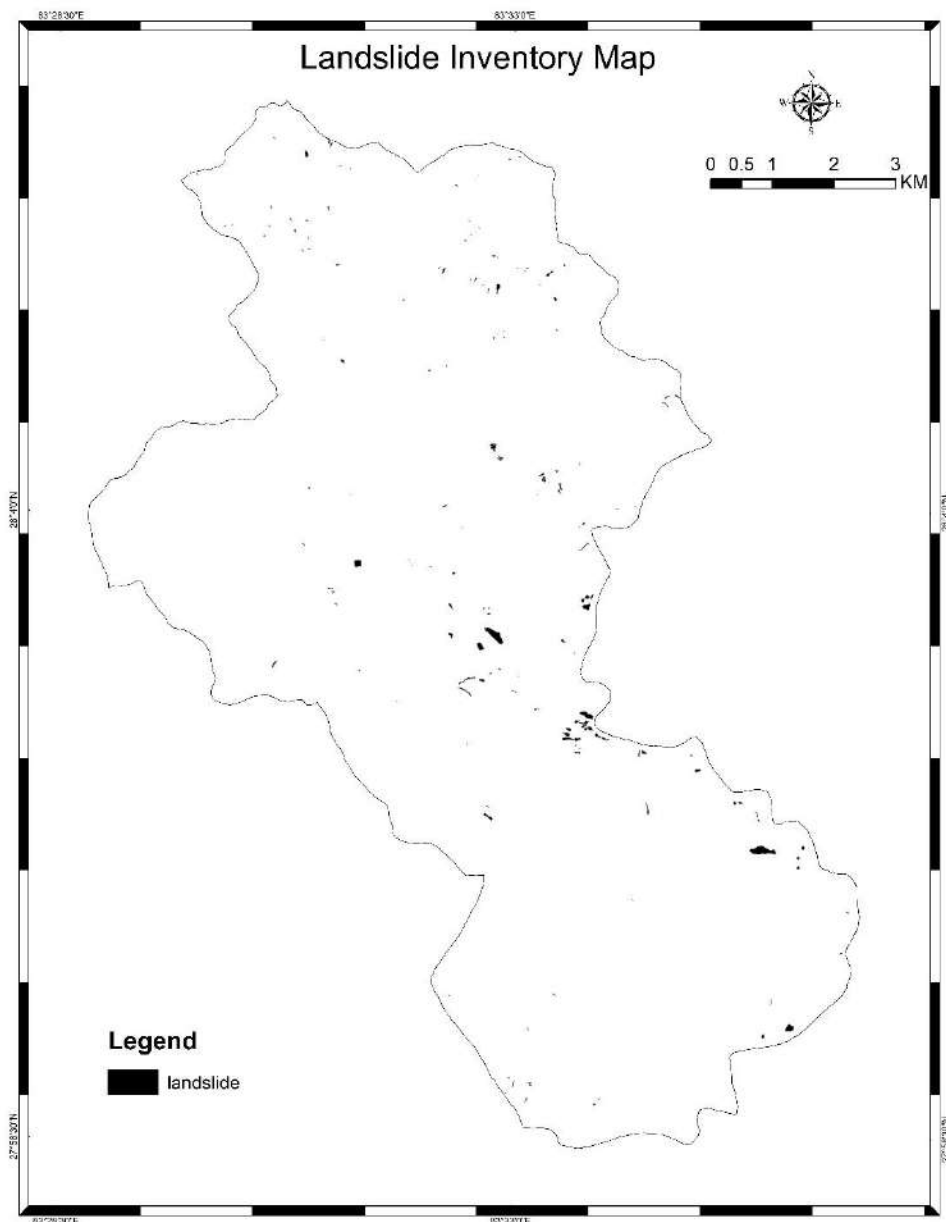


Fig:3 Landslide Inventory Map

2.3.2 Landuse Land Cover

Landuse Land cover (Figure 4) map was prepared by manually digitizing the study area using Landsat and google earth image. Table 1 shows that Forest occupy 52.73 %, Cultivation land

occupy 36.01 %, and sparse forest occupy 10.21 % of the total area. Crossing LULC with landslide shows that 53.17 % of total landslide lies in forest land, 28.70 % of cultivation land, and 17.20 % in sparse forest.

The frequency ratio for the land-use land cover (Table 2) shows that the Landslide and sand are highly susceptible to landslide as they have high frequency ratio of 9.48 and 5.89 respectively compared to other class like Kaligandaki River and rocky terrane which has least FR of 0.

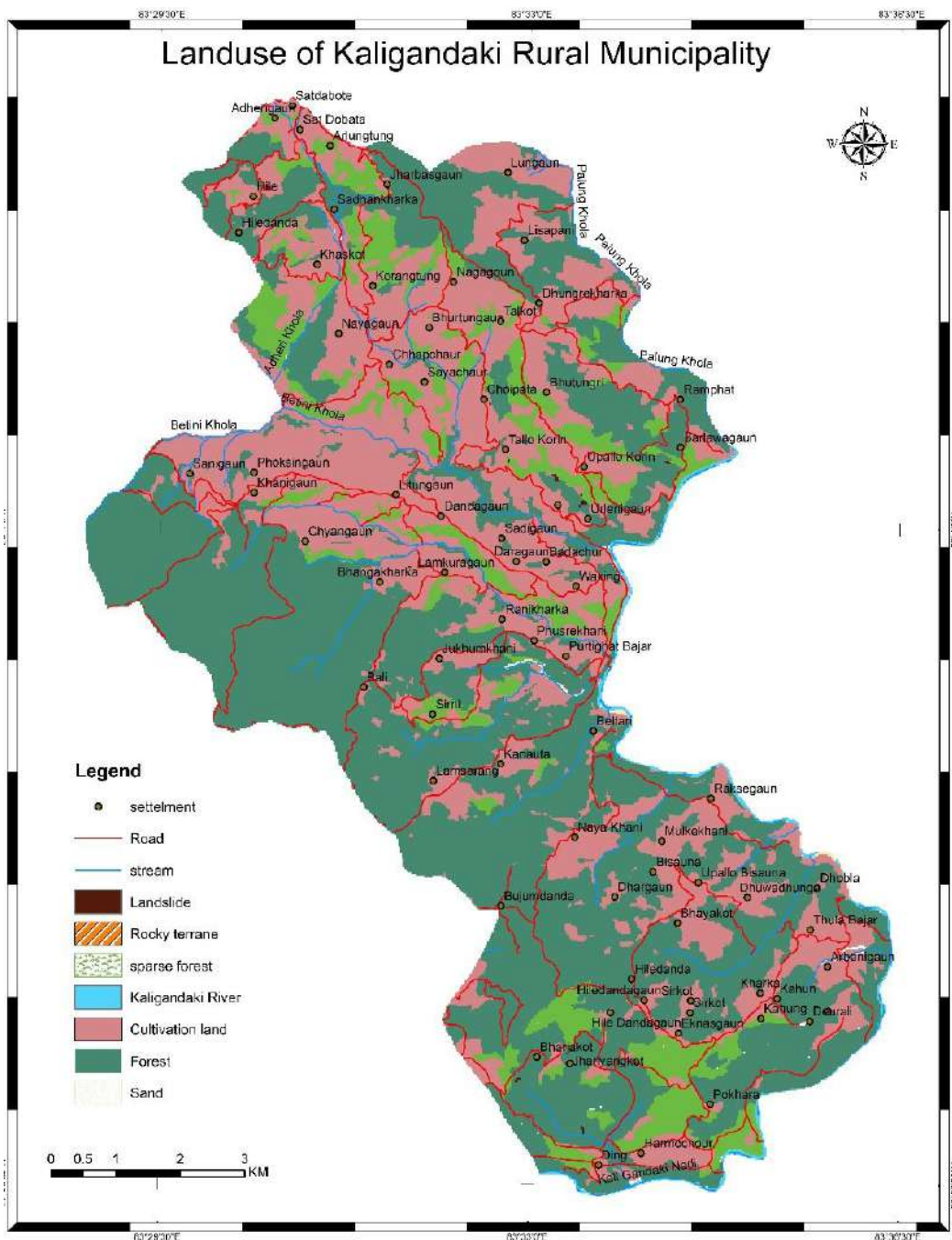


Fig:4 Landuse Map

2.3.3 Geology

Geology (Figure 5) was extracted from geological map Department of mines and geology. Table 1 shows that Dhading dolomite occupy 57.21 % of total area, Norpul Formation occupy 19.97 % and Benighat slate occupy 12.44 %. Crossing LULC with landslide shows that 37.87 % of total landslide lies in Dandagaon phyllite, 26.89 % in Benighat slate, and 22.26 % in Norpul formation.

The frequency ratio for the geology (Table 2) shows that the Dandagaon phyllite and Benighat slate are highly susceptible to landslide as they have high frequency ratio of 5.64 and 2.16 respectively compared to other class like Dhading dolomite and alluvial soil which has least FR of 0.20 and 0.47.

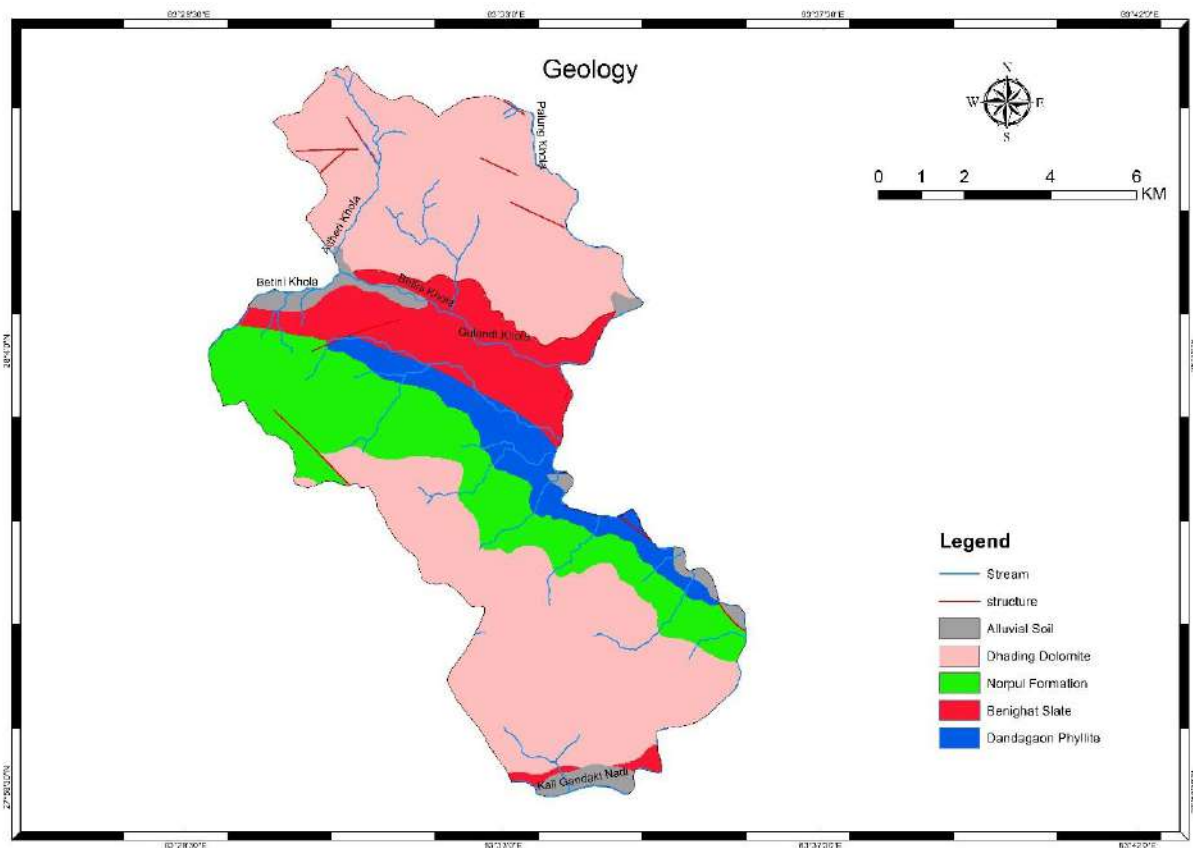


Fig:5 Geological Map

2.3.4 Distance to structure

Distance to structure (Figure 6) was prepared by extracting the center line of the structures and process in ArcGIS using Euclidean Distance tool. The Euclidean distance tools describe each cell's relationship to a source or a set of sources based on the straight line distance. Table 1 shows that the distance from the structure range 0 – 1000 m covers highest area

46.53 % of total area where as > 5000 m covers 3.73 % is the least of the total area. Similarly, highest landslide cover in range between 0 – 1000 m, 1000 – 2000 m and 2000 – 3000 m respectively. Least landslide cover in between 3000 – 5000 m.

The area in the vicinity of 1000 – 2000 m and 2000 – 3000 m from the structure are more prone to landslide as they pose high frequency ratio of 1.53 and 1.22 respectively. The frequency ratio decreases for regions which are far from the structure for instance, at the vicinity of > 5000 m is 0.49 and for 3000 m to 5000 m the FR value is equal to 0.

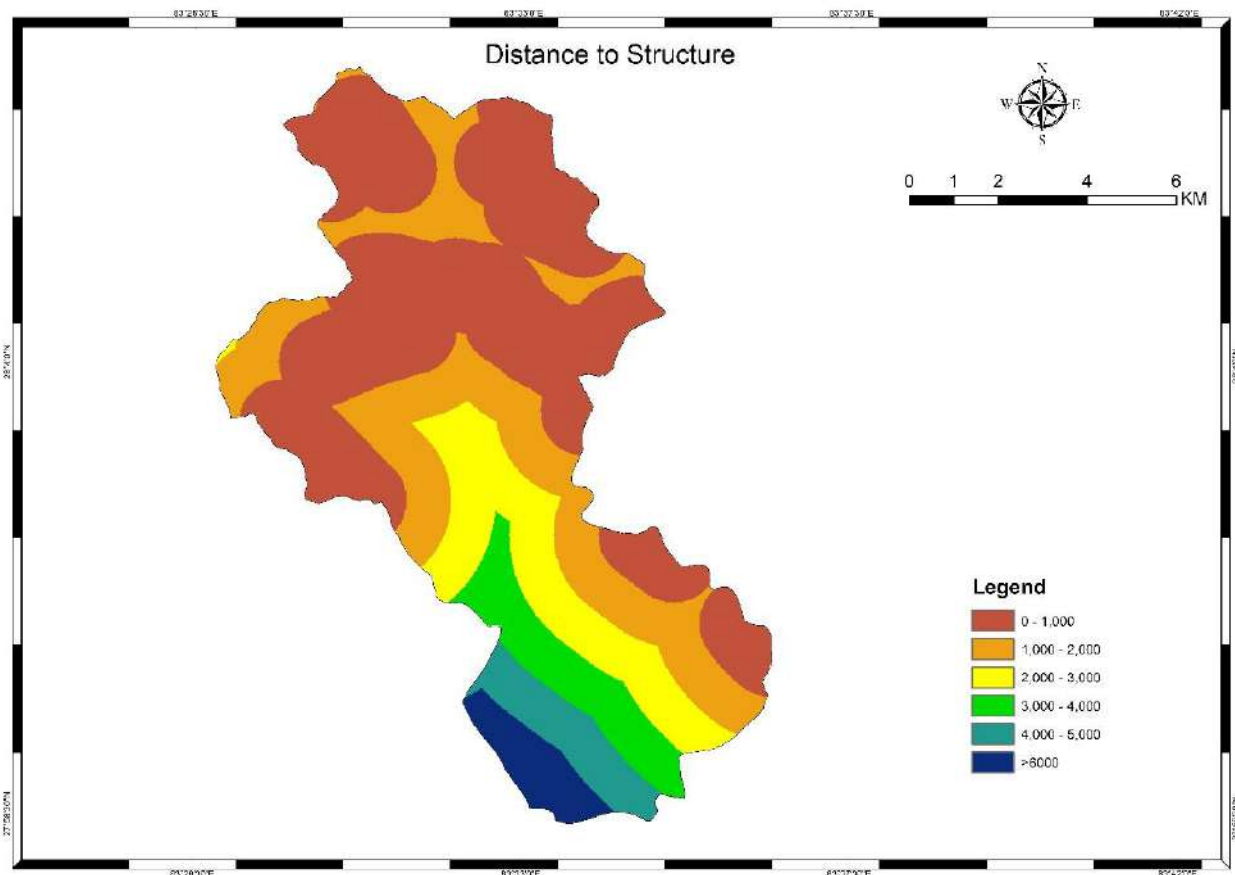


Fig:6 Distance to Structure Map

2.3.5 Distance to Road

Distance to road map (Figure 7) was prepared by extracting the center line of the road and process in ArcGIS using Euclidean distance tool. The Euclidean distance tools describe each cell's relationship to a source or a set of sources based on the straight line distance. Table 1 shows that the distance from the road 0 – 200 m covers 55.87 % of the total area where as > 800 m covers 0 % . Similarly, 71.80 % of total landslide lies in the distance range 0 – 200 m and 11.58 %, 11.48 % of total landslide lies in the same distance of 200 – 400 m and 400 – 600 m respectively.

The area in the vicinity of 0 – 200 m and 600 – 800 m from the road are more prone to landslide as the pose high frequency ratio of 1.29 and 1.11 respectively. The frequency ratio decreases for regions which are far from the road for instance, at vicinity of 200 – 400 m is 0.43 and for > 800 m the FR value is equal to 0.

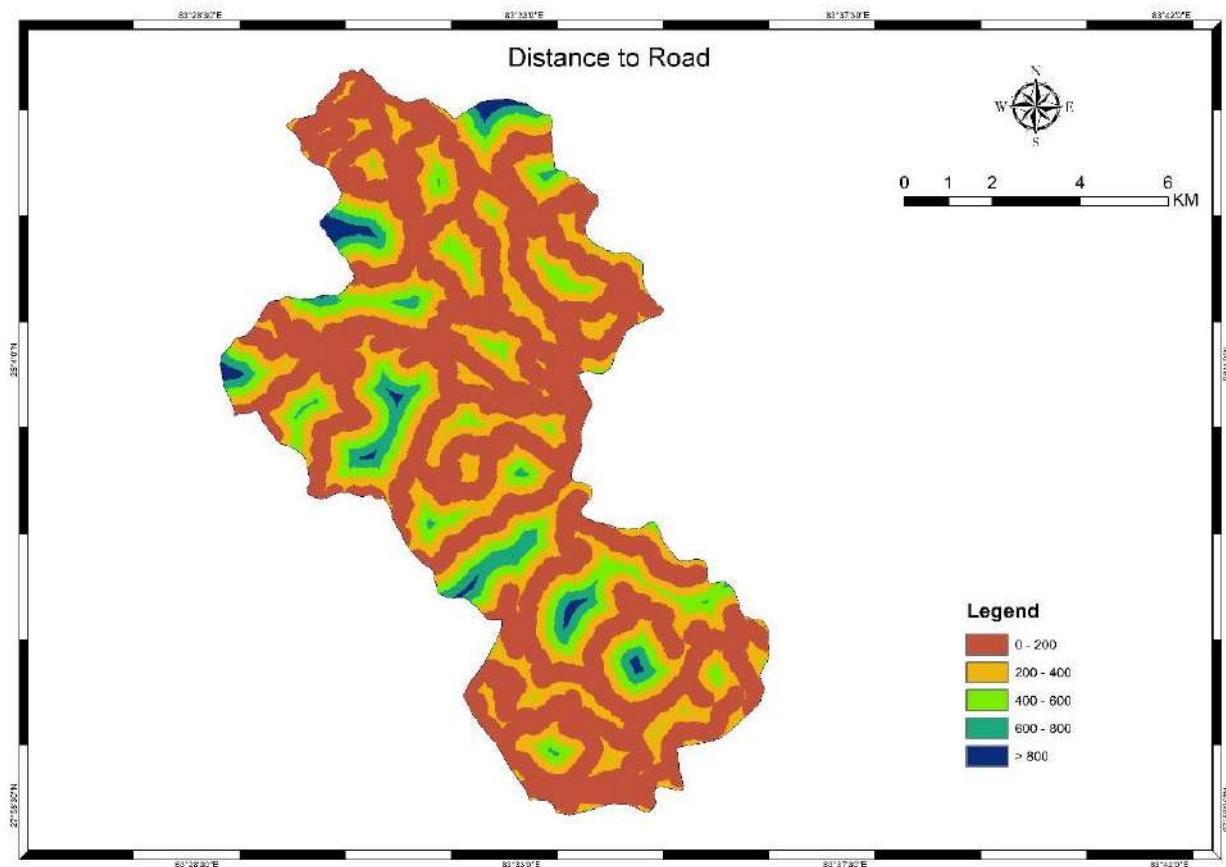


Fig:7 Distance to Road Map

2.3.6 Distance to Stream

Distance to stream map (Figure 8) was prepared by extracting the center line of the road and process in ArcGIS using Euclidean distance tool. The Euclidean distance tools describe each cell's relationship to a source or a set of sources based on the straight line distance. Table 1 shows that the distance from the stream 0 – 400 m covers 52.39 % of the total area where as > 1600 m covers 0.12 %. Similarly, 73.01 % of total landslide lies in the distance range 0 – 400 m and 25.98 % of total landslide lies in the same distance of 400 - 800 m.

The area in the vicinity of 0 – 400 m and 400 – 800 m from the road are more prone to landslide as the pose high frequency ratio of 1.39 and 0.82 respectively. The frequency ratio decreases for regions which are far from the road for instance, at vicinity of 800 – 1200 m is 0.05 and for 1600 m the FR value is equal to 0.

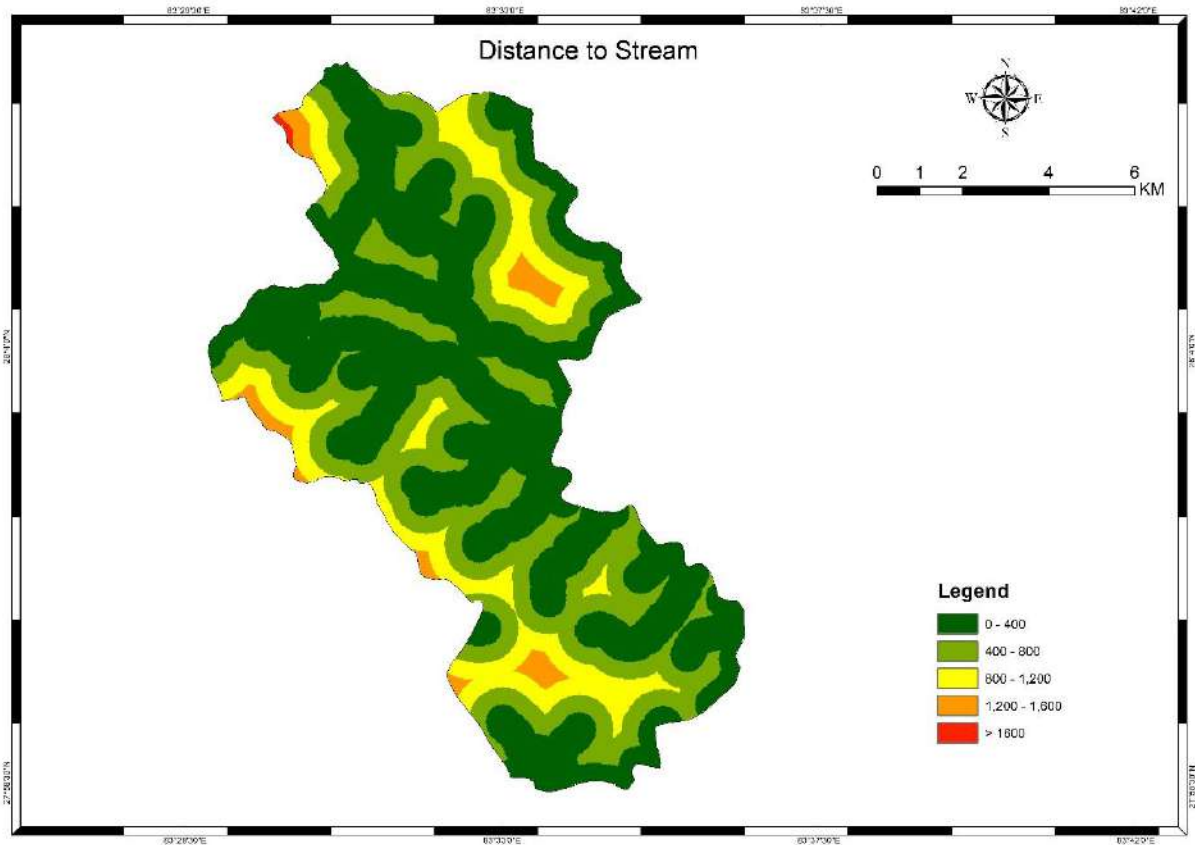


Fig:8 Distance to Stream Map

2.3.7 Slope

Slope map (Figure 9) was generated using 25×25 DEM (Digital Elevation Model) using the algorithm slope of Surface-Spatial Analyst Tool in ArcMap. The slope is classified into 5 classes using equal interval classification method. Table 1 shows that the slope angle ranged 0 – 15° occupies the area of 40.88 % of total study area and has 0.50 % of total landslide in it. Similarly slope angle ranged 35 - 45° occupies 72.61 % of total study area landslide.

The terrain with slope of 35 - 45° is most prone for the landslides with frequency ratio of 2.60 and the terrain with slope gradient of 0 – 15° is least prone to landslides with frequency ratio of 0.5.

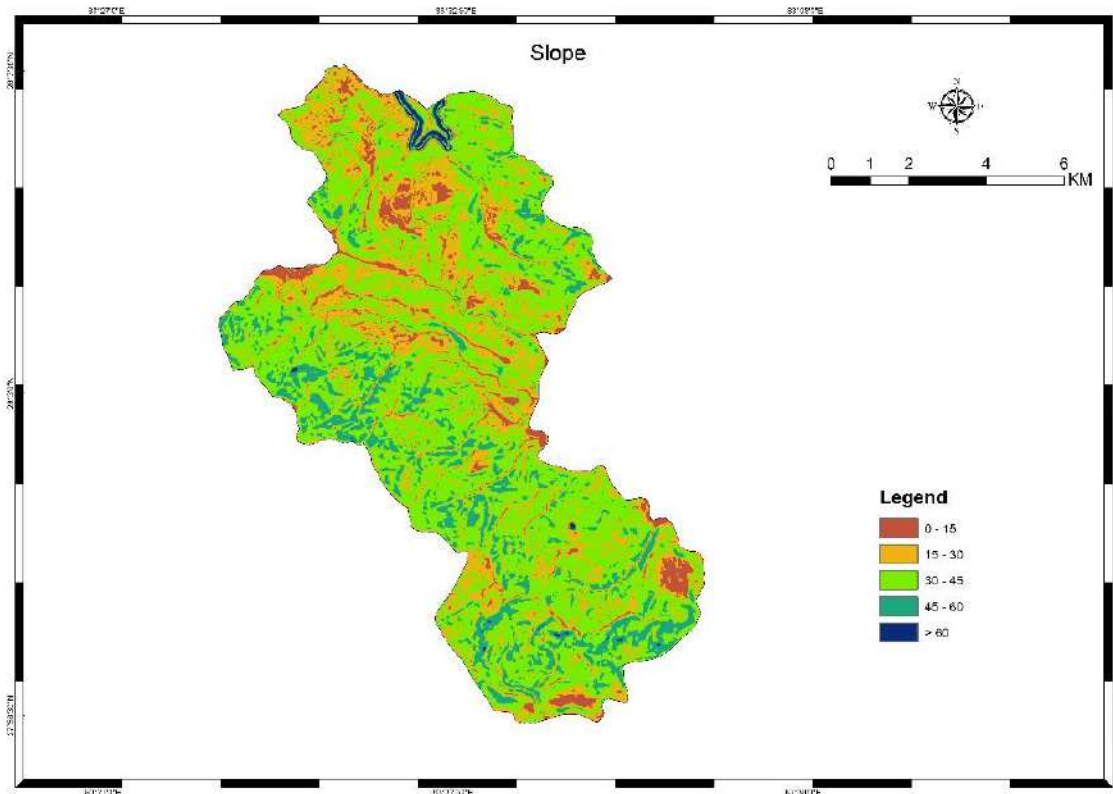


Fig:9 Slope Map

2.3.8 Aspect

Aspect map (Figure 10) was prepared using 25×25 DEM (Digital Elevation Model) using the algorithm aspect of Surface-Spatial Analyst Tool in ArcMap. The aspect was classified into 9 classes as shown in Table 1. It is found that the study area is dominated by east, Northeast and south-east facing slopes that occupies 18.23 %, 16.99 % and 14.58 % respectively. Also most of the landslides were observed in these slopes i.e. east facing slope contains 34.44 % of total landslides, similarly south facing slope contains 37.09 % of landslides and south-east facing slope contain most of the landslide with 18.73 % of total landslides.

The frequency ratio for the aspect map shows that the east and southeast facing aspect has highest frequency ratio values 1.89 and 1.28 respectively (Table 1) and are prone to landslide.

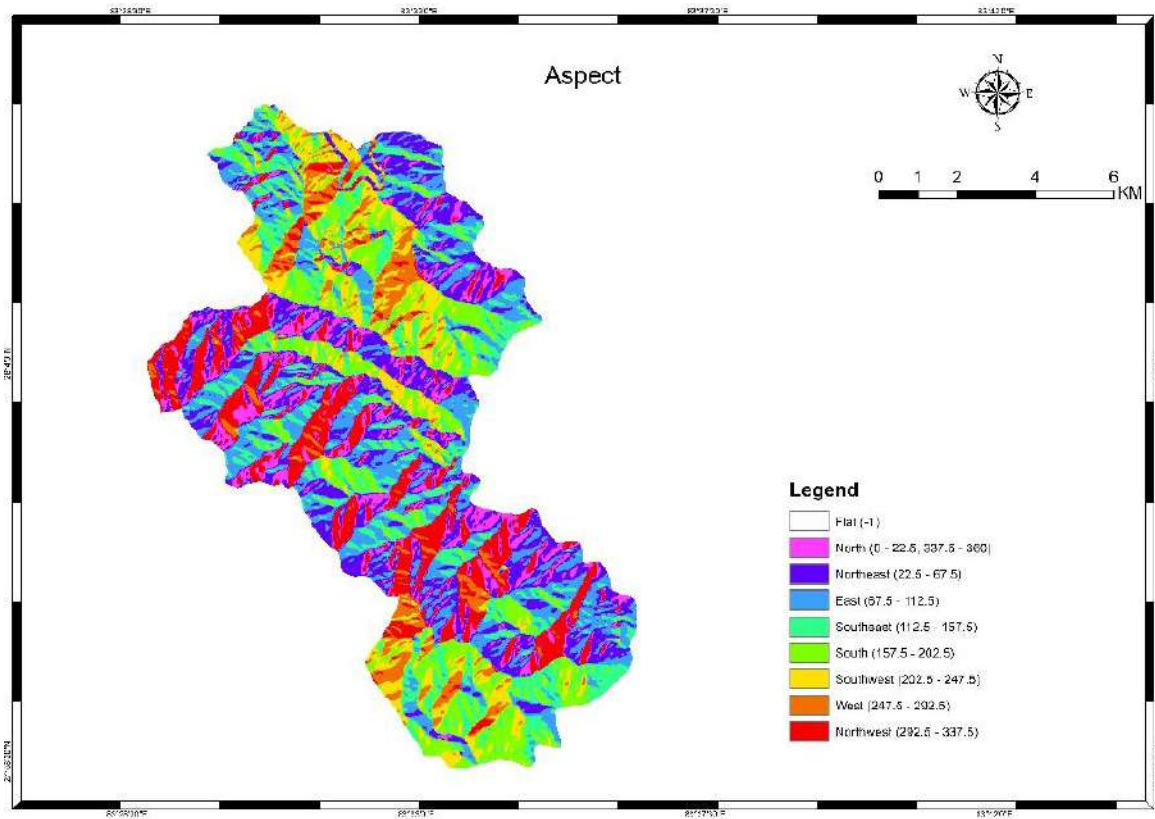


Fig:10 Aspect Map

2.3.9 Relief Map

Relief map or elevation map (Figure 11) of the study area was generated using 25×25 m DEM. The lowest elevation is observed as 0 m and highest elevation is 254 m. By using manual interval method the relief map was classified into 5 classes (Table 1). It was observed that the elevation ranged 50 - 100 m occupies 12.16 % of total study area and has 33.53 % of total landslides.

The highest frequency ratio of 3.47 is observed in the elevation range 0 - 50 m and FR of 0.30 is found in the elevation of 150 - 200 m.

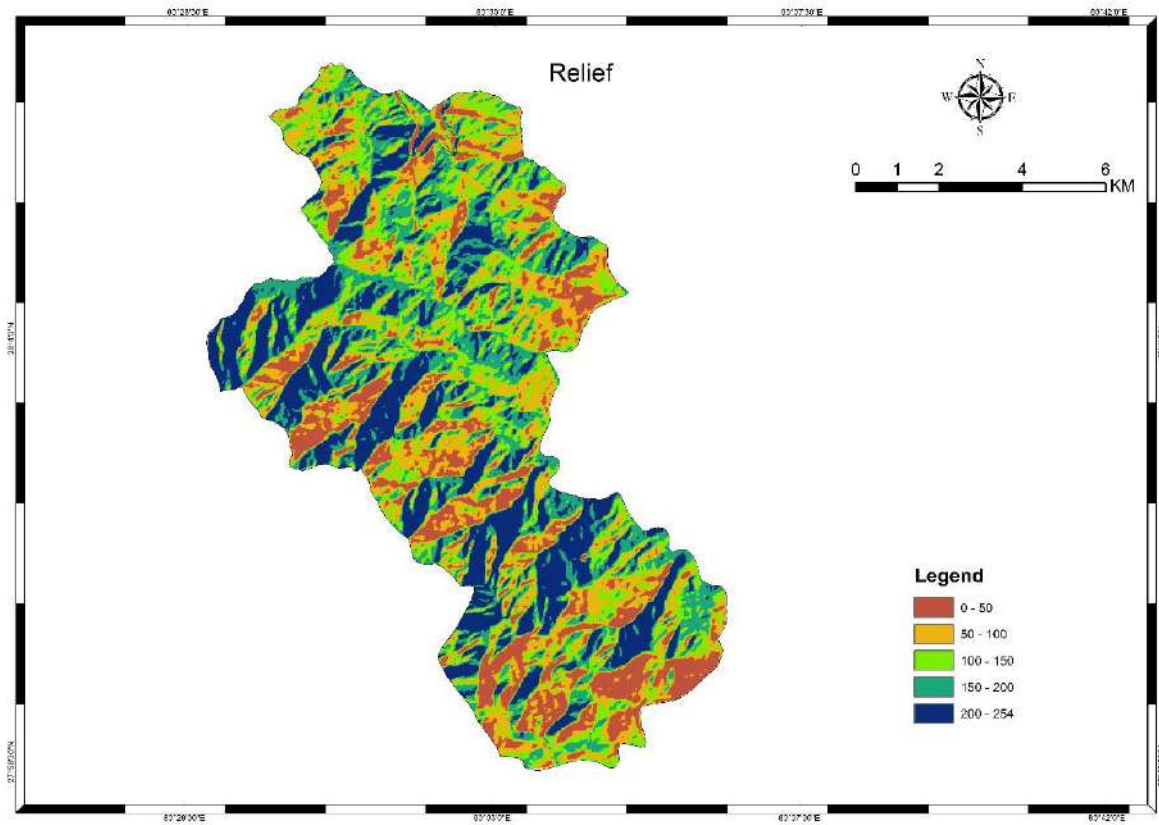


Fig:11 Relief Map

2.3.10 Curvature

The curvature (Figure 12) is the amount by which a curve deviates from being a straight line, or a surface deviates from being a plane. Curvature map was prepared using 25×25 m DEM using the algorithm aspect of Surface-Spatial Analyst Tool in ArcMap. Curvature is categorized into concave, linear and convex surface as shown in figure 12. Table 1 shows that the planar topography cover 47%, whereas concave topography covers 26.35% and 26.83 % area cover by convex topography of the study area. Most of the landslide have occurred in concave surface as 52.77% of total landslide lies in this zone. Hence Concave is more prone to landslide which is also supported by the frequency ratio that value 2.

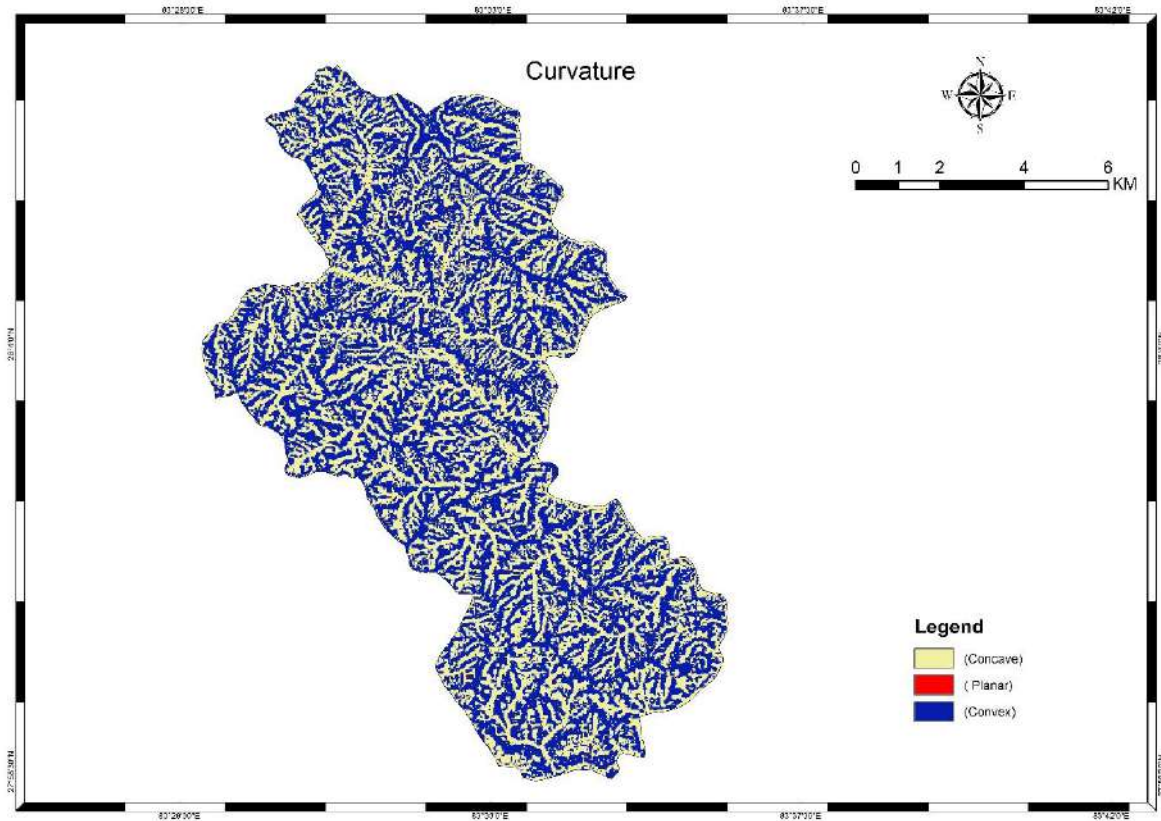


Fig:12 Curvature Map

3 DATA INTERPRETATION AND ANALYSIS

3.1 Landslide Susceptibility Analysis

Landslide susceptibility Index map (LSI) was prepared by combining all 9 factor maps (Figure 14).

$$\text{Final LSI} = \text{PR}_{d1} * \text{FR}_1 + \text{PR}_{d2} * \text{FR}_2 + \text{PR}_{d3} * \text{FR}_3 + \text{PR}_{d4} * \text{FR}_4 + \dots + \text{PR}_{dn} * \text{FR}_n$$

Where,

PR = Predictive ratio of each domain.

FR = Frequency ratio of each class of a domain (Influencing Factors).

Here the predictive ratio (Table 3) is the weight given to the domain or the influencing factor from table 1 which is calculated as in eq.3 below:

$$\text{PR} = (\text{Max RF} - \text{Min RF}) / (\text{Min RF of Max RF} - \text{Min RF}) \text{ ----- Eq. 3}$$

Where RF stands for relative frequency. It is the ratio of FR of a class of a domain to total FR of the domain.

Table : 1. Tabulation of domain with landslide inventory showing area coverage

Domain	Class	Class Pixcel	Class Area	% Class Pixcel	Landslide Pixcel	Landslide Area	% Landslide Pixcel
Slope	0 - 15	138090	13809 000	40.88	5	500	0.50
	15 - 30	84102	84102 00	24.90	150	15000	15.11
	30 - 45	94285	94285 00	27.91	721	72100	72.61
	45 - 60	20400	20400 00	6.04	117	11700	11.78
	> 60	946	94600	0.28	0	0	0.00
Total		337823	33782 300	100.00	993	99300	100.00
Landuse	Landslide	52	5200	0.03	3	300	0.30
	Rocky terrane	111	11100	0.07	0	0	0.00
	Sparse Forest	16651	16651 00	10.21	169	16900	17.02
	Kaligandaki River	1341	13410 0	0.82	0	0	0.00
	Cultivation Land	58739	58739 00	36.01	285	28500	28.70
	Forest	86013	86013 00	52.73	528	52800	53.17
	Sand	223	22300	0.14	8	800	0.81
Total		163130	16313 000	100.00	993	99300	100.00
Distance to Road	0 - 200 m	90293	90293 00	55.87	713	71300	71.80
	200 - 400 m	43577	43577 00	26.96	115	11500	11.58
	400 - 600 m	18415	18415 00	11.39	114	11400	11.48
	600 - 800 m	7506	75060 0	4.64	51	5100	5.14
	> 800	1822	18220 0	1.13	0	0	0.00
Total		161613	16161 300	100.00	993	99300	100.00
Distance to stream	0 - 400 m	84669	84669 00	52.39	725	72500	73.01
	400 - 800 m	51188	51188 00	31.67	258	25800	25.98
	800 - 1200 m	21168	21168 00	13.10	7	700	0.70
	1200 - 1600 m	4388	43880 0	2.72	3	300	0.30
	> 1600 m	200	20000	0.12	0	0	0.00
Total		161613	16161 300	100.00	993	99300	100.00
Distance to structure	0 - 1000 m	75200	75200 00	46.53	443	44300	44.61
	1000 - 2000 m	39618	39618 00	24.51	373	37300	37.56
	2000 - 3000 m	21157	21157 00	13.09	159	15900	16.01

	3000 - 4000 m	11663	11663 00	7.22	0	0	0.00
	4000 - 5000 m	7952	79520 0	4.92	0	0	0.00
	> 5000 m	6023	60230 0	3.73	18	1800	1.81
Total		161613	16161 300	100.00	993	99300	100.00
Geology	Alluvial Soil	5967	59670 0	3.66	17	1700	1.71
	Dhading Dolomite	93325	93325 00	57.21	112	11200	11.28
	Norpul Formation	32585	32585 00	19.97	221	22100	22.26
	Benighat Slate	20300	20300 00	12.44	267	26700	26.89
	Dandagaon Phyllite	10953	10953 00	6.71	376	37600	37.87
Total		163130	16313 000	100.00	993	99300	100.00
Relief	0 - 50 m	26310	26310 00	7.84	270	27000	27.19
	50 - 100 m	40806	40806 00	12.16	333	33300	33.53
	100 - 150 m	104717	10471 700	31.21	184	18400	18.53
	150 - 200 m	125105	12510 500	37.29	111	11100	11.18
	200 - 254 m	38537	38537 00	11.49	95	9500	9.57
Total		335475	33547 500	100.00	993	99300	100.00
Aspect	North (0-22.5, 337.5-360)	13498	13498 00	8.35	55	5500	5.54
	Northeast (22.5-67.5)	27458	27458 00	16.99	142	14200	14.30
	East (67.5-112.5)	29454	29454 00	18.23	342	34200	34.44
	Southeast (112.5-157.5)	23567	23567 00	14.58	186	18600	18.73
	South (157.5-202.5)	22317	22317 00	13.81	104	10400	10.47
	Southwest (202.5-247.5)	13614	13614 00	8.42	94	9400	9.47
	West (247.5-292.5)	10396	10396 00	6.43	29	2900	2.92
	Northwest (292.5-337.5)	21302	21302 00	13.18	41	4100	4.13
Total		161606	16160 600	100.00	993	99300	100.00
Curvature	Concave	89000	89000 00	26.35	524	52400	52.77
	Planar	158218	15821 800	46.83	47	4700	4.73
	Convex	90605	90605 00	26.82	422	42200	42.50
Total		337823	33782 300	100.00	993	99300	100.00

LSI	Stable	77366	77366 00	48.00	138	13800	13.90
	Quasi - Stable	45133	45133 00	28.00	194	19400	19.54
	Unstable	38684	38684 00	24.00	661	66100	66.57
Total		161183	16118 300	100.00	993	99300	100.00

Table : 2. Frequency ratio of each class

Domain	Class	Class Pixel	% class pixels	Landslide pixel	% landslide pixels	Frequency Ratio (FR)	Relative Frequency (RF)	RF (Non %)	RF (INT)	Min RF	Max RF	Max-Min RF	(Max-Min)Min RF	PR
Slope	0 - 15	138090	40.9	5	0.5	0.01	0.00	0.24	0	0.00	0.50	0.50	0.22	2.34
	15 - 30	84102	24.9	150	15.1	0.61	0.12	11.73	11					
	30 - 45	94285	27.9	721	72.6	2.60	0.50	50.30	50					
	45 - 60	20400	6.0	117	11.8	1.95	0.38	37.73	37					
	> 60	946	0.3	0	0.0	0.00	0.00	0.00	0					
Total		337823	100.0	993	100.0	5.17	1.00	100.00	100					
Landuse	Landslide	52	0.03	3	0.3	9.48	0.50	50.30	50	0.00	0.50	0.50	0.22	2.34
	Rocky terrane	111	0.1	0	0.0	0.00	0.00	0.00	0					
	Sparse Forest	16651	10.2	169	17.0	1.67	0.09	8.85	8					
	Kaligandaki River	1341	0.8	0	0.0	0.00	0.00	0.00	0					
	Cultivation Land	58739	36.0	285	28.7	0.80	0.04	4.23	4					
	Forest	86013	52.7	528	53.2	1.01	0.05	5.35	5					
	Sand	223	0.1	8	0.8	5.89	0.31	31.27	31					
Total		163130	100.0	993	100.0	18.84	1.00	100.00	100					
Distance to Road	0 - 200 m	90293	55.9	713	71.8	1.29	0.34	33.57	33	0.00	0.34	0.34	0.22	1.53
	200 - 400 m	43577	27.0	115	11.6	0.43	0.11	11.22	11					

	400 - 600 m	1841 5	11.4	114	11.5	1.01	0.26	26.32	26					
	600 - 800 m	7506	4.6	51	5.1	1.11	0.29	28.89	28					
	> 800	1822	1.1	0	0.0	0.00	0.00	0.00	0					
	Total	1616 13	100. 0	993	100.0	3.83	1.00	100.00	100					
Distance to Stream	0 - 400 m	8466 9	52.4	725	73.0	1.39	0.59	58.58	58	0.00	0.59	0.59	0.22	2.66
	400 - 800 m	5118 8	31.7	258	26.0	0.82	0.34	34.48	34					
	800 - 1200 m	2116 8	13.1	7	0.7	0.05	0.02	2.26	2					
	1200 - 1600 m	4388	2.7	3	0.3	0.11	0.05	4.68	4					
	> 1600 m	200	0.1	0	0.0	0.00	0.00	0.00	0					
	Total	1616 13	100. 0	993	100.0	2.38	1.00	100.00	100					
Curvature	Concave	8900 0	26.3	524	52.8	2.00	0.54	54.30	54	0.03	0.54	0.52	0.22	2.34
	Planar	1582 18	46.8	47	4.7	0.10	0.03	2.74	2					
	Convex	9060 5	26.8	422	42.5	1.58	0.43	42.96	42					
	Total	3378 23	100. 0	993	100.0	3.69	1.00	100.00	100					
Aspect	North (0-22.5, 337.5-360)	1349 8	8.4	55	5.5387 71	0.66	0.09	9.05	9	0.04	0.26	0.22	0.22	0.98
	Northeast (22.5-67.5)	2745 8	17.0	142	14.300 1	0.84	0.11	11.48	11					
	East (67.5-112.5)	2945 4	18.2	342	34.441 09	1.89	0.26	25.79	25					
	Southeast (112.5-157.5)	2356 7	14.6	186	18.731 12	1.28	0.18	17.53	17					
	South (157.5-202.5)	2231 7	13.8	104	10.473 31	0.76	0.10	10.35	10					
	Southwest (202.5-247.5)	1361 4	8.4	94	9.4662 64	1.12	0.15	15.33	15					

	West (247.5-292.5)	1039 6	6.4	29	2.9204 43	0.45	0.06	6.19	6					
	Northwest (292.5-337.5)	2130 2	13.2	41	4.1289 02	0.31	0.04	4.27	4					
	Total	1616 06	100. 0	993	100	7	1.00	100.00	100					
Relief	0 - 50 m	2631 0	7.8	270	27.2	3.47	0.44	43.61	43	0.04	0.44	0.40	0.22	1.81
	50 - 100 m	4080 6	12.2	333	33.5	2.76	0.35	34.68	34					
	100 - 150 m	1047 17	31.2	184	18.5	0.59	0.07	7.47	7					
	150 - 200 m	1251 05	37.3	111	11.2	0.30	0.04	3.77	3					
	200 - 254 m	3853 7	11.5	95	9.6	0.83	0.10	10.48	10					
	Total	3354 75	100. 0	993	100.0	7.95	1.00	100.00	100					
Geology	Alluvial Soil	5967	3.7	17	1.7	0.47	0.05	4.89	4	0.02	0.59	0.57	0.22	2.5823 52
	Dhading Dolomite	9332 5	57.2	112	11.3	0.20	0.02	2.06	2					
	Norpul Formation	3258 5	20.0	221	22.3	1.11	0.12	11.63	11					
	Benighat Slate	2030 0	12.4	267	26.9	2.16	0.23	22.56	22					
	Dandagaon Phyllite	1095 3	6.7	376	37.9	5.64	0.59	58.87	58					
	Total	1631 30	100. 0	993	100.0	9.58	1.00	100.00	100					
Structure	0 - 1000 m	7520 0	46.5	443	44.6	0.96	0.23	22.82	22	0.00	0.36	0.36	0.22	1.6581 02
	1000 - 2000 m	3961 8	24.5	373	37.6	1.53	0.36	36.48	36					
	2000 - 3000 m	2115 7	13.1	159	16.0	1.22	0.29	29.12	29					
	3000 - 4000 m	1166 3	7.2	0	0.0	0.00	0.00	0.00	0					

	4000 - 5000 m	7952	4.9	0	0.0	0.00	0.00	0.00	0					
	> 5000 m	6023	3.7	18	1.8	0.49	0.12	11.58	11					
	Total	1616 13	100. 0	993	100.0	4.20	1.00	100.00	100					

Table : 3. Weight of individual factor

Domain	PR	Weight
Aspect	0.98	98
Distance to Road	1.58	158
Distance to Structure	1.65	165
Relief	1.81	181
Slope	2.34	234
Curvature	2.34	234
Landuse	2.34	234
Geology	2.58	258
Distance to Stream	2.66	266

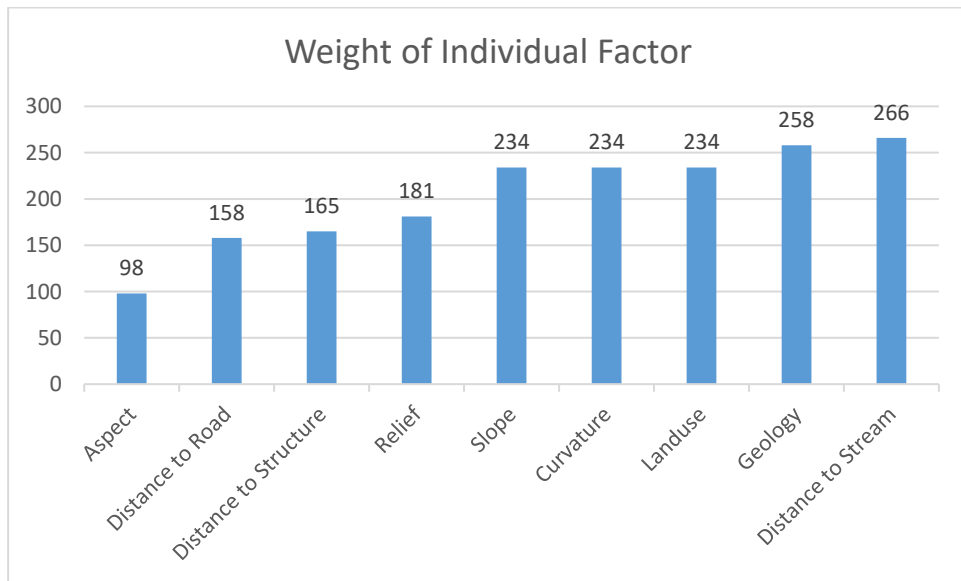


Fig:13 Weight of Individual Factor

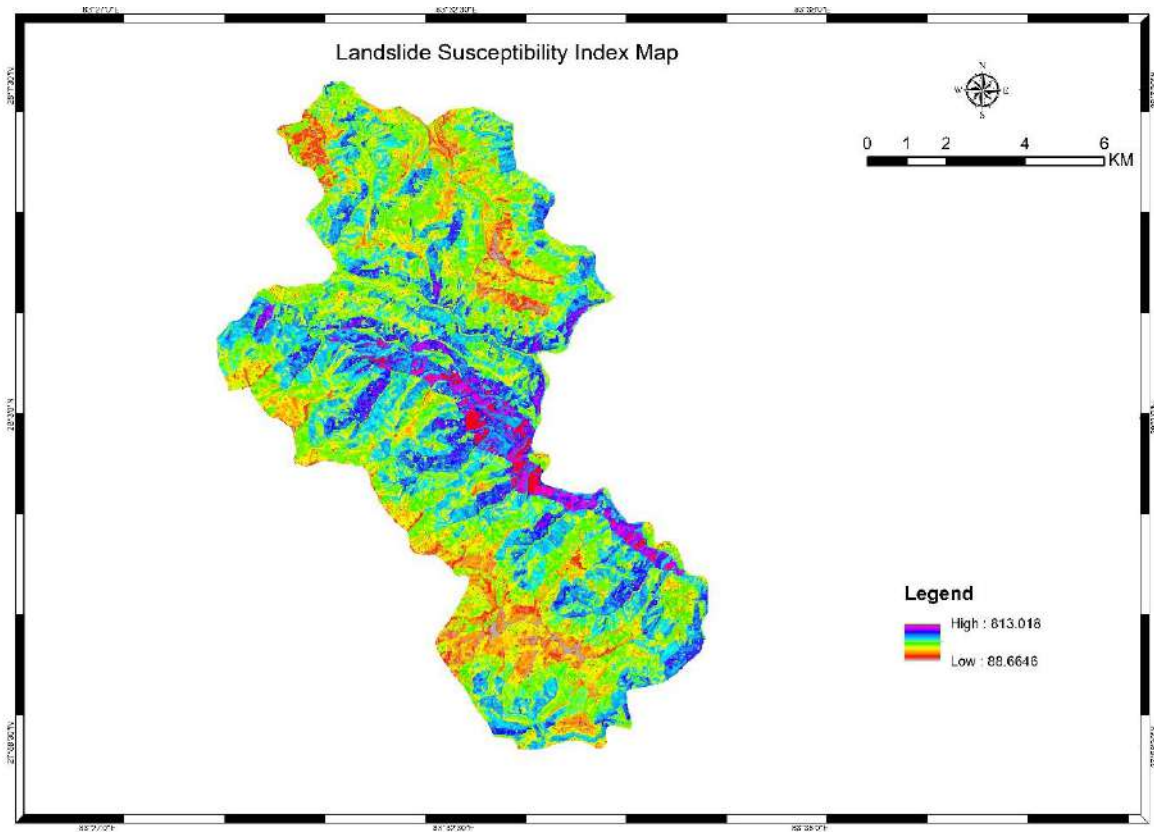


Fig:14 LSI Map

3.2 Validation of Landslide Susceptibility Index (LSI)

For validation, landslide area which has not been used for the construction of model is generally considered as the future landslide area. In this study, all landslides (polygons) were divided into two parts (70% i.e. 35 landslides for modeling and 30% i.e. 15 for validation). Hence to check the predictive power of proposed method for Landslide Susceptibility Map, LSI was qualitatively examined using success rate curves Figure 15.

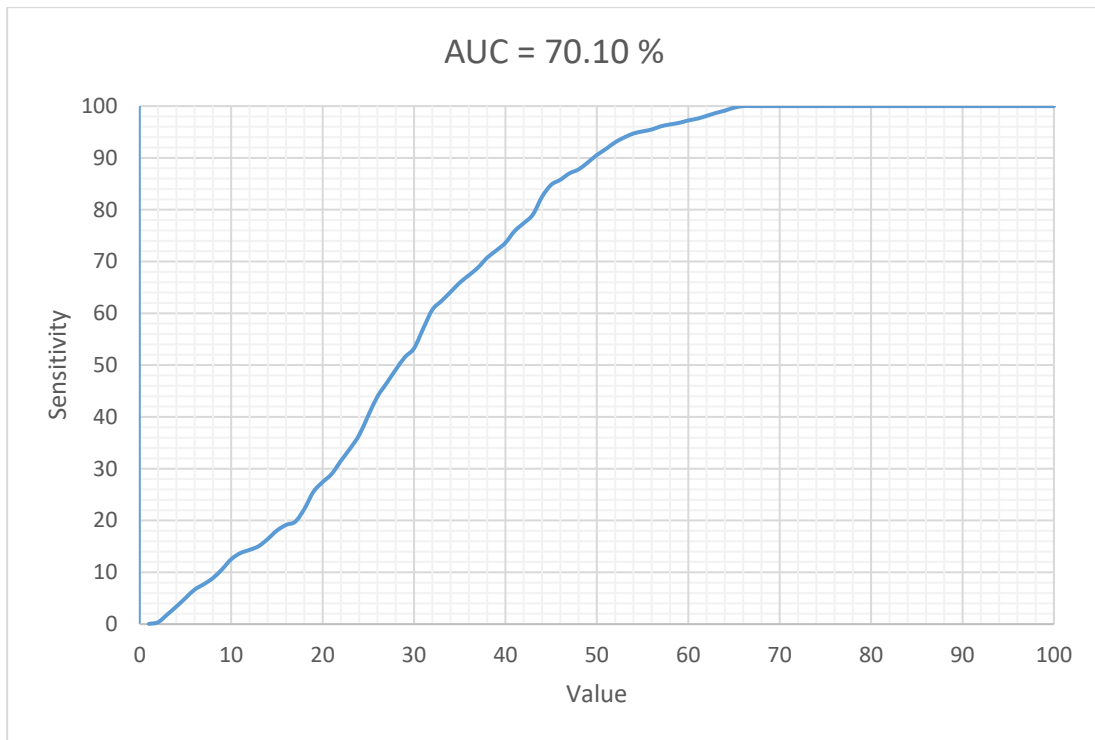


Fig:15 Area Under The Curve

In above diagram (Figure 15), the area under the success rate curve (ROC/AUC) is 0.7010, indicating that the prediction rate was 70.10 %, the analysis is valid. Finally, three Landslide susceptibility classes (Table 4) are established as stable (greater than 52%), quasi-stable (24-52%), and unstable (0-24%) using which final landslide susceptibility maps was prepared (Figure 16).

Table : 4. Boundary value set for different susceptibility classes

Cumulative %	Class Name	Upper bound
48	stable	458.622
76	Quasi Stable	534.129
100	unstable	813.018

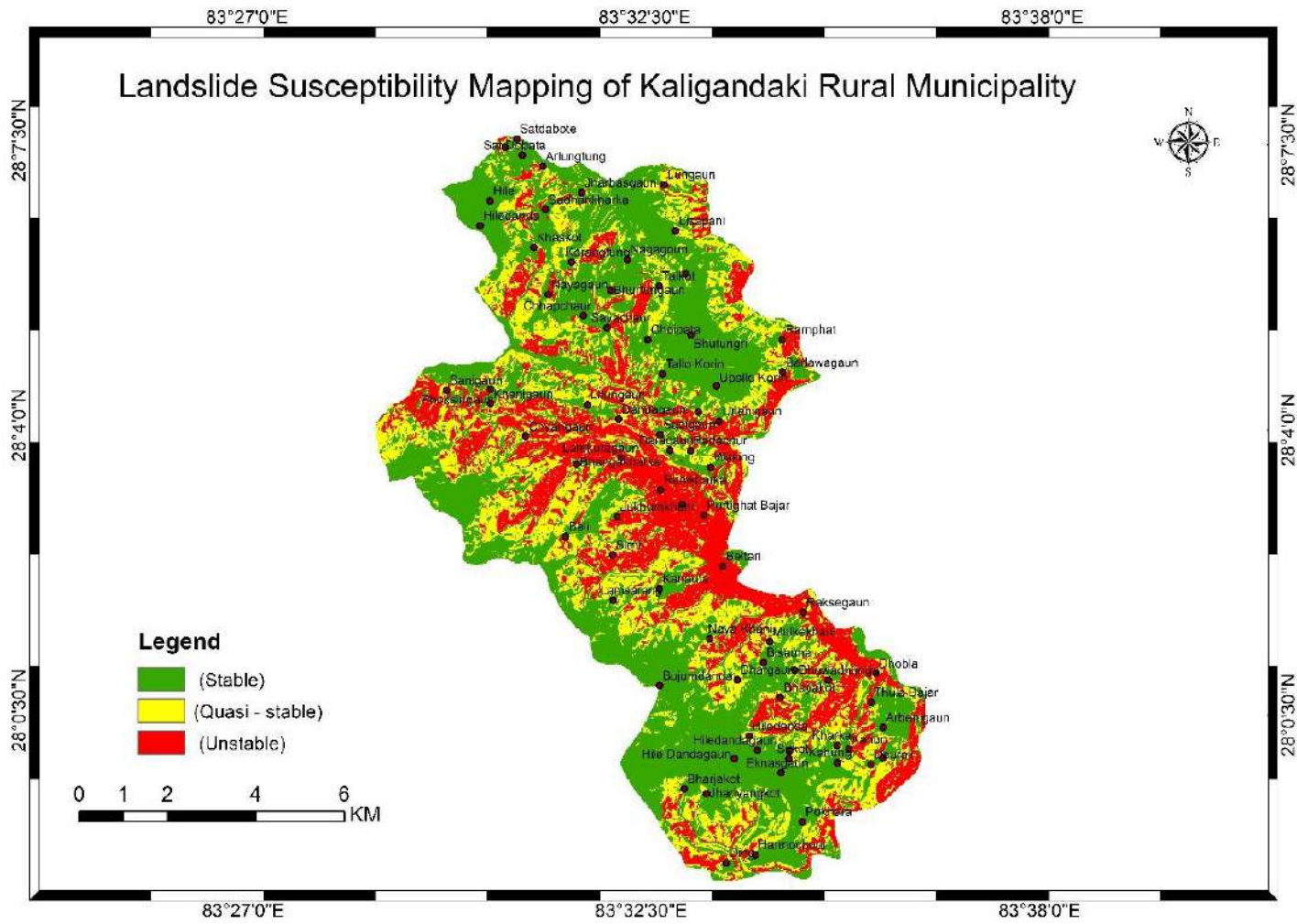


Fig:16 Landslide Susceptibility Map

Table : 5. Area coverage by different landslide susceptibility class

Landslide Susceptibility				Classification Method
Class	Count	area	Area %	
Stable	77366	7736600	48.00	ROC/AUC
Quasi - Stable	45133	4513300	28.00	
Unstable	38684	3868400	24.00	
Total	161183	16118300	100.00	

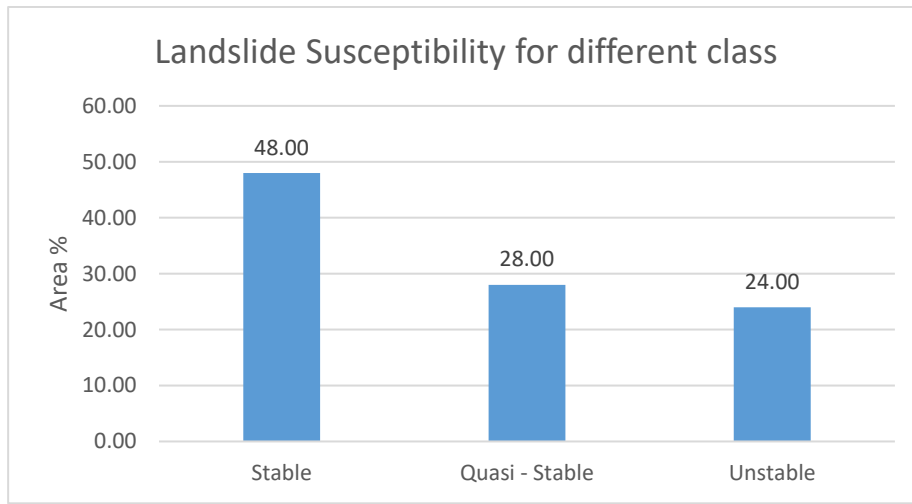


Fig:17 Landslide Susceptibility For Different Class

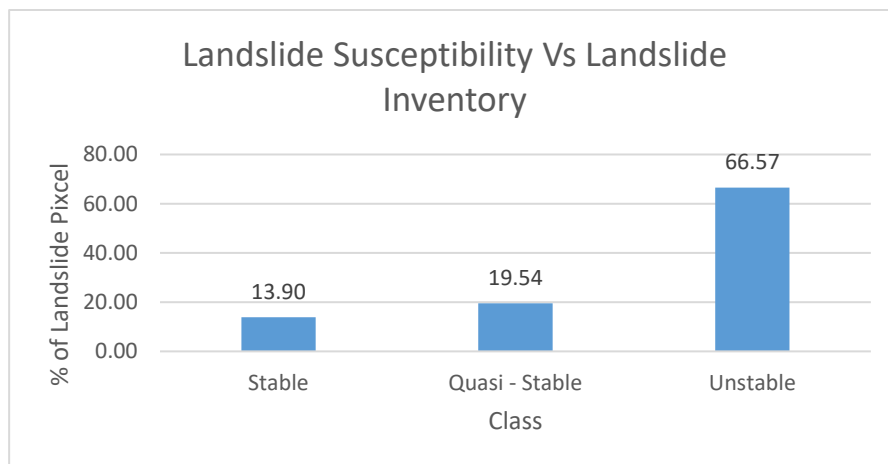


Fig:18 Landslide Susceptibility Vs Landslide Inventory

3.3 Field data and Model, Interpretation and Analysis

The data collected from desk study, field study, and landslide susceptibility mapping of the study area illustrates, Kaligandaki rural municipality is high risk of landslide under the consideration of monsoon and earthquake, because there is steep topography with highly crushed and fracture rock, ancient landslide, secondary structures like faults and thrust. This structures with fragile geology and ancient landslide are highly sensitive for landslide during rainfall and earthquake. In susceptibility mapping shows that most of the unstable or high risk area are located near about structures, streams and roads. As similar to susceptibility analysis, field visit data also demonstrated that most of the landslide was observed in highly fracture geology, ancient landslide, secondary structures, newly constructed roads. These parameter facilitated to slope instability. Most of the landslide observed during field visit illustrates landslide occur in colluvial soil i.e. previous landslide, highly weathered rocks, and residual soil which is shown in given table. The main causes of landslide occur during in this monsoon are the newly constructed low budget road and without study of engineering geology of the study area. During field visit landslide data are shown in table 6.

Table : 6. Landslide and geological study in Kaligandaki rural municipality

Landslide and Geological study in Kaligandaki Rural Municipality, Gulmi					
Location No	Landslide Type	Geometry(m)	Description	Geology/ lithology /soil	Remarks
L1	Cut slope failure	10×5×2	Located at Giduwa , affected 1 houses caused due to road construction, which is above the road Lat: 27.99331, Long: 83.53752	Residual soil, sandy clay Dolomite rock type	Ward No: 01 Mr. Preetamshing Rana
L2	Cut slope failure		Located at Giduwa NERA school, affected newly built trust building Lat: 27.99596, Long: 83.53759	Residual soil, sandy clay Phyllite, dolomite	Ward No: 01 Mr.Tulsi Ram Pandey (Head Teacher)
L3	Translation slide		Located at Tuthum village happen before 1 year during monsoon, affected 2 houses	Residual soil, silty clay (Red clay)	Ward No: 01 Ms. Mina Rakaskoti
L4	Creep failure		Located at Tuthum village, affected 2 houses Lat: 27.994, Long: 83.55206	Residual soil, Silty clay	Ward No: 01 Mr. Dal Bdr Rakaskoti

L5	Creep failure		Located at Tuthum village, affected 1 houses Lat: 27.99299, Long: 83.55187	Residual soil, Silty clay	Ward No: 01 Mr. Min Bdr Sinjali
L6	Cut slope failure	12×9×5	Located at Vayakot, Janajyoti primary school affected school toilet and building during in this monsoon Lat: 28.01288, Long: 83.0572	Silty gravel, colluvial soil	Ward No: 02 Mr. Mr. Indra Bdr Darlami Mr. Kasi ram Thapa (ward Member)
L7	Plane failure	17×8×4	Located at Vayakot, affected 1 newly built house during on this monsoon need gabion wall on both side of house i.e. forward and backward of house Lat: 28.0118, Long: 83.57345	Silty gravel weathere d phyllite	Ward No : 02 Mr. Hira Bdr Thapa
L8	Translation slide		Located at Nigare , caused due to road construction and affected 5 houses, high risk due to large boulder (29×28×10) just 200 m above the village and High risk of landslide due to highly weathered phyllite with colluvial soil. Lat: 28.02433, Long: 83.57077	Highly weathere d phyllite colluvial soil	Ward No : 02 Mr. Dumber Buddha ward No : 02
L9	Cut slope failure	50×20×10	Located at Mulka Khani village, affected 3 houses caused by Kaligandaki corridor Lat. 28.03138, Long: 83.57719	Silty sand	Miss. Sarmila Thapa
L10	Plane failure		Located at view Khani, caused by road construction Lat: 28.03788, Long: 83.55151	Crushed phyllite	Ward No :03
L11	Plane failure	20×30×5	Located at Lamsarang affected 2 houses, during on this monsoon, it is more risk to stay in this situation	Silty gravel Crushed phyllite	Ward No: 03 Mr. Gagan Bdr Khatri Mr. Yam Bdr Thapa
L12	Complex slide		Located at 100m upward from Beltari affects is destruction of road there is series of landslide, large scale landslide	Colluvial soil	Ward No : 03 Miss. Gau maya B.K
L13	Plane failure		Located at Nayakhani village, destruction of road Lat: 28.03532, long: 83.55721 caused by road construction and affected 3 houses		
L14	Complex slide		Located at Nayakhani village, affected 3 houses there is series of landslide, both side has landslide and high risk of disaster lat.28.03617, long: 83.55799	Highly weathere d phyllite colluvial soil	Ward No : 03 Miss. Dil Maya Budhathok i

L15	Plane failure	30×23×10	Located near about Sarashwati Primary School, Jukhumkhani destruction of road Lat. 28.0528, Long: 83.54381	Silty gravel Dolomite rock type	Ward No : 04 Mr. Min Bdr Shrees
L16	Translation slide		Located at Saurani village, affected 3 houses Lat: 28.05342, long: 83.53755	Weathered dolomite	Ward No: 04 Gopi ram pun
L17	Complex slide		Located at Bhankharka, affected 1 houses, happen during on this monsoon caused due to road construction lat:28.04884, long: 83.53755	Weathered Phyllite, slate colluvial soil	Ward No: 04 Mr. Min Bdr Bhandari
L18	Large scale slide		Located at Khottrok village large scale landslide (2018 BC) affected total village		ward No : 04 Miss. Pabitra Giri
L19	Creep failure		Located at Wakin, caused by road construction deposited material affected to lower Wakin village Lat:28.05809 Long: 83.55824	Residual soil	Ward No : 04
L20	Complex slide		Located at Phusre Khani, copper mining area 3 houses affected in 30 years ago	Crushed phyllite	Ward No: 04 Mr. Min Bdr Shrees
L21	Plane failure	100×50×10	Located at Phusre Khani, caused due to road construction	Crushed phyllite	Ward No: 04
L22	Plane failure	150×50×5	Located at 500 m ahead of Danda village caused by road construction and affected below the road cultivation land and houses Lat: 28.06757, long: 83.53634	Dolomite rock type	Ward No : 05
L23	Creep failure		Located at Phoksin (Litung Mangalsthan lower Sec.School) affected 3 houses caused by low budget road construction Lat: 28.07121, long: 83.52859	Phyllite, colluvial soil	Ward No : 05 Mr. Tek Bdr B.K
L24	Translation slide		Located at lamkura village, affected 1 house caused due to road construction Lat: 28.05985, long:83.53086	Colluvial soil	Ward No: 05
L25	Translation slide		Located at lamkura village, affected 3 houses, due to road construction Lat: 28.05896, long: 83.53111	Phyllite, dolomite colluvial soil	Ward No : 05 Mr. Rudra Bdr Suprai

L26	Creep failure	100×50×10	Located at Dhungrekharka (Dhawa), Affected 7 houses due to the causes of low budget road construction Cultivation land over the village (rice plantation) Lat: 28.1008, Long: 83.55826	Silty gravel Dolomite rock type	Ward No : 06 Mr. Hari Chandra Thapa
L27	Rotational slide	150×100×15	Located at backward from Marin village. Affected Korang to Lung road seepage on landslide body Lat: 28.10777, Long: 83.54525	Colluvial soil (Silty gravel) Highly weathered dolomite	Ward No : 06
L28	Plane Failure	20×12×4	Located backward from Lung village at Shree Sukra Secondary School affected building school during on this monsoon Lat: 28.11617, Long: 83.54178	Silty gravel Dolomite rock type	Ward No : 06 Mr. Prem Bdr Pun
L29	Plane Failure		Located at uppallo Korang below the ward office. caused due to road construction Lat: 28.07381, Long: 83.55865	Weathered dolomite	Ward No : 06 Mr. Kabiraj Dhakal
L30	Complex slide		Located at Tallo Korang, Affected 5 houses upward from the landslide Road obstruction	Weathered and crushed dolomite	Ward No : 06 Mr. Atma Ram Dhakal
L31	Creep failure		Located at Janata Bal Kalyan Primary School Caused due to overburden pressure on newly built wall on forward side road construction material was sided on backward of building Lat: 28.06929, Log : 83.55185	Silty gravel	Ward No : 06 Mr. Birendra Bdr K.C
L33	Complex slide		Located at Urleni village Affected 7 houses and caused due to newly constructed road Lat. 28.06741, Long: 83.56497	Colluvial soil (silty gravel)	Ward No : 06
L34	Creep failure		Located at Karangthung village, Affected one house whereas other five houses will affect Caused due to road construction and depositional mass has been failed Lat: 28.10306, 83.52053	Residual soil, silty gravel	Ward No : 07 Miss. Radhika Dhakal Mr. Gagan Bdr Karki
L35	Complex slide		Located at Dhuwa Khola Kanchne Gaunda, caused due to road construction and seepage of water during on this monsoon in between clay layer of this slide	Crushed dolomite and slate and made white and black clay	Ward No : 07 Mr.

			Lat: 28.11956, Long: 83.51342		
L36	Plane Failure		Located at Nayagaun, Caused due to road construction, affected 1 house Depositional mass failed during on this monsoon Lat: 28.09206, Long: 83.51635	Weathered dolomite, residual soil, silty gravel	Ward No : 07 Miss. Uma Khatri
L37	Creep failure(crack)		Located at Nayagaun Caused due to road construction and this will affected 16 houses Lat. 28.09536, Long: 83.51762	Residual soil, silty sand(red clay)	Ward No : 07 Mr. Tara B.K

Similarly, landslide susceptibility mapping illustrates that, most of the unstable area are near about the streams, roads, structures and previous landslide. The highly risk of the study area are shown in table 7.

Table : 7. High risk of landslide in Kaligandaki rural municipality

High risk of landslide in Kaligandaki rural municipality	
Village Name	Ward No
South west side of Bharjalkot	1
Bhayakot	2
Thulabazzar	2
Dhobla	2
Dhuwadhunga	2
Raske gaun	3
Mulka Khani	3
Nayakhani	3
Purtighat	4
Phusre Khani	4
Ranikharka	4
Lamkura	5
Chyangaun	5
Khani gaun	5
Sanigaun	5
Bhangkharka	5
Jukhumkhani	5
Sirni	5
Bali	5
Eastern side of Lungaun(near about Palung Khola)	6
Eastern side of Lisapani(near about Palung Khola)	6

Ramphi gaun	6
Barlwa Gaun near about Kaligandaki corridor	6
Urleni gaun	6
Khamaripata	6
Eastern side of Bhurtunggaun	7
Sayachaur	7
North east side of Korangtung	7
Arlungtung gaun	7
Adheri gaun	7
Southern side of khaskot	7
Nayagaun	7

Comparison of both landslide susceptibility mapping and field visit data shows that almost all the area are similar or covered i.e. verified the landslide susceptibility mapping data with the field visit landslide data. The main objective of this study is to safe the settlement from landslide during monsoon and earthquake. On this purpose, first of all we need to identify landslide prone area and consequently we identify landslide prone area through susceptibility mapping and which is verified by field visit.

4 DISCUSSION

4.1 Landslide Causative Factors

The contributing factors were selected in this study based on the presence or absence of the factors and their importance. The landslide conditioning factors incorporated the geomorphological, anthropogenic and extrinsic factors. In this study, 9 conditioning factors were considered to prepare the landslide susceptibility map namely, Geology, aspect, curvature, slope, land use land cover, relief, distance from the stream, distance from the road and distance to structure. The assigned weights to each class of the causative factors is given in the Table 1. The derived weights shows that the terrain slope has a significant impact on the landslide distribution. Generally occurrences of landslides increases with increase in terrain gradient, however, weight is reduced for terrain slope of $>60^\circ$. For the study area, the terrain with slope of $30 - 45^\circ$ is most prone for the landslides with frequency ratio of 2.60 and the terrain with slope gradient of $<15^\circ$ is least prone to landslides with frequency ratio of 0.01.

The frequency ratio for the aspect map shows that the east, southeast, south and northeast facing aspect has highest frequency ratio values (Table 1). East aspect got the maximum weight of 1.89 followed by southeast with 1.28 (Table 1). The area range of 0 – 400 m from the streams has high frequency ratio of 1.39. During field visit also verified that most of the landslide was observed around the stream area. Also the area in the vicinity of 0 – 200 m from the road shows high frequency of 1.29. This is the main causes of landslide in the study area. Various low budget road has to be found during field visit and which has no proper channel system and no simultaneously made any engineering structures (Gabion wall, concrete wall, and Retment wall etc.). Therefore this type of manmade landslide was observed in the study area such as Nigare landslide, Duwa Khola landslide, Nayagaun landslide, Urleni Landslide, and Baralwa landslide etc., which is shown in table 6. Among the Landuse land cover, previous landslide, sandy layer has the highest frequency ratio of 9.48 and 5.89 respectively. Observing Table 1, it was found that concave curvature has high frequency of landslide occurrence with the value of 2.00. Similarly, Dandagaun phyllite has the highest frequency ratio of landslide which is 5.64 whereas least frequency ratio is Dhading dolomite. Dandagaun phyllite is highly sheared, crushed, and weak geology/lithology therefore it has high frequency of landslide. During field study and geological map of this area shows that, it has observed many structures such as Faults, Joints, and Folds which also played main role for landslide. For instance 1000 to 2000 m and 2000-

3000m has the high frequency of landslide which is 1.53 and 1.22 respectively. Which is directly could observed in the field and susceptibility map also, such as Urleni Gaun, Khamaripata, Adheri Khola, Hiledanda, Rakse Gaun, etc., these area has to be found faults and which directly initiate to landslide.

4.2 Topographic Parameters

Digital elevation model (DEM) has been used as an important factor in the study of earthquake induced landslides (Kamp et al., 2008; Wang et al., 2015). Research shows an increase in the probability of landslide occurrence for higher elevation although there is absence of any direct relationship between the elevation and landslide occurrence (Ercanoglu et al., 2004). The elevation ranges of the study area in between 550-1976 m. The steepness of the slope is another major topographic factor used in landslide susceptibility studies (Wang et al. 2015; Kamp et al., 2008; Regmi et al., 2016; Regmi et al., 2010; Pradhan and Lee, 2010). The slope ranges from 0° – 73° as shown in Figure 7. The landslide concentration was maximum along the slope range from 30° – 45° . The aspect of the slope resembles the moisture retention and it's relation to attitude of bedding of the rock formation which in turn affects the physical properties of slope material and it's susceptibility to failure (Dai et al., 2001). In this study, aspect to the east, northeast and south-east contributes mostly to landslides (Figure 8).

The surface undulation of the slope can play major role in triggering landslide as it has a strong influence on creating slope instability. In curvatures, the landslides are usually distributed in concave slopes and convex slope (Figure 11). The convex slopes usually have earthquake induced landslides (Reneau and Dietrich, 1987)

4.3 Anthropogenic Factor

Landuse is considered to be one of the landslide conditioning factors as the variation in the landuse might play a role in changing the vegetation cover varying the mechanical (e.g. soil strength and slope behavior) and hydrological (e.g. Greenway, 1987; van Westen et al., 2003; Reichenbach et al., 2014). The variation in land use distribution may be either natural, human induced or a combination of both. In the study area, the main causes of landslide are the newly constructed road. I already mention in filed visit data but some of the major event happened during constructed low budget roads are Urleni gaun, Adhere Khola road section, Nigare gaun, Rakse gaun etc. In addition to that, susceptibility mapping was verified by field visit and this report illustrates that high risk and landslide prone area of this study area are

Nayakhani, Phusre Khani, Ranikharka, Jukhumkhani, Urleni, and Adheri Gaun, Nigare etc., which is shown in table 7.

5 CONCLUSION AND RECOMMENDATION

In this study, Frequency Ratio model based on statistical method was used for determining the spatial probability of landslide occurrence where each factor layer was weighted according to the contribution on landslides. This method predicted the probability of landslide occurrence efficiently which was validated by positive correlations between the field conditions and the results obtained by the model. A total of 181 landslides were identified. It is found that landslides are more influenced by distance to the stream i.e. most of the landslides are controlled by the presence of water. Factor map distance to the road suggest that most of the landslide have occurred near distance of 0 – 200 m from the existing narrow road. Slope map exhibit that the landslides are more focused in the slope angle between 30° to 45°, result shows landslide mostly occur in higher slopes or increasing relief. It was observed that the slope angle less than 15 degrees didn't contribute much to induce landslide.

The results suggested that the landslides are mostly common in slope facing towards east, south-east and Northeast. While the curvature suggested that concave curvature is the role player to predict landslides.

The forest area followed by cultivation land covered maximum area in the Kaligandaki rural municipality as obtained from the results. The statistical analysis obtained from the results of the susceptibility map prepared by using Frequency Ratio model gave the results that maximum area of landslide distribution was observed in high susceptibility class or unstable class i.e. (66.57%) followed by Quasi stable (19.54%) and stable (13.90%). Among the different factors determined, slope, aspect, distance to the stream and distance to the road, and distance to structures were found to be the major contributors to trigger the rainfall induced landslide in the Kaligandaki rural municipality. Similarly, during field visit obtained data shows the major factor for rainfall induced landslide for this study area are distance to stream, distance to structures, fragile geology, newly constructed low budget roads.

Among the finding of this study recommends the highly unstable or prone area of the Kaligandaki rural municipality needs to detail study for the construction of roads, buildings, settlements, and landuse.

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7 ANNEX

Area under the curve data

Area	Percentage	Cumulative frequency	AUC = 70.10
0	0	0	0.051335
625	0.102669405	0.102669405	0.359343
3125	0.513347023	0.616016427	1.848049
15000	2.464065708	3.080082136	3.38809
3750	0.616016427	3.696098563	5.030801
16250	2.669404517	6.36550308	6.673511
3750	0.616016427	6.981519507	7.700205
8750	1.437371663	8.41889117	8.880903
5625	0.924024641	9.342915811	10.57495
15000	2.464065708	11.80698152	12.52567
8750	1.437371663	13.24435318	13.70637
5625	0.924024641	14.16837782	14.32238
1875	0.308008214	14.47638604	15.04107
6875	1.12936345	15.60574949	16.4271
10000	1.642710472	17.24845996	18.06982
10000	1.642710472	18.89117043	19.14784
3125	0.513347023	19.40451745	19.76386
4375	0.718685832	20.12320329	22.22793
25625	4.209445585	24.33264887	25.56468
15000	2.464065708	26.79671458	27.41273
7500	1.232032854	28.02874743	29.00411
11875	1.950718686	29.97946612	31.51951
18750	3.080082136	33.05954825	33.8809
10000	1.642710472	34.70225873	36.49897
21875	3.593429158	38.29568789	40.29774
24375	4.004106776	42.29979466	43.94251
20000	3.285420945	45.58521561	46.50924
11250	1.848049281	47.43326489	49.12731
20625	3.388090349	50.82135524	51.54004
8750	1.437371663	52.2587269	53.23409
11875	1.950718686	54.20944559	57.03285
34375	5.646817248	59.85626283	60.67762
10000	1.642710472	61.49897331	62.37166
10625	1.745379877	63.24435318	64.11704
10625	1.745379877	64.98973306	65.91376
11250	1.848049281	66.83778234	67.35113
6250	1.026694045	67.86447639	68.83984
11875	1.950718686	69.81519507	70.73922
11250	1.848049281	71.66324435	72.12526
5625	0.924024641	72.58726899	73.61396
12500	2.05338809	74.64065708	75.87269

0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
0	0	100	100
608750	100		7010.678
			70.10678

Bar diagram showing the factor map crossed with landslide inventory

