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SUSCEPTIBILITY MAPPING OF RAINFALL INDUCED LANDSLIDES USING WEIGHT OF EVIDENCE METHOD IN JUMRE KHOLA WATERSHED OF PYUTHAN DISTRICT, NEPAL

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ABSTRACT:
The world's development infrastructure is at risk from landslides and their consequences in many areas across the globe. There is evidence that landslide disaster is increasing in developing countries. Lesser Himalaya of Nepal is highly susceptible for landslide and various people lose their life and property each year due to landslide. The main aim of this study was to prepare 1) to identify the specific characteristics of landslides in Jumre Khola watershed. 2) To relate the rainfall intensity with landslides distribution in Jumre Khola watershed. & 3) To prepare landslide susceptibility map of Jumre Khola watershed. For this, a detailed landslide inventory was prepared by field survey and Google Earth imagery interpretation. This inventory map was separated into two groups for training the model and validating the result. A landslide susceptibility maps was developed by WOE model. Finally, validation of the model was done by using the success rate curve analysis. The verification result showed that the model performed very well with the success rate of 86.79%. The generalized linear model was performed between landslide and rainfall to know if there is significant relationship between landslide and rainfall. The Jumre Khola watershed is selected for the present study due to the presence of a large number of landslides in the region as well as due to the presence of huge amount of settlement in the mountain slopes and the river valley that are in high risk of landslides. The produced susceptibility map can be useful for general land-use planning, as well as it can provide information to the planners for the adaptation of appropriate mitigating measures for landside in the Jumre Khola watershed.

Keywords: GIS modeling, Inventory map, Landslide Susceptibility, Rainfall, Weight of Evidence

INTRODUCTION

The world's development infrastructure is at risk from landslides and their consequences in many areas across the globe. Therefore, developing landslide susceptibility maps, vulnerability assessment and adopting suitable land use policies for different environmental settings are urgently needed. According to Varnes (1978), Landslide is the "downward and outward movements of slope-forming materials along surfaces of separation". Landslide usually occurs as secondary effects of heavy rainfall and earthquakes. Landslides involve flowing, sliding, toppling, falling, or spreading, and many landslides exhibit a combination of different types of movements, at the same time or during the lifetime of the landslide.

Due to the variation in distribution of rock and soil types, geological structures, rock deformations, geomorphology, and climatic conditions, the level of risk of these geological hazards differ from place to place in Nepal according to the geological divisions (TU- CDES & UNDP 2015). Because of its topographical variation and geological characteristics, together with torrential rain during the monsoon season, Nepal frequently experiences landslides, debris flows, floods, and earthquakes.

Landslide susceptibility is defined as the tendency of an area to generate landslides (Guzzetti et al. 2006). Landslide susceptibility mapping (LSM) can be used to determine areas prone to landslides by correlating some of the major factors that are responsible for the slope failure with the past distribution of landslides in that area (Brabb 1984). These landslide susceptibility maps can assist planners and engineers in the decision-making process regarding the use of such lands.

Weight of Evidence is a bivariate analysis which contains predictive variable as independent variable and landslide occurrence as dependent variable (Bousta & Brahim, 2018).WOE was initially used for identification and exploration of mineral (Carter, 1994) but later it gained popularity for used in landslide assessment. The usefulness of a susceptibility map is greatly increased when it is divided into 5 zones: very low, low, moderate, high and very high susceptibility to land sliding (Fell *et al.*, 2008). This zoning is accomplished by assigning LSI values to the boundaries between the zones such that a certain proportion of the mapped landslides fall within each zone.

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MATERIALS AND METHODS

Study Area

The study area lies in Pyuthan district which is one of the hilly districts of Mid-western Development Region of Nepal. The study area covers an area of 64 sq. km with perimeter of 32 km. It is located at longitude from 82°84'54" to 82°87'14" E and latitude of 28°10'52" to 28°17'49" N with elevation ranges from 788 m to 2048 m (Figure 1). Most slopes are south facing and gradient ranges from 0^0 to 77.5^0. Climatic condition of the study area is lower tropical, upper tropical and subtropical. Maximum rainfall occurs during the monsoon months from June to September.

The study area is comprised of meta-sedimentary rocks of the Lesser Himalaya with slates, sandstones, limestones, and quartzties as dominant rock types. The geological map prepared by the Department of Mines and Geology of Government of Nepal divides the lithology of the study area into six formations namely: Sangram Formation, Suntar Formation, Melpani Formation, Ramkot Formation, Khara Formation and Gawar Formation separated from the Siwalik rocks in the south by the Main Boundary Thrust. The study area consists of alluvial deposits along with Benighat slate.

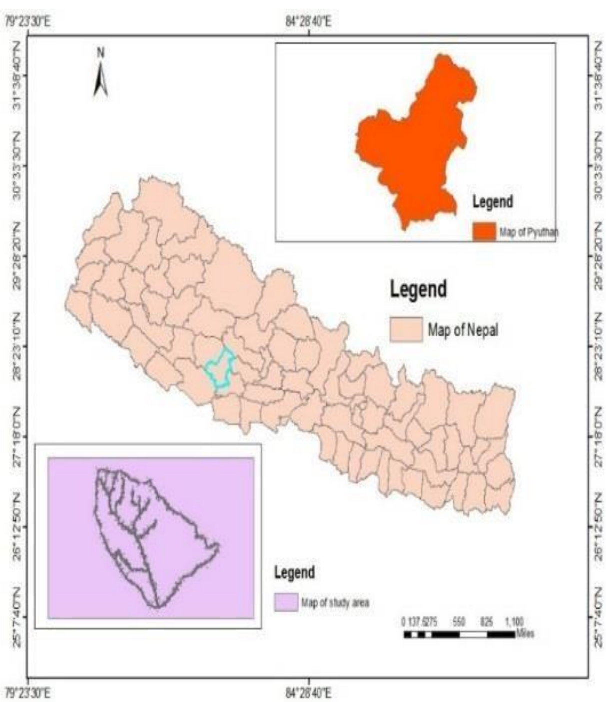

Figure 1: Map of study area

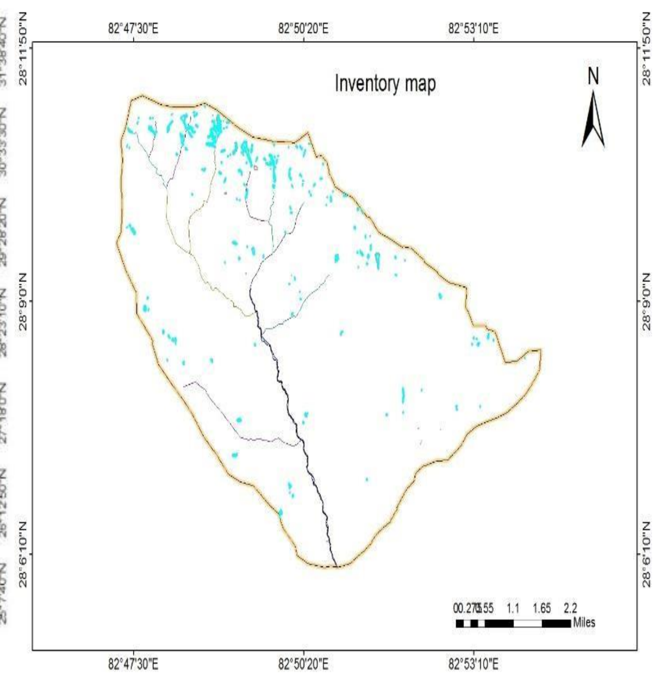

Figure 2: Inventory Map of the study area

Input data preparation

Both primary and secondary data were collected. Use of observation, checklist and GPS was done for primary data collection was done. Soil was collected for the texture analysis. Landslide data were collected from field through checklist. For secondary data collection, 30 year of rainfall data were collected from DHM and landslides data were collected from Google earth, MoHA and DesInventar respectively.

Landslide inventory was done by using the high resolution imagery of Google Earth. In Google Earth, landslide was marked in polygon shape and then it was imported into the Arc GIS 10.1 Software for the further analysis. For the detail study, polygon shape landslides were converted into raster data type and the projection was WGS 1984 UTM Zone 45 N. All together 199 landslides were observed in Google Earth and 16 landslides were studied in the area (Figure 2). Landslides seen were highly weathered and vegetation found was in sparse condition. Road construction was found to be the main reason for landslides occurrence at most of the sites.

All the data obtained from landslide checklist was analyzed and was used to get the information like length of slope, rate of movement, style of landslides, distribution, types of landslide, groundwater condition, damage of landslide etc. which was shown in bar diagrams and tables. Area of landslide along slope, aspect, geological formation, hillshade, land use, elevation, curvature and drainage distance was obtained. Soil collected from field was tested in lab to get information like moisture level, bulk density, soil color and texture analysis.

For Landslide Susceptibility Mapping six intrinsic factors and one extrinsic factor was used to prepare a susceptibility map. Slope, Slope aspect, Elevation map was prepared by using the Digital Elevation Model. Similarly, Land use map was extracted from ICIMOD land cover map. Geological map was prepared by using the geo referenced map of DMG and Drainage map was prepared from hydrological tool of Arc GIS. All factors map was prepared in Arc GIS 10.1 software with 12.5*12.5 m cell size resolution. For Landslide susceptibility, Weight of Evidence (WOE) Model was used as stated by Regmi et al., 2010.

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Weight of evidence model is a quantitative model which is based on weightage value. For data analysis, the total landslide were also classified in 152 train and 47 test landslides with reference to 80% of landslide as training landslides and remaining 20% as test landslides (Ozdemir & Altural, 2013).

The present study calculated the weighted values for the classes of landslide-affected factors by using the following equations (Regmi et al., 2010):

$$W^{+} = \ln \frac{\{A1/A1+A2\}}{\{A3/A3+A4\}} \quad (1)$$

$$W^{-} = \ln \frac{\{A2/A1+A2\}}{\{A4/A3+A4\}} \quad (2)$$

Where,
A_1= the number of landslide pixels present in given factor class;
A_2= the number of landslide pixels not present in the same factor class;
A_3= the number of pixels in the given factor class in which no landslide pixels are present
A_4= the number of pixels in the given factor class when neither a landslide nor the given factor is present
W^+ = presence of landside as well as positive correlation between landslide and the given factor class
W^- = absence of landslide and negative correlation between landslide and given factor class.
$C = W^+ - W^-$, where C reflects the overall spatial association between a predictable variable and landslide occurrence. Thus, obtained C value can be 0, negative or positive value. Zero indicates not significant for study whereas positive indicates positive correlation between given factor and landslide and vice-versa for negative value.

Validation

The validity of the landslide susceptibility map can graphically be ascertained with the help of the success rate curve (Chung and Fabbri 1999). The cumulative percentage of observed landslide occurrence is plotted against the areal cumulative percentage in decreasing LSI values to obtain the success rate curve for the study area. To assess the accuracy of prediction of the model Area under Curve methodology has been used. Validation was done by using the field data of landslides. Success rate curve were prepared by calculating an AUC value by using Riemann Sums methods. The test landslides were used for Success rate curve analysis which was obtained by plotting cumulative field landslide area percentage against the cumulative hazard value percentage.

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The flow chart below shows the general procedure followed during the landslide hazard analysis:

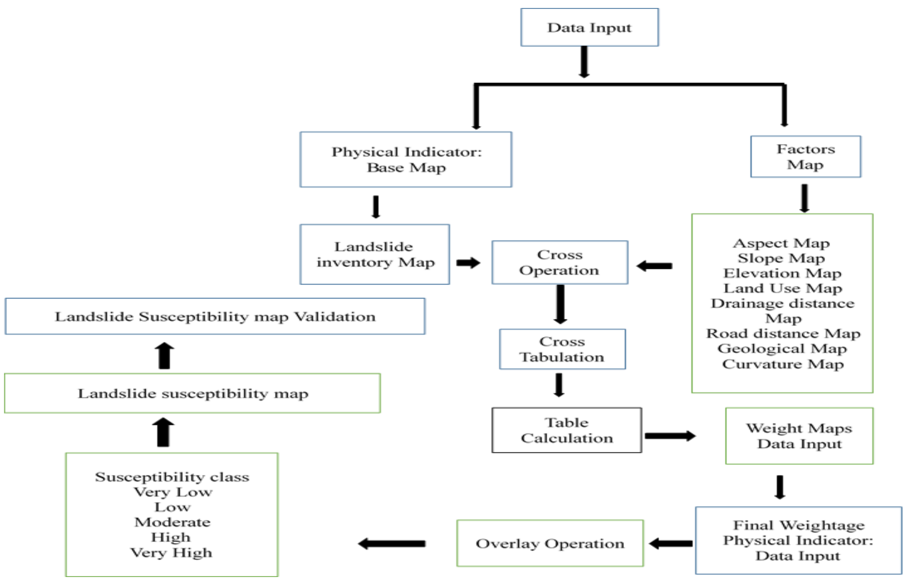

Figure 3: Methodological framework for susceptibility mapping

RESULTS AND DISCUSSIONS

Landslide characterization

All together 199 landslides were observed and 16 landslides were studied in the area. Figure 2 shows the landslide observed in the study area. Road construction was the main cause found that triggered the landslide in the study area through observation. In order to establish and characterize the nature of the slope material in terms of its implications for slope stability, a range of analyses was carried out. Soil properties like texture, color, moisture, bulk density were obtained from the soil collected from each site. With the help of checklist, groundwater condition, land use pattern, vegetation type, rock properties, state, distribution, style and other parameter was obtained and analyzed.

The landslide perimeter and area was measured. The frequency of landslide was found to be higher with of perimeter 100-1000 m (Figure 4) and higher with area 10-100 m^2 (Figure 5). The location wise area and length of studied landslides are shown in Table 1.

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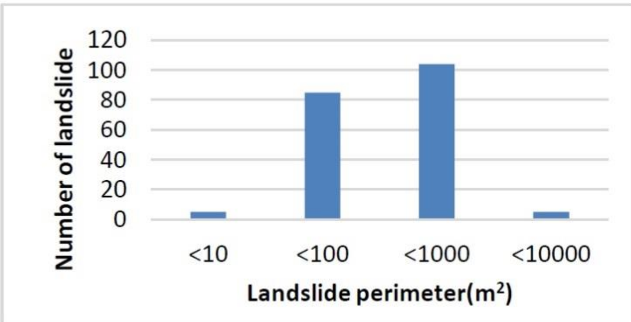

Figure 4: Bar diagram shows Perimeter and frequency of landslide

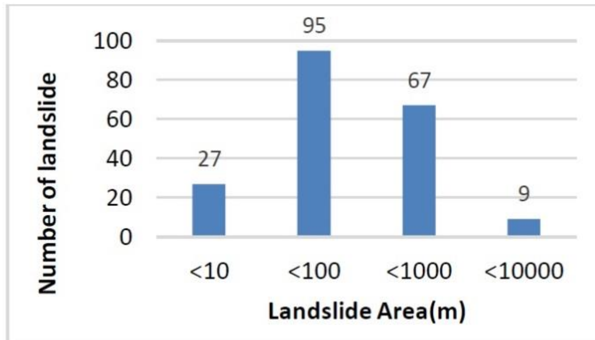

Figure 5: Bar diagram shows area and frequency of landslide

Table 1: Texture analysis

S.N.	Sand (%)	Clay (%)	Silt (%)	Textual class	Soil color	Moisture (%)	Bulk density(gm./cm3)
1	55.76	23.48	20.76	Sandy clay	Light brownish gray	0.5	0.447
2	58.98	20.4	20.62	Sand	Olive brown	1.5	0.47
3	36.6	28.5	34.9	Sand	Yellowish Brown	2.3	0.4711
4	37.2	22.2	40.6	Silty	Brownish yellow	1.35	0.4561
5	61.7	19.9	17.18	Sandy clay	Dark grayish brown	0.97	0.5011
6	59.42	23.13	17.46	Sand	Light olive brown	1.33	0.616
7	37.19	45.28	16.93	Clay	Pink	0.72	0.5644
8	36.1	38.4	25.5	Clay	Light yellowish brown	0.88	0.5732
9	27.5	52.9	20.8	Clay	Dark grayish brown	4.65	0.526
10	60.3	20.8	19.22	Sandy clay	Olive brown	0.59	0.62
11	50.86	31.35	17.79	Sandy clay	Light brownish gray	0.95	0.604
12	38.74	44.06	17.2	Clay	Yellow	0.82	0.734
13	27.6	47.7	24.9	Clay	Light grayish brown	1.28	0.626
14	37.9	48.1	14	Clay	Light gray	0.33	0.656
15	33.53	36.67	29.1	Clay	Yellow	0.39	0.6253

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Soil texture data from the 15 landslides is presented in Table 1. Soil samples for landslides 1, 2, 3, 5, 6, 10 and 11 have high sand content which indicates the landslides are shallow ones. Soil samples for landslides 7, 8, 9, 12, 13, 14 and 15 has clay content exceeding 32%, implying extremely high expansive potential. High clay contents indicate increase in pore water pressure which exhibits large landslides (32% clay content exhibits extreme expansion potential, Van Der Merwe 1964). As the field was held before monsoon season so the moisture content of soil was found to be less than 1.5%. With less moisture content, bulk density was also found to be less than 0.8 gm/cm^3 (Table 1). Field observation showed steep slope angles, weak geology, rugged topography and groundwater were also responsible for the formation of landslide as major inherent reasons for landslides. Similar reasons were reported along with rainfall in Dumrebesi section of Narayanghat- Muglin road (Regmi et al., 2013). Through the texture analysis it was found that clay content was high in landslide areas.

Table 2: Characterization of landslides

S.N.	Depth of landslide(m)	Length of slope	Landslide types	Weathering condition	Surface Roughness	Damages	Impact factor
1	2.5	11	Flow	Highly Weathered	Crack	Road	Rainfall, Road construction, Vibration
2	3.3	21	Flow	Slightly weathered	Highly cracked	Road, Vegetation, Stream	Rainfall
3	2.5	10.5	Fall, Flow	Highly Weathered	Highly cracked	Forest	Rainfall
4	5	9.5	Flow	Highly Weathered	Highly cracked	Road, Forest	Rainfall, Road construction, Vibration
5	5	30	Slide	Highly Weathered	Slightly cracked	Water Channel, Road, River	Rainfall, Road construction, Vibration
6	4.3	15	Slide	Highly Weathered	Highly cracked	Water Channel, Road, River	Rainfall, Vegetation
7	2.5	6	Flow	Highly Weathered	Highly cracked	Road, Water channel	Rainfall, Vegetation
8	15	106	Slide	Highly Weathered	Highly Fractured	Road, Farming	Rainfall
9	4	150	Flow	Highly Weathered	Highly cracked	Road, Farming, Water Channel	Rainfall
10	4	28	Slide	Highly Weathered with human disturbance	Highly Fractured	Road, Cultivation	Rainfall, Deforestation
11	3	180	Slide	Slightly weathered	Highly cracked	Water Channel Blockade	Loosening of rock due to Earthquake, Rainfall
12	50	150	Flow	Highly Weathered	Highly cracked	Settlement, People, River shifting, Cultivation	Rainfall, Road construction, Vibration
13	14	32	Flow	Highly Weathered	Highly cracked	Cultivable land, Road, Forest)	Weathering, Rainfall
14	5	32	Flow	Highly Weathered	Slightly cracked	Road	Vegetation, Road, Rainfall
15	15	160	Slide	Highly Weathered	Highly cracked	Road, Cultivation	Rainfall
16	5	16	Flow	Highly Weathered	Less crack	Road, Forest	Rainfall

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From Table 2, it is seen that all the 16 landslides studied in the study area were found to be highly cracked and weathered. Mostly thin type of vegetation type was found in most landslide area. Bamboo, Banmara, Sisnu, Simal, Nilkada, Chiuri, Daero, Khayar, Salla, Epilipi, Bakaino, Kans, Dhupi, Katuke, Raju, Ryajo, Sori were the types of vegetation found in the study area. Forest, grazing land, settlement area, cultivation and road were the types of land use pattern found in the study area. People mainly used the land around the landslide area for settlement, grazing, cultivation purpose. Road construction, rainfall, deforestation, loosening of rock due to Earthquake, weathering were seen to be the reason for the occurrence of landslide in the study area. The occurrence of landslides had affected not only lives of people but also road, forest, cultivation and water channel.

Table 3: Landslides with state and distribution

Landslide No.:	State	Rate of movement	Groundwater condition	State	Distribution
1	Reactivated	Slow	Dry	Reactivated	Retrogressive
2	Reactivated	Moderate	Wet	Reactivated	Advancing, Widening
3	Inactive	Slow	Dry	Inactive	Confined
4	Inactive	Moderate	Wet	Inactive	Advancing, Widening
5	Active	Moderate	Wet	Active	Advancing, Widening
6	Active	Moderate	Wet	Active	Advancing
7	Inactive	Slow	Dry	Inactive	Retrogressive
8	Reactivated	Rapid	Dry	Reactivated	Advancing, Widening
9	Active	Moderate	Dry	Active	Advancing
10	Inactive	Moderate	Dry	Inactive	Retrogressive
11	Inactive	Moderate	Wet	Inactive	Advancing, Moving
12	Active	Rapid	Wet	Active	Advancing, Widening
13	Active	Moderate	Dry	Active	Advancing, Widening
14	Inactive	Slow	Dry	Inactive	Advancing
15	Active	Rapid	Dry	Active	Advancing, Widening
16	Inactive	Slow	Dry	Inactive	Confined

Moderate type of rate of movement was seen in 8 landslides while slow type of movement was seen in 5 landslides and rapid type of movement was seen in 3 landslides. Dry type of

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groundwater and surface water condition was found to be higher. Out of 16 landslides, 7 were in inactive state, 6 were in active and 3 were in reactivated state. Mainly landslides were found to be advancing and widening in the study area. Mostly flow type of landslides was seen in the studied area.

It is seen from figure 6 that the area coverage is high in >60° slope class and less in 20°-40° class. Likewise, area coverage for hillshade class 250-300 is higher than 50-100 (Figure 7). Gawar formation occupied high area of 149.2 while Suntar Formation occupied only 8.2 areas (Figure 8). Out of three curvatures class, convex occupy high area of 25.2 (Figure 9). Likewise, out of 9 aspect class, South class occupied high area of 9.5 and Northwest occupied less area of 4 (Figure 10). Drainage class 200-250 has high area coverage than 50-100 drainage class (Figure 11). Agricultural land occupied larger area while shrub land occupied less area in Land use class (Figure 12). Elevation class 1500-2000 m occupied high amount of area than 2000-2500 m class (Figure 13).

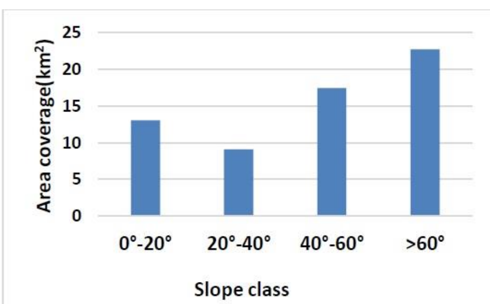

Figure 6: Area of landslides in the Slope class

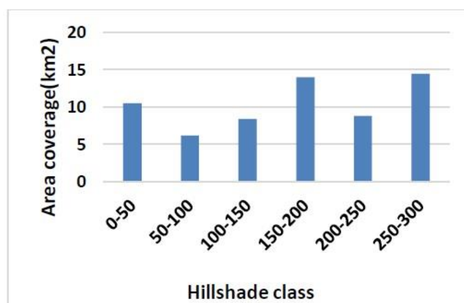

Figure 7: Area of landslides in the Hillshade class

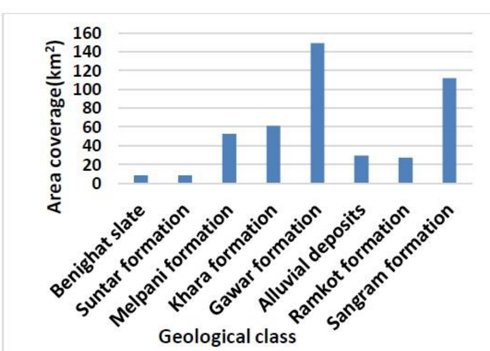

Figure 8: Area of landslides in the Geological class

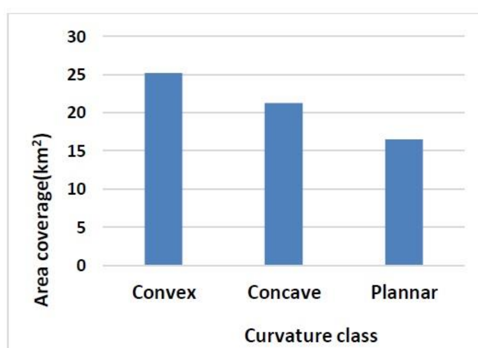

Figure 9: Area of landslides in the Curvature class

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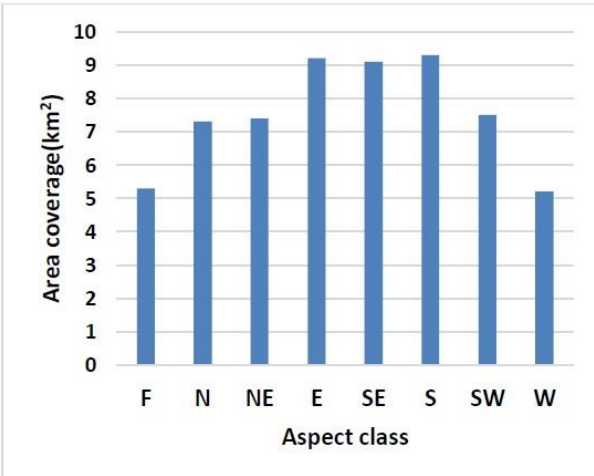

Figure 10: Area of landslides in the Aspect class

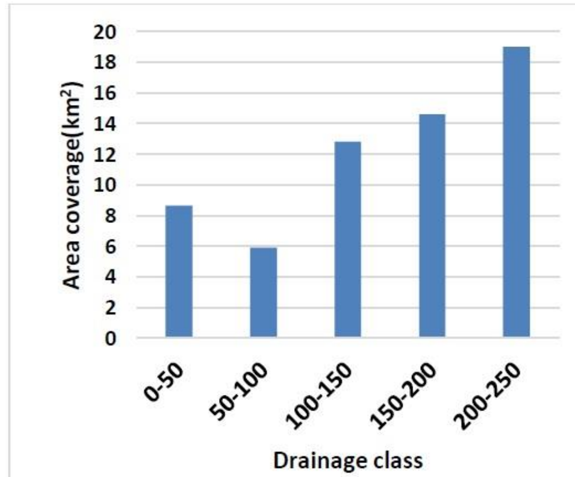

Figure 11: Area of landslides in the Drainage class

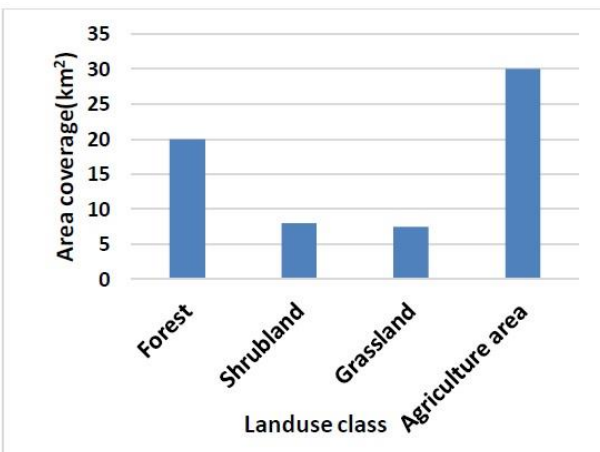

Figure 12: Area of landslides in the Land use class

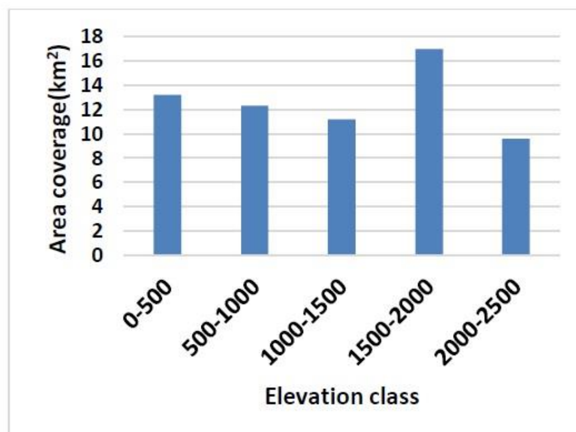

Figure 13: Area of landslides in the Elevation class

Rainfall induced landslide

Rainfall is main cause of landslide, either directly or indirectly. Landslides are major result of the rainstorm followed by slope failure and other parameter. The rainstorm with less than rainfall amount of 200 mm cannot cause soil failure, as the rainstorm with less than rainfall amount of 200 mm entirely infiltrates into soil, the resulting water table rise is not enough to trigger landslide. The occurrence of landslide is related to the rainfall duration and rainfall pattern for the rainstorm with greater than rainfall amount of 200 mm. Rainfall data of 30 years of Bijuwartar station from DHM and landslides data from MoHA, DesInventar and Google earth

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and field visit was used to see if rainfall was the main cause for landslide occurrence in the study area.

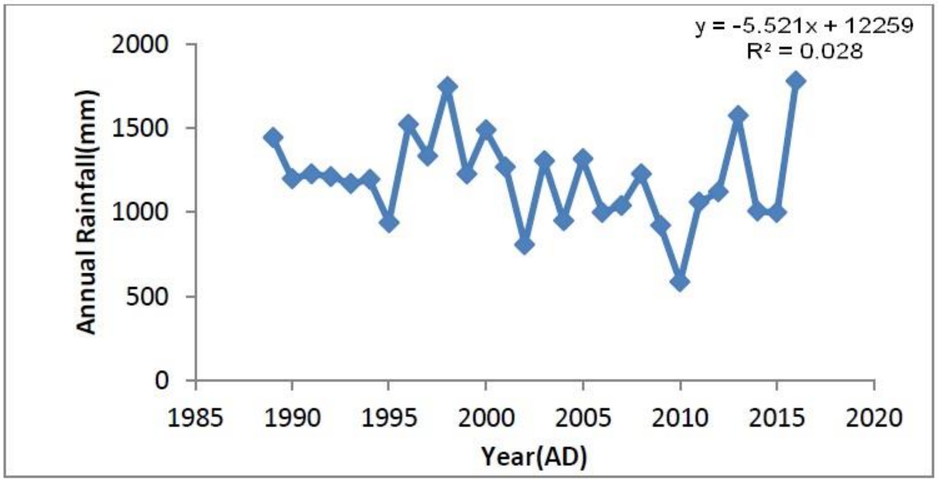

Figure 14: Graphical representation of changes in total annual precipitation with time

From Figure 19, it is seen that rainfall has increased and decreased from 1980 A.D. to 2016 A.D. The highest rainfall was in 2016 A.D. with 1776.5 mm and lowest was in 2002 A.D. with 807 mm.

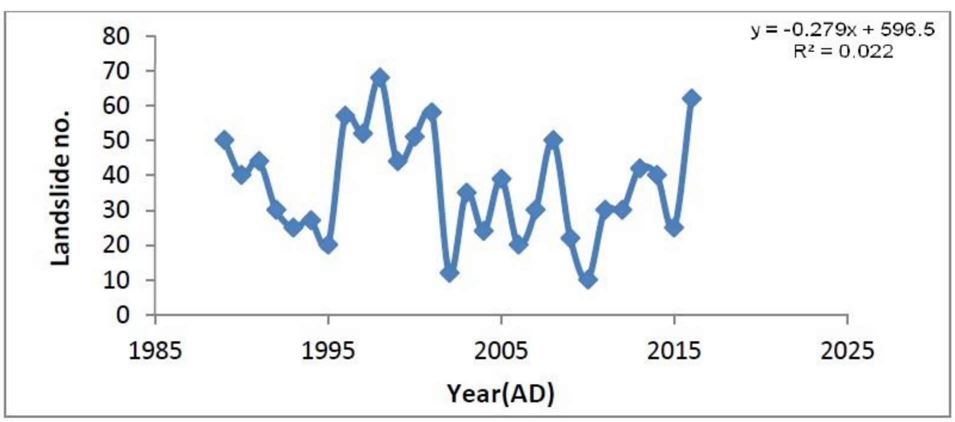

Figure 15: Graphical representation of occurrence of landslides with time

From Figure 20, it is seen that there was decrease in number of landslide till 1995 then gradually there was increase in number of landslide by 2001 A.D. 2016 A.D. has highest number of landslides.

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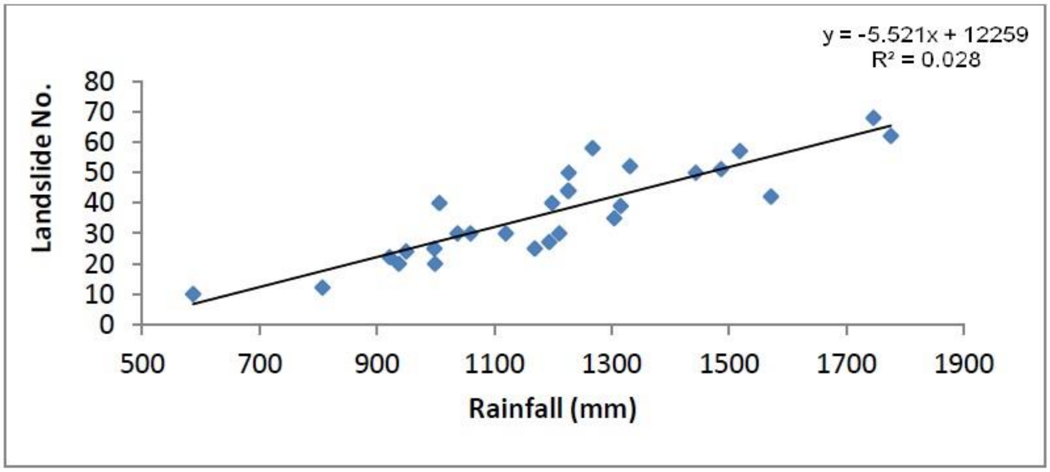

Figure 16: Graphical representation of relation between rainfall and landslide

From Figure 21, we can say that rainfall played important role in occurrence of landslides as with increase in rainfall, landslide also increased. In 2016 A.D., there was high number of landslides occurrence with heavy rainfall due to continuous rainfall. Generalized linear model (GLM) was tested between rainfall and landslide to know the relation between them. The generalized linear model performed between landslide and rainfall shows there is significant relationship between landslide and rainfall. The reason for this may be topography, weathering, rock structure or slope.

Landslide Susceptibility using WOE Model

8 causative factors **(**elevation, curvature, slope, aspect, geology, land use, elevation, and distance from river) were combined to produce a landslide susceptibility index map using WOE.

From Table 4, it is seen that the weightage value is higher for slope greater than 60 °, the landslide are identified more by 26.6 % in the slope gradient between >60° which covers 43% of the study area. As the slope angle increases, the shear stress in the soil or other unconsolidated material generally increases making them prone to failure. About 7.4% and 4.5% of the study area falls in South and North-East aspect covering 10.3% and 12 % of landslides within the study area. The relative relief or Hillshade under the gravitational force tends to dislodge the slope materials, thus comprising direct relation to landslide occurrence. Table 4 shows the presence of maximum number of landslide pixel in 250-300 class covering 59.88% of total area and 23.8 % of landslides.

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Table 4 shows the presence of maximum number of landslide in convex region covering 40.77% of total area. The convex slopes are regularly attacked by the external forces making the soil loose and hence susceptible to failure. The study area lies in eight geological formation areas; namely; Alluvial deposit, Khara Formation, Ramkot Formation, Suntar Formation, Sangram Formation, Melpani formation, Benighat Slate and Gawar Formation. This kind of surficial deposit is Quaternary to Recent in origin. Phyllite, Slate, Quartzes and sandstones were mainly rock found in the study area. Benighat slate contains high number of landslides i.e. 55%. Weightage value, C shows the positive correlation between landslide occurrence and Suntar Formation, Benighat slate and alluvial deposit whereas negative correlation between other formation. That shows that Suntar Formation, Benighat slate and alluvial deposit portions are highly susceptible for the landslides occurrences.

Drainage plays its role in slope instability. Weightage value, C showed the higher positive correlation between landslide occurrence and river distance between 0 to 50 m of river distance respectively. That shows that drainage distance from 0-50 m are highly susceptible for the landslides occurrences. Land use is often considered as a static factor in landslide studies, and few researches involve constantly changing land use as a factor in the analysis (Van Beek & Van Asch, 2004). The map was mainly classified into four land use; mainly, forest area, agricultural land, shrub land, grassland area as shown in Figure 23. Most of the land is covered by forest and agricultural area. Grassland, shrub land, agricultural and forest area covered 13.5 % 5.5%, 14.8% and 66.2% of the total study area respectively. Table 4 shows the presence of maximum number of landslide in agriculture area followed by forest area i.e. 46% and 20.5 respectively. Weightage value, C showed the higher positive correlation between landslide occurrence and agriculture area. That shows that agriculture areas are highly susceptible for the landslides occurrences.

Elevation is another frequently used parameter for landslide susceptibility studies. It is stated that the landslides have more tendency to occur at higher elevations (Ercanoglu et al. 2004). The elevation values were divided into 5 categories ranging from 0-500 m, 500-1000 m, 1000-1500 m, 1500-2000 m and 2000-2500 m with an interval of 500 m as shown in Figure 29. Elevation class 1500-2000 occupied 39.62% of study area. The weightage value as indicated in Table 4

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shows that weightage value are higher for elevation 2000-2500 m, indicating that the probability of landslide occurrence becomes higher as the altitude increases.

The final landslide susceptibility map of the Jumre Khola watershed using WOE model was constructed by the summation of each weightage value and dividing it into five susceptible classes according to the accepted principle as very low, low, moderate, high, and very high. For map validation, Success Rate Curve (SRC) was prepared which indicates the suitability of map. The success rate curve was obtained based on the comparison of the result from the WOE model and the training data 152(80 %), while the prediction rate curve was procured from the randomly selected remaining 47 (20 %) landslides that were not used in the training stage. Landslide susceptibility map validated by using success rate curve found the validation with 86.79 %. Kayastha et al., 2012 has also found the 75.5 % and 75.2 % validation results from the success rate curve of landslide susceptibility predicted with the frequency ratio method and with the multiple linear regression method. The result obtained from this model is quite good. Thus, this model can be used in other similar watershed with similar geological and morphological setting. In addition, the susceptibility map of the watershed can be very valuable in landslide hazard and risk reduction here, as well as it can be used for designing future development works in the area.

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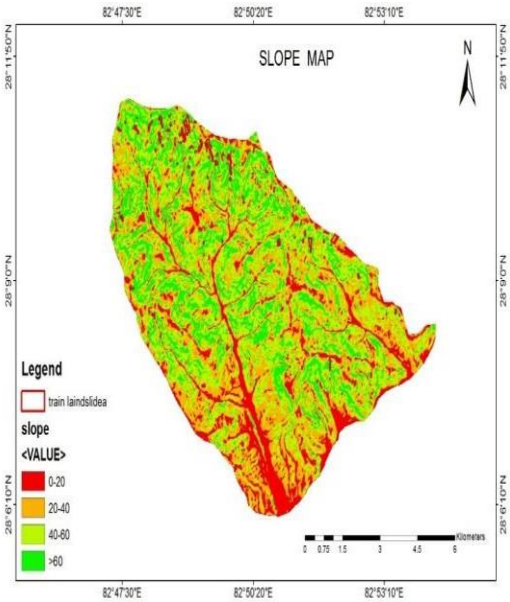

Figure 17: Slope Map of the study area

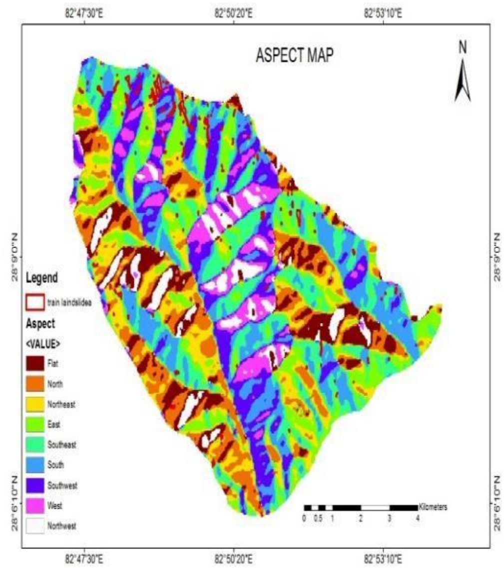

Figure 18: Aspect map of the study area

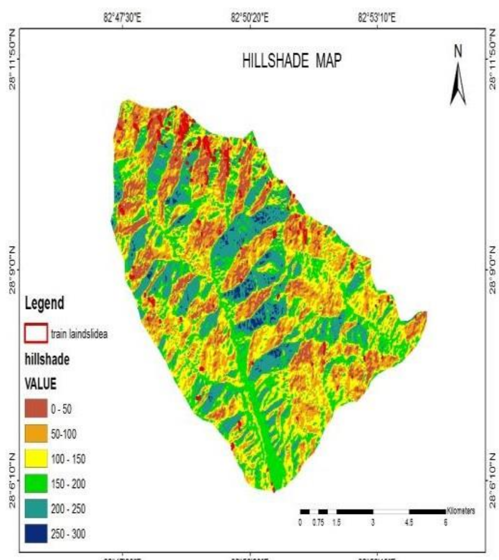

Figure 19: Hillshade map of the study area

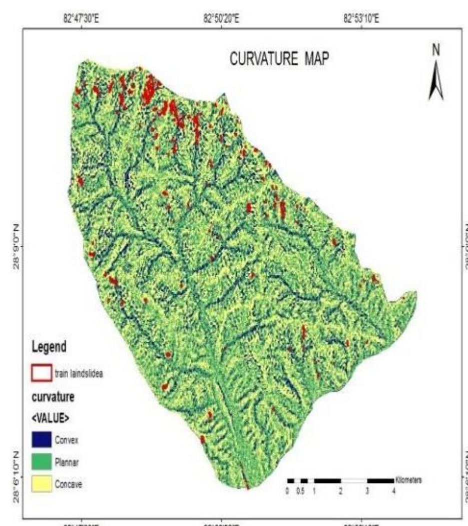

Figure 20: Curvature map of the study area

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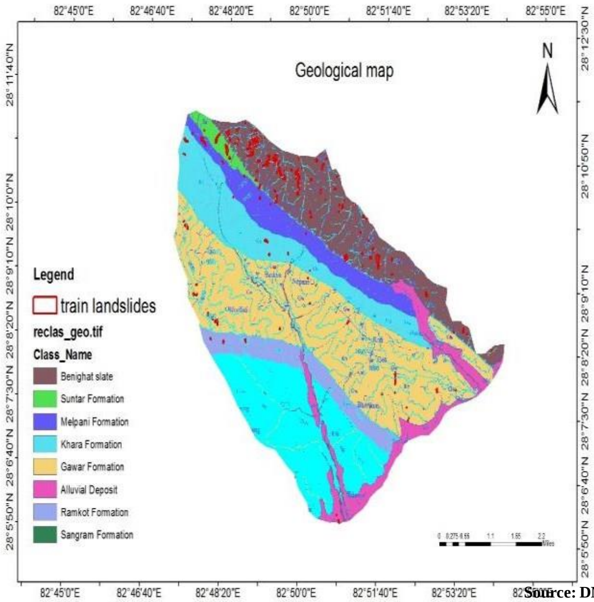
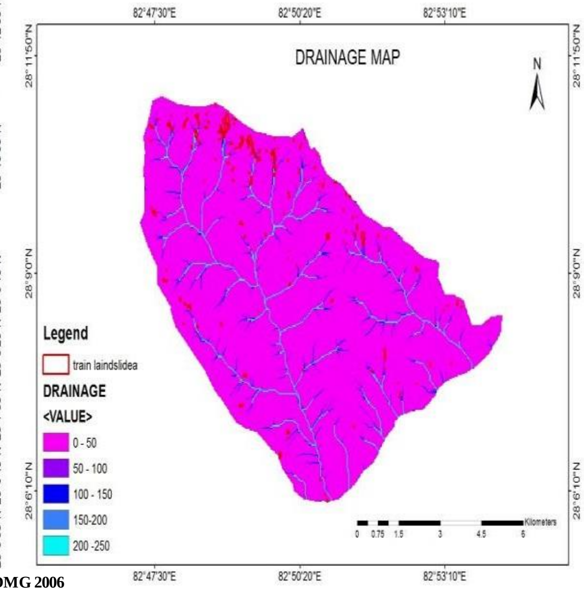
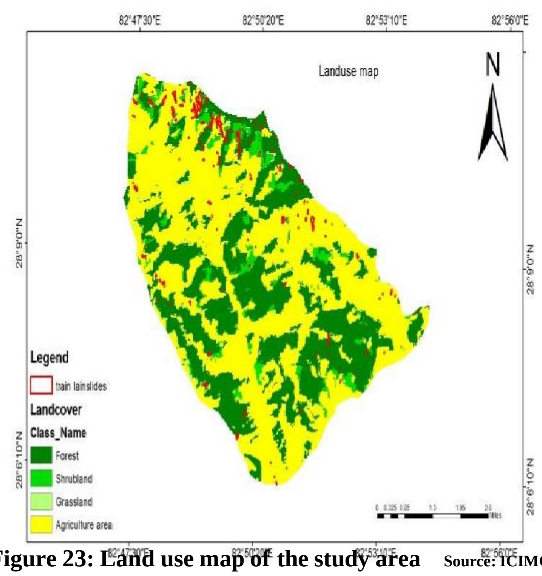




Source: DMG 2006

Figure 21: Geological map of the study area

Figure 22: Drainage map of the study area



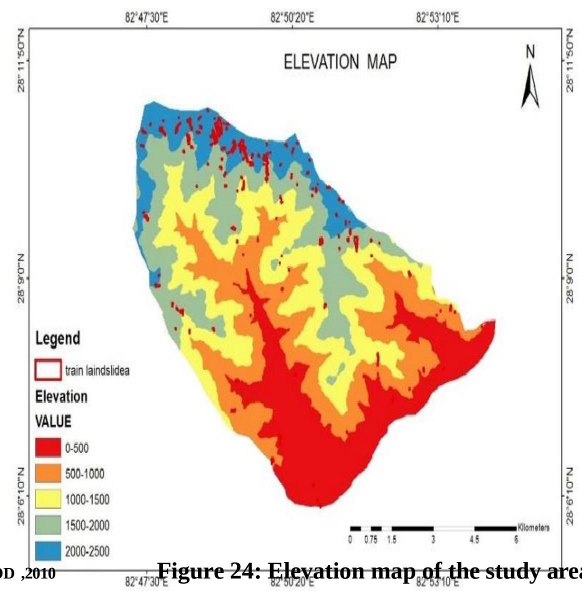


Figure 23: Land use map of the study area **Source: ICIMOD ,2010**

Figure 24: Elevation map of the study area

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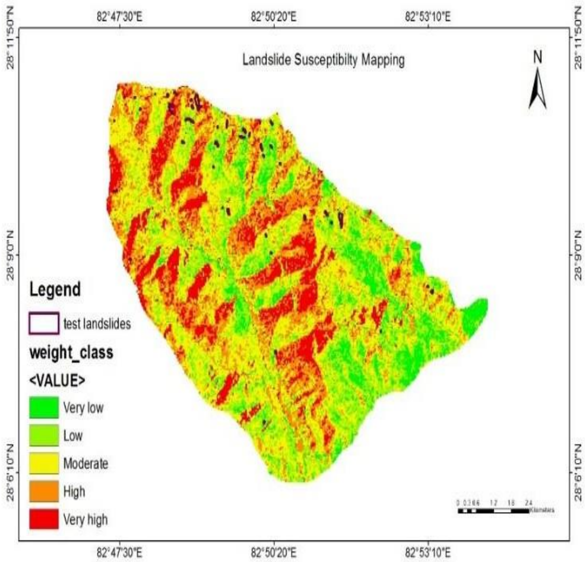

Figure 25: Landslide Susceptibility Map of the study area

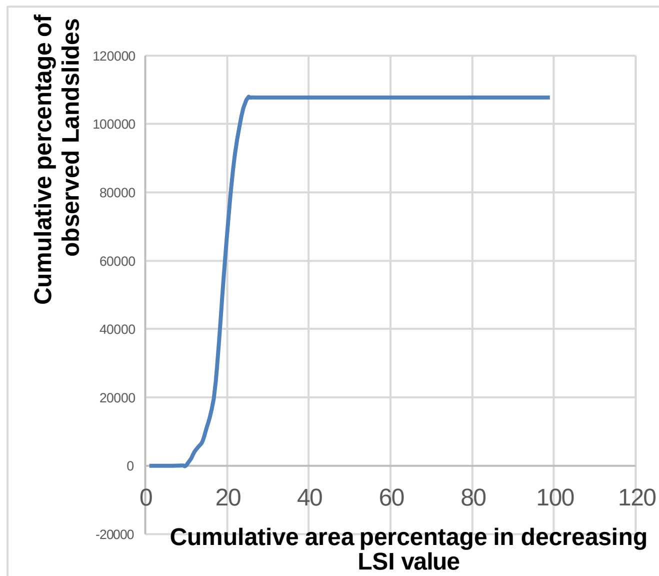

Figure 26: Validation map by using Success Rate Curve

The train landslides were also overlaid over the each factor maps and the values were obtained as per formula of WOE model. These calculations are provided in Table 4:

Table 4: Weightage table for factor maps

Factors	Class	Pixel Count	Landslide%	W+	W-	C
	0- 20°	18390	22.2	-2.3275	0.043308	-2.37081
Slope	20°-40°	50300	25.4	-0.90719	0.083664	-0.99085
	40°-60°	110909	25.8	-0.25992	0.085633	-0.34555
	>60°	145505	26.6	0.29733	-0.1356	0.43293
	F	33999	11.9	-2.45343	-0.08992	-2.36351
	N	44483	7.04	-2.18466	-0.11936	-2.06529
	NE	47240	12	-2.12453	-0.12725	-1.99727
Aspect	E	56191	22.04	-1.95101	-0.15330	-1.79771
	SE	55498	15.2	-1.96342	-0.15126	-1.81216
	S	57589	10.3	-1.92643	-0.15743	-1.76899
	SW	44374	11.2	-2.18716	-0.11905	-2.06806
	W	30053	7.5	-2.57689	-0.07906	-2.49784
	NW	25922	2.6	2.72467	0.06782	2.65686
	0-50	20515	23.5	-2.94965	-0.05378	-2.89587

	51-100	36604	11.92	-2.37065	-0.09808	-2.27257
Hillshade	110-150	47985	17.79	-2.09991	-0.13064	-1.96927
	160-200	53360	12.62	-1.67578	-0.17157	-1.50421
	210-250	54602	10.35	-1.97073	-0.15007	-1.82066
	260-300	53760	23.88	-1.98627	-0.14758	-1.83869
	Concave	498	16.63	-6.67692	-0.00126	-6.67566
Curvature	Plannar	4908	32.6	-4.38992	-0.01248	-4.37744
	Convex	54692	50.77	1.97805	0.14889	1.82916
	Benighat slate	537779	25.2	-0.08701	-0.77688	0.68987
Geology	Suntar Formation	52660	20.4	1.47446	-0.93369	2.40815
	Melpani Formation	335861	7.54	-0.28533	0.02734	-0.31267
	Khara Formation	392426	5.46	-1.00668	0.08118	-1.08787
	Gawar Formation	954819	10.37	-1.26647	0.25312	-1.51959
	Alluvial Deposit	187467	21.14	3.46207	0.05077	3.41129
	Ramkot Formation	169985	6.14	-1.96986	0.04521	-2.01507
	Sangram Formation	716580	3.8	-0.65412	0.12325	-0.77737
	0-50	389407	26.77	-0.01514	-4.19772	4.18258
	50-100	2521	17.75	-5.05511	-0.0064	-5.04872
	100-150	1090	23.85	-5.89359	-0.00276	-5.89083
Drainage	150-200	782	12.85	-6.22567	-0.00198	-6.22369
	200-250	407	18.78	-6.87871	-0.00103	-6.87768
	Forest	78	20.5	-0.40547	0.34042	-0.74589
Land use	Shrub land	465	15	-2.60167	0.85066	-3.45233
	Grassland	5	18.5	-0.68636	0.00634	-0.6927
	Agriculture area	238	46	0.65746	-0.51727	1.17473
	0-500	47334	15.8	-2.12254	-0.12752	-1.99502
	500-1000	51273	35.2	-2.0426	-0.13891	-1.90369
Elevation	1000-1500	54879	33.25	-1.97464	-0.14944	-1.98234
	1500-2000	57855	9.49	-1.92183	-0.15822	-1.76361
	2000-2500	57489	6.26	1.92818	0.15714	1.77104

CONCLUSION

The rapid increase in population as well as lack of policy regarding the land-use system in Nepal has forced people to live in steep hill slopes and along the river valleys. Besides, the road construction practices in most places do not follow any established principles. The problem of landslide is on the increase in the mountainous area of Nepal due to adverse geological conditions, prolonged and high-intensity rainfall and anthropogenic factors, which leads to enormous loss of life and property every year. A landslide inventory map containing 199 landslides was developed using the earlier published/unpublished reports and maps, by the analysis of Google Earth images and by the detailed field survey. From the inventory map, 152 (80 %) landslides were used for model training and the remaining 47 (20 %) for validation purpose. The generated LSM was validated using area under curve (AUC).

South East and South aspects, slope >60°, elevation ranging from 2000-2500 m, Benighat slate, alluvial deposits and Suntar formation, haphazard road construction on mountains, and river erosion were major contributors of landslide Susceptibility in the Jumre Khola watershed of Pyuthan district, Nepal. Landslides were mostly seen in the agricultural area followed by forest area. The class ranging from 0-50 in drainage distance showed the positive weight values for the landslide occurrence in the study area. A graph between rainfall, landslide and year was plotted simultaneously to see the trend. It was found that the relationship was medium. Rainfall and landslide has close relation as landslide occurrence increased with heavy rainfall.

The susceptibility class was also classified to very low, low, moderate and high and very high classes based upon these conditioning factors. The success rate curve showed 86.79 % of the area lying area under the curve. The landslides were found mainly in moderate zone maybe because landslides have occurred many times in the past so there is high chance of occurrence of same landslides in adverse conditions. The developed susceptibility map can be valuable for the future land-use practice as well as for the development in the area.

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REFERENCES

1. Bonham-Carter, G. F. (1994). *Geographic Information Systems for Geoscientists: modelling with GIS. Computer methods in the geosciences, Vol 13.* Oxford: Pergamon Press, P 398.
2. Brab, E. (1984). Innovative approaches to landslide hazard mapping. *Canadian Geotechnical Society* , 307-324.
3. Bousta, M., & Brahim, L. A. (2018). Weights of evidence method for landslide susceptibility mapping in Tangier, Morocco. Paper presented at the *MATEC Web of Conferences.*
4. Chung, C.-J. F., & Fabbri, G. A. (1999). Probabilistic prediction models for landslide hazard mapping. Photogramm Eng Remote Sensing. *Photogrammetric engineering and remote sensing , 65* (12), 1389–1399.
5. Ercanoglu, M., Gokceoglu, C., & Van Asch, T. W. (2004). Landslide Susceptibility Zoning North of Yenice (NW Turkey) by Multivariate Statistical Techniques. *Natural Hazards* , 1-23.
6. Fell, R., Corominas, J., Bonnard, Ch., Cascini, L., Leroi, E., and Savage, W. Z.(2008). Guidelines for landslide susceptibility, hazard and risk zoning for land use planning, *Engineering Geolology*, 102, 85–98.
7. Guzzetti, F., Reichenbach, P., Ardizzone, F., Cardinali, M., & Galli, M. (2006). Estimating the quality of landslide susceptibility models. *Geomorphology* , 166-184.
8. Kayastha, P., Dhital, M. R., & Smedt, F. D. (2012). Landslide susceptibility mapping using the weight of evidence method in the Tinau watershed. *Natural Hazards* , 479-498.
9. Regmi, A., Devkota, K., Yoshida, K., Dhital, M. R., & Devkota, K. (2013). Effect of rock weathering, clay mineralogy, and geological structures in the formation of large landslide, a case study from DumreBesei landslide, Lesser Himalaya Nepal. *Landslides* , 1-13..
10. Regmi, N. R., Giardino, J. R., & Vitek, J. D. (2010). Modeling susceptibility to landslides using the weight of evidence approach: Western Colorado, USA. *Geomorphology* , 172-187.
11. TU-CDES, & UNDP. (2015). Disaster Risk Management: Concept, Policy and Practices in Nepal. *Strengthening Disaster Risk Management in Academia.*
12. Van Beek, L., & Van Asch, T. (2004). Regional assessment of the effects of land-use change and landslide hazard by means of physically based modelling. *natural Hazards* , 289-304.
13. Varnes, D. J. (1978). *Slope Movement Types and Processes in Landslide, Analysis and Control.*