GIS Based Landslide Susceptibility Mapping along the Road Section from Bandeu to Barahabise, Sindhupal Chowk District of Nepal

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Abstract: ***Landslide is the one of the natural hazards that occurs frequently in the Nepal Himalaya causing huge loss of life and property every year especially during rainy season. Landslides occurred in the Sindhupal chowk District, Jure (2nd August 2014), along the road corridor of Araniko Highway blocked Sunkoshi River resulting loss of 156 lives, damaged road section and huge property loss. Due to the weak geological condition, rapid developmental activities and other inherent natural conditions, Barhabise area of Sindhupal chowk District has been exposed to landslide hazard. Therefore, present study concentrates on landslide susceptibility mapping of the area along the road corridor of the Araniko Highway about 30 km from Bandeu to Barhabise, Sindhupal chowk District by using Arc GIS 10.3. Statistical index method was used to prepare the landslide susceptibility maps. The causative factors considered for the study were elevation, slope angle, slope aspect, geology, distance from drainage, distance from road, land use and rainfall. For the preparation of slope, aspect and elevation map a cartosat image 30m*30 m resolution was used and for land use, geology and distance from drainage and road factor data was taken from Department of Survey and for rainfall factor data of Department of Hydrology and Meteorology was used. The landslide index map was varied from -6.8213 to 5.0883. Statistical Index method shows that LSI value less than -3.038251 was classified as low susceptibility zone, values between -3.038251 and -1.870643 was considered as medium susceptibility zones and more than -1.870643 was considered as high susceptibility zone respectively. Thus, these maps can be used for slope management, land use planning and disaster management planning by the concerned authorities.***

Keywords: landslides, susceptibility, hazards, causative factors, statistical index

1. Introduction

Lesser Himalaya and Siwalik is more prone to landslides due to of its high relief, high intensity monsoon rainfall, natural factors and human interferences which contributes floods also. Landslides are natural events but may turn into hazard and cause loss of lives and damage to man-made and natural structures. Landslides are influenced by several preparatory and triggering factors which vary significantly from region to region due to the variation in distribution of rock and soil types, geological structures, rock deformations, geomorphology, and climatic conditions, the level of risk according to the geological divisions. The concept of landslide is dealt by many authors differently. Varnes and IAEG (1984) defined landslides as 'almost all varieties of mass movements on slope including some such as rock falls, topples and debris flow that involve little or no true sliding'. According to Brabb (1993) at least 90% of landslide losses can be avoided if the problem is recognized before the landslide event. Application of Remote Sensing and Geographical Information System is of immense importance for effective landslide susceptibility mapping, hazard assessment and risk assessment which results into awareness, mitigation and management. Landslide-susceptibility maps describe the relative likelihood of future land sliding based solely on the intrinsic properties of a locale or site. Prior failure (from a landslide inventory), rock or soil strength, and steepness of slope are the three site factors that most determine susceptibility.

Susceptibility does not consider the temporal probability of failure (i.e. when or how frequently landslide occur) nor the magnitude of the expected landslide (i.e. how large and destructive the failure will be) (Brabb, 1984). Hence, there is a dire need for landslide hazard assessment at various spatial scales. Landslide causes loss of around 1000 lives and property worth $4 billion annually (EM-DAT 2007). According to the database created by the Centre for Research on Epidemiology of Disasters, landslides and related processes have killed over 61,000 people worlds over in the period between A.D. 1900 and A.D. 2009 (EMDAT 2010).

Gabet et al. (2004) applied rainfall threshold for landslides in Nepal Himalaya considering daily and seasonal rainfall threshold for modeling. They suggested that enough antecedent rainfall is necessary to produce positive pore pressure and trigger landslides. Landslides are the most lethal geological hazard in Nepal in terms of frequency of its occurrence which is most triggered by an earthquake and intense rainfall (Dhakal, 2015). Statistical method which determines spatial landslide instability is used to describe the functional relationships between instability factors and the past and present distribution of slope failures (Carrara, 1983).

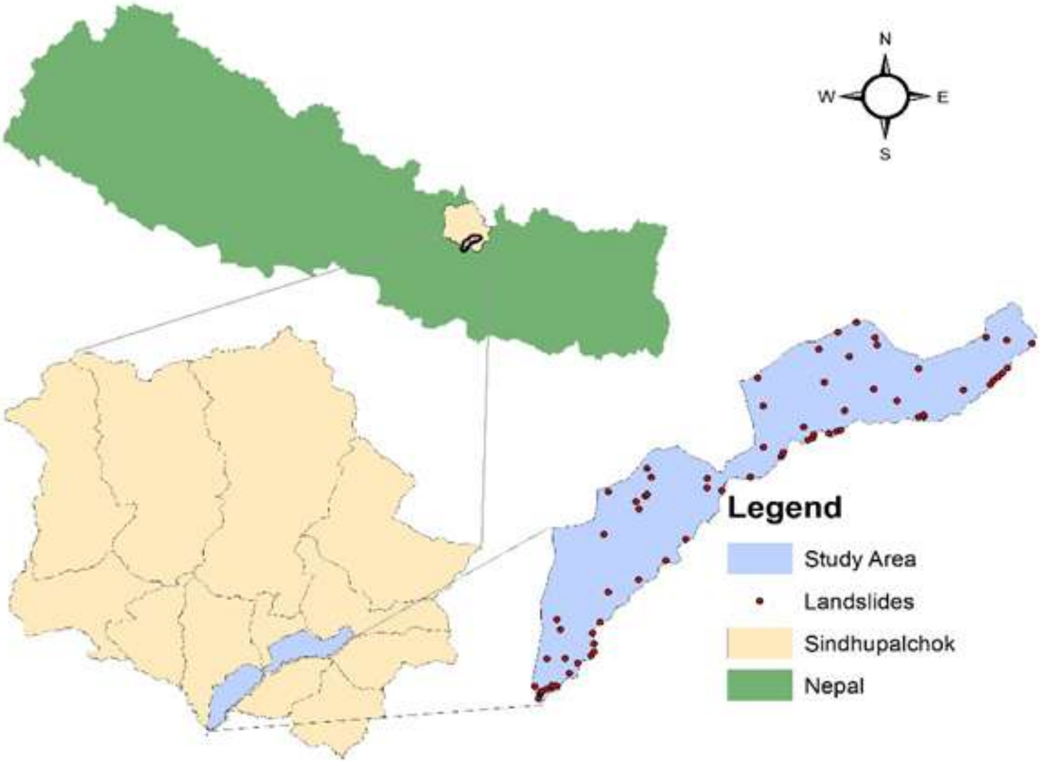

Figure 1: Study area with the distribution of landslides

The bivariate methods are a modified form of the quantitative map combination with exception that weights are assigned based on statistical relationships between past landslides and various factor maps (Van Westen, 1994).

1.1 Study Area

The study area lies in the Sindhupal Showk district of Central Development region. It includes mainly five VDCs as Sangachowk, Kadambas, Fulpingdandagau, Mankha and Ramche for the study of landslide susceptibility mapping includes the road corridor length of about 30 km. It is bounded by the latitudes 27°39'21.8" N and 27° 39'21.8" N, and the longitudes 085°42'20.0" E and 085°42'20.0" E covers 6.7km^2 (Fig 1). The altitudinal ranges extend from 600m to 2361m characterized by cut slope hills along the road corridor. The Sunkoshi River is the main river system in the study area where the average maximum daily rainfall is of the order of 121 mm. The maximum rainfall occurs during the monsoon months from June to August. The area is dominated by the slopes ranging between 15° to 60° and land use at the study area is mainly forest, cultivation land, grassland, scrub land and steeps hill slopes.

1.2 Landslide Inventory Map

The first step for mapping susceptibility was to make landslide inventory map. Landslide inventory is the simplest output of direct landslide mapping which records location, date of occurrence and type of movement (Guzzeti, 2003; Dahal, 2012). The most straightforward initial approach to any study of landslide susceptibility and hazard is the compilation of the landslide inventory and such inventories are the basis of most susceptibility mapping technique (Dai et al., 2002). Inventory map basically gives the information on landslide distribution location through which we can apply the mitigation measures. Since landslide occurrence in the past and present are keys to future spatial prediction (Guzzetti et al., 1999). It provides the basic information to evaluate and mitigate the landslide hazard on the regional scale. Therefore, the preparation of landslide inventory map requires serious effort and of course a lot of time. In this context, landslide inventory map was prepared by using the high resolution of Google Earth imageries and carried out detailed field survey of the area (Fig.1). A total of 71 landslides were observed in the study area which covers an area of about 1088426.0837m^2 and landslides depth varies from 0.2m to 40m. From these, 57(80%) landslides were randomly selected as training data and the remaining 23(20%) was kept for validation purposes. Most of the landslides are located near the highway and river banks. Different type of landslides is observed in the study area such as rotational, transitional, flows and fall and rock falls, debris flow and slides are mostly observed along the highway.

2. Landslide Causative Factor

Eight different parameters used in this study are elevation, slope, aspect, drainage distance, road distance, slope angle, rainfall and landuse. The topographic map was used to prepare the digital elevation model (DEM) of the study area with 30×30 m pixel size. Using this DEM and the ArcGIS 10.3 software, different thematic data of factor were generated (fig 2) to produce susceptibility map in final.

Topographic factors

Elevation is useful to classify the local relief and locate points of maximum and minimum heights within terrains (Ayalew &Yamagishi, 2005) which have direct or indirect relationships to cause the landslide and weathering phenomena which is the reason of sliding closely related to elevation. The elevation was prepared by using DEM ranges from 600m to 2361m and is reclassified into five classes.

(Krishna et al., 2014) reported that the slope with > 20° has high influence in the landslide susceptibility zonation. Slope of the study area was classified into four classes as less than 15° (fair slope), 15° -30° (moderate slope), and 30°-45° (steep slope) and 45°- 60° (very steep slope).

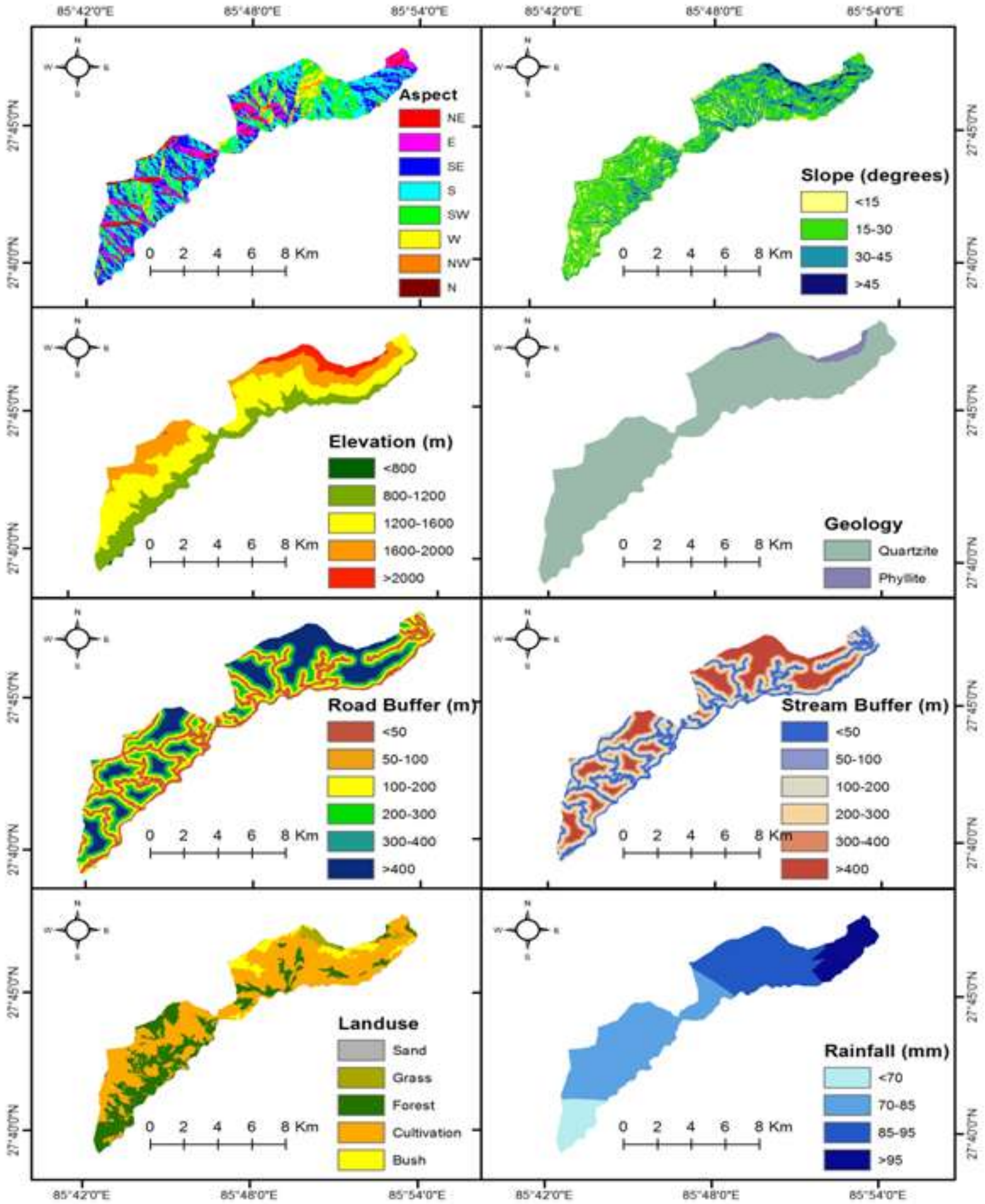

Figure 2: Different thematic maps used for present study

Aspect is one of the important factors in preparing landslide susceptibility maps (Carrara et al., 1999). The slope aspect is classified into eight classes as North East (NE), East (E), South East (SE), South (S), South West (SW), West (W), North West (NW) and North (N) from DEM.

Geology

Geology is one of the strong parameters that influences the slope instability as study area was present in lesser Himalaya found geologically weak and fragile. A geological map of the study area was prepared through digitization from the geological map of Central Nepal provided by Department of Survey.

Land Use

It is one of the most commonly used human induced factors responsible for the occurrence of landslides (Sujatha et al., 2012). Land cover data were obtained from Google earth image 2016 by drawing polygon and obtained the results from Arc GIS 10.3. The map has been classified into five classes as barren land, forest land, cultivation, bush and grass.

Distance from drainage and road

Runoff plays an important role as a triggering factor for landslides. Similarly, due to the road construction disturb the natural channel which increases anthropological instability. Based on rivers and road on the topographic map provided by Department of Survey drainage and road map was prepared in GIS using multiple ring buffer tools classifying the distance into six classes as <50m, 50-100m, 100-200m, 200-300m, 300-400m and >400m.

Rainfall Map

Daily maximum rainfall was taken for rainfall data analysis from nine different stations of surrounding the study area from DHM. Bahrabise, Chautara, Sangachowk, Thokarpa and Nawalpur were in Sindhupalchowk District whereas Panchkhal, Mandan and Dolalghat were in Kavrepalanchowk district and one from Charikot station which was in Dolakha district.

Methods

There are several methods in the statistical approach of landslide susceptibility mapping and here, statistical index method of bivariate analysis was used.

Statistical Index Method

This bivariate method was first introduced by (Van Westen, 1997) for landslide susceptibility analysis. In the statistical index method, a weight value for a parameter class, such as a certain lithological unit or a certain slope class is defined as the natural logarithm of landslide density in the class divided by the landslide density in the entire map. This method is based upon the following formula (Van Westen, 1997):

$$W_{ij} = Ln\left[\frac{f_{ij}}{f}\right] = Ln\left[\frac{\left(\frac{A^*_{ij}}{A_{ij}}\right)}{\left(\frac{A^*}{A}\right)}\right]$$

Where, Wij = weight given to class i of parameter j, Fij= landslide density within class i of parameter j, f = landslide density within entire map, Aij* = area of landslide in class i of parameter j, Aij = area of class i of parameter j, A* = total area of landslide in entire map, A = area of entire map. The resultant landslides susceptibility index map is prepared by overlaying the weighted parameter maps in the GIS application. The process can be represented by the following equation:

$$\mathrm{HI} = \sum_{j=n}^{n} W_{ij}$$

Where, LSI = Landslide Susceptibility Index, Wij= weight of class i of parameter j and n = number of parameters. Statistical Index method calculates Wij to class which have landslide occurrences but due to the natural logarithm, it cannot determine the weight for class where there is no landslide occurrence. The weight (W_{ij}) for each factor class was obtained by using above equation after the result of class% and landslide% 10.3 shown in Table 1. These data were reclassified to make susceptibility map by using the weighted sum option in the spatial analyst tools of ArcGIS 10.3.

Factor	Factor Class	Factor Area (A_{ij})	Landslide Area (A_l)	Landslide area modeled (A_{ij}*)	A_{ij}*/A_{ij}	Weight (W_{ij})
Stream						
	<50	5354284.98	134971.75	7.96	12.40	0.44
	50-100	12339533.23	201592.43	18.34	18.52	0.01
	100-200	13361338.64	157467.04	19.86	14.46	-0.32
	200-300	9897328.77	158467.04	14.71	14.55	-0.01
	300-400	7507371.34	151616.62	11.16	9.00	-0.21
	>400	18793281.26	284311.16	27.94	26.11	-0.1922
Road						
	<50	5570180.54	135836.95	8.28	12.48	0.41
	50-100	12309827.90	199862.02	18.30	18.36	0.03
	100-200	13271934.27	163523.47	19.73	15.02	-0.27
	200-300	9840825.33	154006.23	14.63	14.14	-0.03
	300-400	7496988.88	147084.60	11.14	13.51	0.01
	>400	18763381.29	288113	21.21	26.46	-0.15
Landuse	Barren land	429240.96	40664.56	0.63	3.73	1.76
	Forest	19584707.87	189979.58	29.12	17.45	-0.52
	Cultivation	41208060.55	799970.37	61.27	73.49	0.18
	Bush	4411026.95	17843.29	6.55	1.63	-1.38
	Grass	1620101.88	39968.26	2.40	3.67	0.42
geology	Quartzite	64860005.99	1079504.49	96.44	99.18	0.03
	Phyllite	2393132.24	8921.58	3.55	0.81	-1.46
isoheytal	<70mm	6114393.58	71811.89	9.09	6.59	-0.32
	70-85mm	30778751.59	102094.02	45.76	9.38	-1.58
	85-95mm	22341286.43	105554.83	33.21	9.69	-1.23
	95-121mm	8018706.63	808965.33	11.92	74.32	1.83
elevation	<800	256965.46	3460.81	0.38	0.31	-0.18
	800-1200	17034992.97	394532.82	25.33	36.25	0.36
	1200-1600	29716281.61	456827.48	44.18	41.97	-0.05
	1600-2000	16174980.63	182557.95	24.05	16.77	-0.36
	>2000	4069917.56	51047.01	6.05	4.69	-0.25
aspect	NE	3323246.88	31147.32	4.94	2.86	-0.55
	E	7941703.51	28551.71	11.80	2.62	-1.50
	SE	15621250.35	400589.25	23.22	36.80	0.46
	S	20438703.79	408376.08	30.39	37.51	0.21
	SW	12690805.87	140162.97	18.87	12.87	-0.38
	W	5256976.85	41529.77	7.81	3.81	-0.72
	NW	1260601.59	20764.88	1.87	1.90	0.02
	N	719849.36	17304.07	1.07	1.58	0.39
	NE	3323246.88	31147.32	4.94	2.86	-0.55
Slope	>15°	8135220.70	64025.06	12.09	5.88	-0.72
	15°-30°	38693345.39	407008.08	57.53	37.39	-0.43
	30°-45°	18720121.12	551639.46	27.83	50.68	0.59
	45°-60°	1704451.02	65753.47	2.53	6.04	0.87

3. Result and Discussion

Statistical Index Method by Van Westen, (1997) was used to calculate the weight value for each class of the factors. Landslide susceptibility index (LSI) map was prepared by combining all the weight value of landslide causative factors by using weighted sum function of the GIS application shown in Fig.3. The landslide index map was varied from -6.8213 to 5.0883. The LSI value was categorized manually into three different categories to facilitate the assessment of landslide hazard and reclassified to make the landslide susceptibility zonation map. LSI value less than -3.038251 was classified as low susceptibility zone, values between -3.038251 and -1.870643 was considered as medium susceptibility zones and more than -1.870643 was considered as high susceptibility zone. According to this map, the road side slope and barren and bush areas of hill side found to be high susceptible to landslide. And slopes above the road side found moderate hazard and upper part showed low susceptibility zones.

Positive weight value has significant relation to landslide occurrence whereas negative weight value shows the insignificant relation to landslide occurrences. So that from table 1 shows the elevation ranging between 800 and 1200m occurs mostly near to the road corridor and river side having higher chance of landslides. The slope angle found between 30°-45° and 45°-60° were most vulnerable to cause landslides due the road alignment is in cut slope section. The present study shows that slope facing SE, S, SW, NW and N were found most vulnerable having abundant sunlight and plenty of rainfall during monsoon. Landuse and landcover play important role instability of slopes and landslide. Majority of the land was covered by cultivation and forestland. The distance from drainage was considered for the susceptibility mapping as it influences to cause landslides.

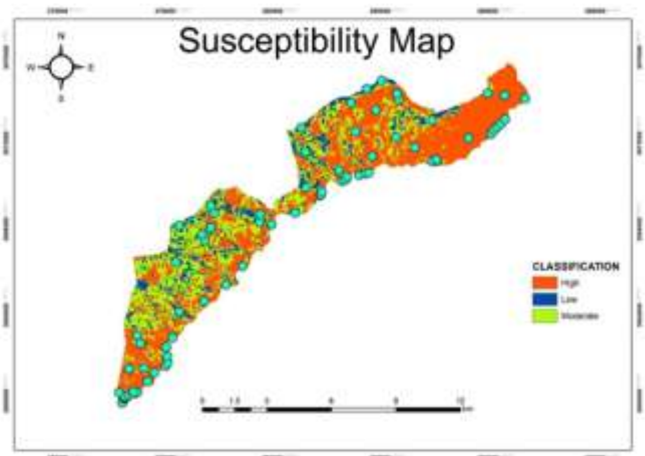

Figure 3: Suspectibility Map showing high, low and moderate zone

Intense bank erosion by the streams in hilly terrain cuts the toe of the slope and makes the slope unstable. The area having drainage distance less than 50m contains highest weight value. The toe cutting phenomenon by the streams may be responsible for most of such instabilities and erosion. Likewise, drainage, distance from road map ranges as <50m, 50-100m, 100-200m, 200-300m, 300-400m and >400m where highest weight value was found near the roadside as 50m range. More than 80% of annual rainfall occurs during monsoon season and on the same season most of the landslide occurs. So, it has been necessary to include rainfall as one of the factors in the landslide susceptibility modeling. Nine different stations were Barabise, Mandan, Thokarpa, Chautara, Panchkhal, Dolalghat, Gunthang, Charikot and Nawalpur where the ranges between 95-121mm areas have greater possibility to cause the landslide occurrence.

Validation of Landslide Susceptibility

There are several methods to validate the susceptibility maps. In the present study, validation of landslide susceptibility maps was done by comparing susceptibility map with the landslide locations that were used during the model building process {57(80%)}. The area under the curve (AUC) was calculated from 100 subdivisions of LSI values of the cells in the study area and the cumulative percentage of landslide occurrences in the classes. The area under curve (AUC) represents the success rate percentage of the model (Fig.4). The result shows that 85.3% fall under success rate.

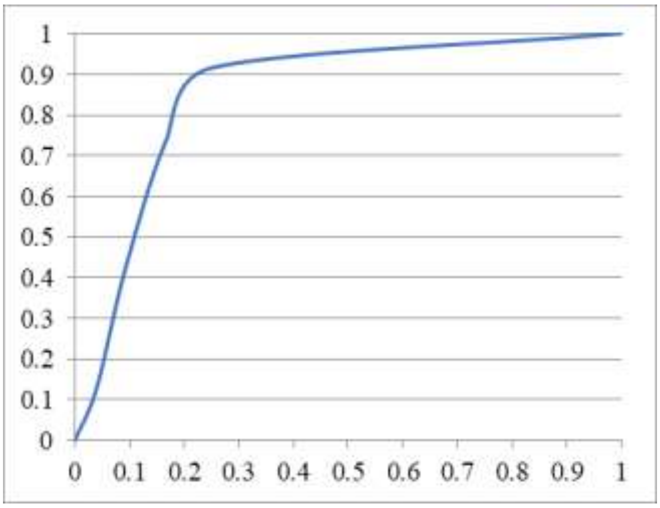

Chart 1: Area Under Curve showing success rate of model

4. Conclusion

Landslide studies are important in the mountainous countries like Nepal since the landslides in such mountainous terrain results on a huge loss of life and property every year. Due to the rapid human interference, climate change disasters and developmental activities in hilly regions influence to cause landslides. Landslide susceptibility mapping helps to know about relative likelihood of future land sliding based solely on the intrinsic properties of a local or site which can put forward useful recommendation to minimize the damages. In this research, statistical index model of bivariate method was used for identifying the susceptibility zone to land sliding at Bandeu- Barahabise road and its surrounding areas. For this purpose, eight landslides causative factors (i.e., slope elevation, slope angle, slope aspect, rivers and roads, landuse, geology and rainfall) were used. Landslide inventory map is the preliminary activities to locate the past landslides were prepared from the Google Earth Imageries and field survey. Altogether 71 landslides were identified in which 57(80%) landslides were used for model building purpose and 23(20%) landslides were used for validation purpose. Bivariate statistical Index method was used to fulfill the objective to make susceptibility map. To prepare the susceptibility map eight causative factors was used which are slope, aspect, elevation, geology, land use, drainage distance, road distance and precipitation. The thematic layers of all causative factors and existing landslides were prepared in Arc GIS 10.3 software. Mainly, Digital elevation model based causative factors and field data were used to prepare the data layers of the causative factors. For the best resolution 30*30m pixel cell size was used for all thematic layers. Altogether, 71 landslides were studied in the study area. Statistical Index method shows that LSI value less than -3.038251 was classified as low susceptibility zone, values between -3.038251 and -1.870643 was considered as medium susceptibility zones and more than -1.870643 was considered as high susceptibility zone respectively. From this study, highway is the major reason to make the slope unstable and river passing along the highway though both acts mutually to affects the natural channel to cause the landslides. The models were verified by the success rate curve found very effective in validating of the region as 85.3%. The landslide susceptibility map provides planners with tools for selecting suitable areas for development. It helps planners to decide the suitable site for the construction of roads, bridges, hydropower plants and so on. It is obvious that the scientific studies of the landslide can put forward useful recommendation to reduce the loss of life and property.

Acknowledgement

The authors grateful to DOE (Department of Environment, Nepal) for funding the present study, Dr. Subodh Dhakal for continuous supervision, Mr. Padam Budha for helping in field world and my friends and family for constant support.

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