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HAZARD MAPPING OF SINDHU KHOLA WATERSHED, SINDUPALCHOWK, NEPAL

Chandra Prakash Poudyal

Department of Civil and Geomatics Engineering, Kathmandu University

Corresponding author: cppoudyal@ku.edu.np

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ABSTRACT

The aim of present study is to produce landslide susceptibility map of Sindhu Khola watershed, Sindhupalchok, Kavre, Nepal, using Geographic Information System (GIS) by means of frequency ratio. The ArcView was used as primary software for the management of spatial data. Landslide locations were identified during the field visit. There are altogether seven different factors such as topographic slope, aspect, distance from drainage and so on, and their respective relations with the occurrence of landslides in the study area were analyzed. These factors were used to produce landslide susceptibility map using frequency ratio method. The frequency ratio suggests that distance near to drainage and slope angle higher than 30° are main factor contributing landslide occurrences. To assess the performance of the produced susceptibility map, the area under curve (AUC) is drawn. The AUC value of the produced landslide susceptibility map has been obtained as 79.65%. According to the results of the AUC evaluation, the produced map has exhibited a satisfactory performance.

Keywords: Landslide, Hazard, Frequency ratio, Nepal

BACKGROUND

A landslide is the outward and downward movement of mass of rock, earth or debris due to gravity. Landslides are the most common natural hazards in the Nepalese mountains [1]. Landslides occur due to the combination of factors such as heavy rainfall, steep slopes, rugged topography, lack of vegetation or deforestation, incompetent geological formations, and structurally fragmented rocks. Human activity also often aggravates hazards due to insufficient attention being given in the traditional methods of cultivation and during infrastructure development, or in the over-exploitation of natural resources.

The landslides are classified on the basis of the material involved i.e. rock or soil and the type of movements (fall, topple, avalanche, slide, flow, spread etc.). Thus, term landslide also refers to mass movements such as rock falls, mudslides and debris flows. In the Himalayan region the landslide can occur everywhere at any time however, the landscape can be divided into different zone of stabilization, which is commonly termed as landslide hazard mapping.

Landslide hazard mapping is the mapping of the probable landslide occurrence within the specific area and specific contributing factor. The slope failure phenomena are largely controlled by two different factors; 1) Intrinsic factors (geology, geological structures, geomorphology, soil depth, soil type, slope gradient, slope aspect, slope convexity and concavity, elevation, land use pattern, drainage pattern) and 2) extrinsic factor (rainfall, earthquakes, and volcanoes) etc. Slope failure and flooding are usually associated with the loss of lives and damaging properties.

The study area

The Himalayan range is highly prone to landslide due to the composition of weak rock types and the rough terrain with extreme variation of the slope angles. The elevation difference between the lowest and highest is nearly 1540 m within the short distance. The Sindhu Khola comprises narrow tract and also some flat lands are used for cultivation and settlements. The trend of resettlement is increasing as the area grows economic activities on the forest and cash crops within the Lesser Himalayan region. The landuse pattern of the area shows the cultivated land is predominance followed by forest at the upper part of the hills. The forest land is found at the higher slope angle, where as the cultivated land is found considerably gentle slope. During the last few years the land use and land cover pattern has been changes tremendously.

The expansions of cultivated lands in the steep slope are more prone to landslide and indicate environmental degradation and livelihood vulnerability. The catchment area of the Sindhu Khola extends parts of Bansbari, parts of Thakani, parts of Sindhukot, parts of Haibung and parts of Bhotechaur VDC of the Sindhupalchok District of Bagmati zone. The Sindhu Khola, sub-watershed of the Indrawati River runs North-west to South-east almost centre of the catchment area. The parts of Sindhukot, Thakani and Bansbari VDC are prone to landslide problems due to the steep slope and fragile nature of the geology and geomorphological characteristics. The location map of the study area is shown in figure 1. The geomorphology of the area is shown in figure 2.

Fig: 1 Location map of the site in Sindhupalchowk district

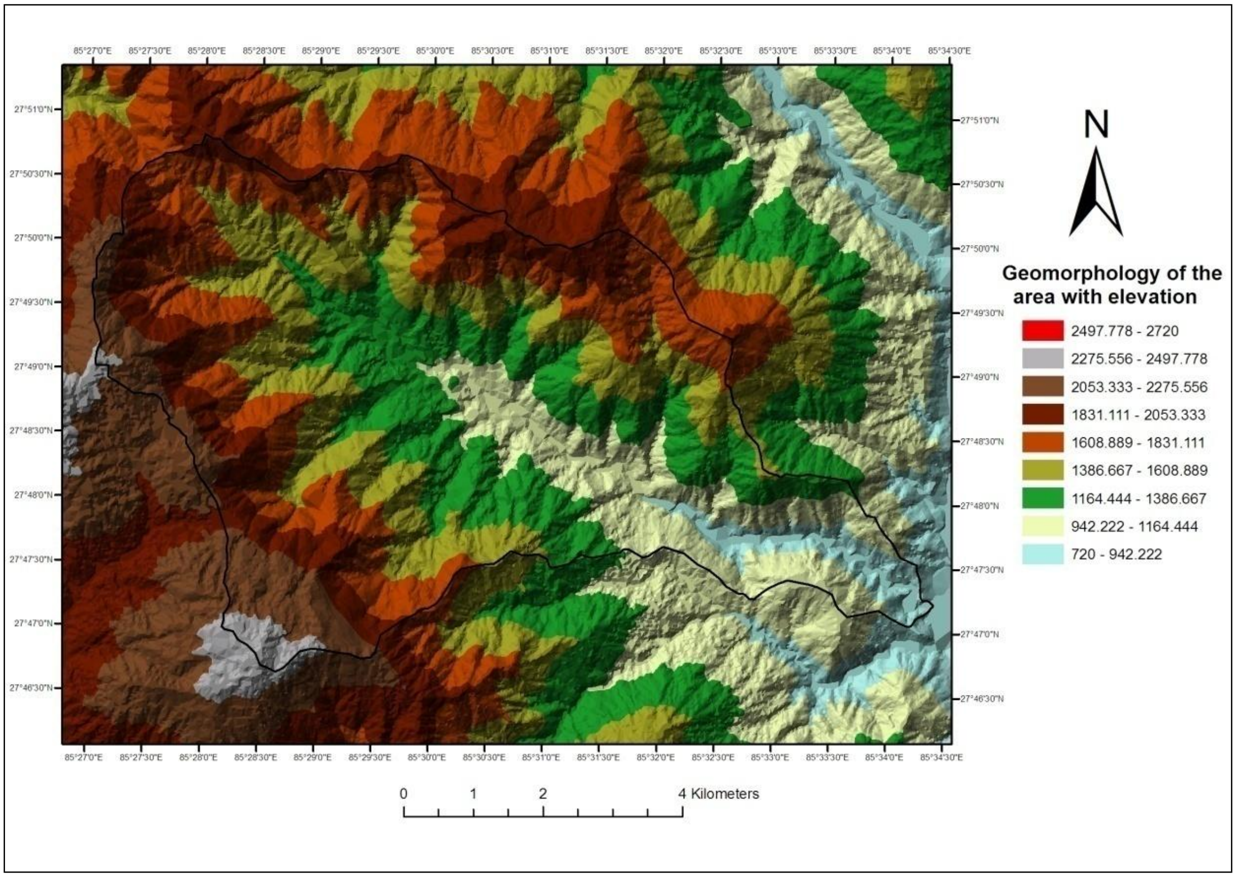


Fig: 2 Geomorphological setting showing the watershed boundary

General geology

The geology of the Nepal Himalaya has been divided into five major tectonic units from south to north and extending east-west direction. They are as follows:
Terai Zone
Sub-Himalayan Zone (Siwaliks or Churia)
Lesser Himalyan Zone
Higher Himalayan Zone, and
Tibetan-Tethys Zone

Among these major units of the whole Himalayan range present study area belongs to the Higher Himalayan Zone. The area comprises two local thrusts running east west direction at the north-western corner and second at the south eastern corner. The annual rainfall of this area has higher frequency and the intensity is also high. This leads the instability of the area causing shallow and deep landslides. Besides the rainfall steep slope angle and the tectonic structures that found within small area have also positive role in initiates the instability. The major drainage i.e. Sindhu Khola runs almost parallel to the axis of anticline and its tributary passes with major thrusts of the area. There are five different tectonic units each of which are separated with the thrust faults. Major rock types that found in the area as follows

a) Sermathang Formation. The major rock type of the area comprises schist, augen gneiss, quartzite as intercalation.

b) Simpani Formation: The major rock types of this formation are kyanite biotite schist, migmatite, and biotite feldspathic schist.
c) Hadi Khola Schist: This formation chiefly comprises thin to medium bedded fine garnet biotite schist, calcarious schist and alternet bands of gneiss rock.
d) Dhad Khola Gneiss: This formation consists of augen gneiss with alternate bands of quartzite and schist.
e) Gyalthung Quartzite: This formation is predominant of medium to thick bedded of Quartzite. In this formation fine grained biotite schist are also found as interbedded with quartzite.

The rocks of the Sermathang Formation found in most places of the study area. The Sermathang Formation has characteristics of intercalation of schist and quartzite with some bands of augen gneiss. The schist is more vulnerable to the weathering and its intercalation makes the area very unstable. The area also found Augen gneiss and it is primarily associated with the shearing of the rocks. The shearing of the rock makes weak and prone to weathering as well. The anticline also has positive influence on the vulnerability due to brittle property of rock and occurrences of extreme stress during folding.

Another formation of the area is Simpani Formation. The rock type of this formation includes kyanite-biotite schist, migmatite and biotite-feldspathic schist. The rocks containing biotite are more vulnerable to the weathering due to its flaky nature. This formation includes the parts of the Sindhukot and also parts of Badegau VDC. Major Thrust runs almost middle part of the Sindhukot VDC near upper part of the Dhungechhap, passes to Bhotechaur VDC at Tallo Jaisegaun and also passes to Haibung VDC.

MATERIAL AND METHODS

The main objective of this study is to prepare landslide hazard maps of the Sindhu Khola watershed. The specific objectives of this study are as follow:

- To analyze the geological and geomorphological data and information for hazard mapping; and
- To prepare landslide hazard map

Data preparation

To fulfil main objective ie, preparation of landslide hazard map; spatial data collection were done at first step and different factors were extracted. After extraction of different factors the relationship with the landslides were calculated and validated. The relationship with the landslide leads to the preparation of possible hazard zones and need to compare with the observed landslides.

To prepare hazard zonation map there are several thematic maps were prepared as they have relation with the landslides viz. slope angle, slope aspect, landuse, geology, distance from drainage, topographic wetness index (TWI) and stream power index (SPI). The digital data were collected from the survey department of Nepal and Google Earth was taken in account for the preparation of digital elevation model (DEM) and preparation of above mentioned layers. Field surveys were carried out for data collection and to prepare of landslide distribution map. These data sources were used to generate various data layers using ArcView and ARC/GIS software.

Landslide mapping

The landslide distribution map is the main map which is used for the relation with the other factors and prepared by the field verification. With the use of field data and Google Earth images, both new and old landslides scar were delineated. Some of the present landslides area shown in figure 4 and landslide inventory map is shown in figure 5. The relationship of landslides with different causative factors shows that south facing slopes, slope near to stream and high slopes angle are more susceptible to the occurrences of landslide.

Tama Khani landslide

Along the road infront of Shri-Krishna Ma Vi

East of pati bhangyang

view from east to west at pati bhangyang

West of Chilaune along the road to Pati bhangyang

Rock fall on the north of Chilaune front view

Fig: 3 Photograph of landslides found in the Sindhu Khola watershed

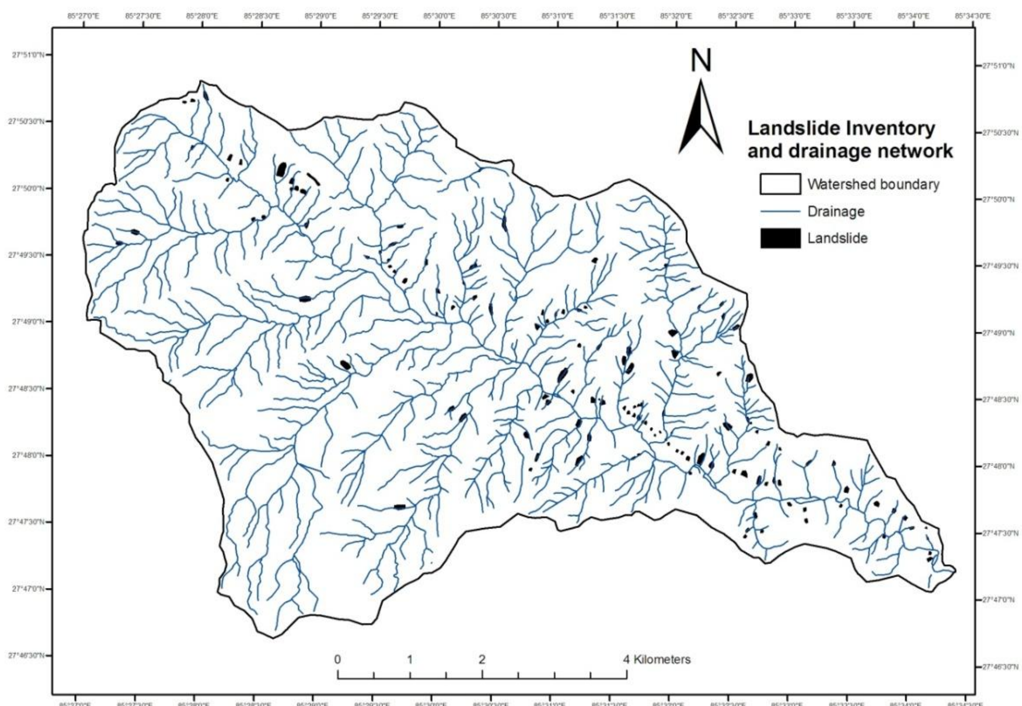


Fig: 4 Landslide inventory and drainage map of the Sindhu Khola watershed area

ANALYSIS AND RESULTS

For the analysis of landslide hazard map of the area all the landslide present in the area are depicted during the field works and compared with the various thematic data layers separately. The values for each component of the different thematic maps were calculated with the individual relation with the landslide using GIS. We use the frequency ratio method to calculate the weight for the each factor and final map were prepared. The frequency ratio method was used previously by various authors [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15] in their papers.

The frequency ratio (FR) is the ratio of occurrence probability to nonoccurrence probability, for specific attributes. In the case of landslides, if we set the landslide occurrence event to A and the specific factor's attribute to B, the frequency ratio for B is a ratio of conditional probability. So if the ratio is greater than 1, the greater the relationship between a landslide and the specific factor's attribute; and if the ratio is less than 1, the lower the relationship between a landslide and the specific factor's attribute. For the landslide susceptibility analysis GIS is the main software for calculation of relationship between the landslide and causative factor. The frequency ratios are based on observed relationships between each factor and the distribution of landslides.

For the calculation of frequency ratio a table was constructed having landslide related factors. In this approach the percentage of the cells in a given parameter range are computed for both the landslide area and for the whole region. Afterward the ratio of landslide occurrence and non-occurrence were calculated for each factor and the area ratio for each factor to the total area was calculated. The frequency ratios for each range or factor type were calculated by dividing the landslide occurrence ratio by the area ratio. All thematic maps were stored in raster format with a pixel size of 10m × 10m and they were combined with landslide inventory map for the calculation of weight value of each component. First the frequency ratio was calculated for each range or type of factor.

$$\text{Frequency ratio} = \frac{\dfrac{\text{Npix}(SX_i)}{\sum_{i=1}^{m}\text{Npix}(SX_i)}}{\dfrac{\text{Npix}(X_j)}{\sum_{j=1}^{n}\text{Npix}(X_j)}}$$

Where:

Npix (SXi): number of pixels with mass movements within class *i* of parameter variable *X*.
Npix (X_j): number of pixels within parameter variable X_j
m: number of classes in the parameter variable X_i
n: number of parameters in the study.

The frequency ratio were then summed to calculate the landslide susceptibility index and the formula for calculation is

$$\boldsymbol{LSI} = \sum \text{FR}$$

where FR is the frequency ratio. The determination of frequency value of each factors are described in table 1.

Table: 1 Different parameter used for the frequency ratio calculations

Classes	No of pixel of landslide	Pixel %	No of Pixels	Pixel %	Frequency	Round Figure	Frequency Value
Landuse							
Cultivation	3478	45.39	336545	66.25	0.69	69	16
Forest	114	1.49	69358	13.65	0.11	11	3
Grassland	647	8.44	9904	1.95	4.33	433	100
Bushes	3418	44.60	88049	17.33	2.57	257	59
Sand	6	0.08	4133	0.81	0.10	10	2
Aspect							
North	807	10.53	112381	22.12	0.48	48	19
North-East	314	4.10	66708	13.13	0.31	31	12
East	558	7.28	58065	11.43	0.64	64	25
South-East	1082	14.12	56078	11.04	1.28	128	50
South	2176	28.40	56642	11.15	2.55	255	100
South-West	1818	23.72	55489	10.92	2.17	217	85
West	600	7.83	32562	6.41	1.22	122	48
North-West	159	2.07	27475	5.41	0.38	38	15
Flat	149	1.94	42680	8.40	0.23	23	9
Slope angle							
0-9	512	6.68	51294	10.10	0.66	66	30
9-18	90	1.17	32955	6.49	0.18	18	8
18-25	1221	15.93	137424	27.05	0.59	59	26
25-35	2559	33.39	159565	31.41	1.06	106	48
35-45	2145	27.99	85215	16.77	1.67	167	75
45-55	749	9.77	29884	5.88	1.66	166	75
55-65	311	4.06	9231	1.82	2.23	223	100
65-75	68	0.89	2193	0.43	2.06	206	92
75-80	8	0.10	298	0.06	1.78	178	80
80-90			21	0.00	0.00		
Geology (Rock Type)							
Gyalthung Formation	147	1.92	44064	8.67	0.22	22	15
Hadi Khola Schist	67	0.87	4509	0.89	0.99	99	66
Sermathang Formation	5261	68.65	233255	45.91	1.50	150	100
Simpani Formation	2188	28.55	220218	43.34	0.66	66	44
Dhad Khola Formation	0	0.00	6034	1.19	0.00	0	0

Classes	No of pixel of landslide	Pixel %	No of Pixels	Pixel %	Frequency	Round Figure	Frequency Value
Stream Power Index (SPI)							
0-0.399	3140	40.98	276713	54.46	0.75	75	29
0.399-1.098	2793	36.45	155102	30.53	1.19	119	46
1.098-1.797	926	12.08	47357	9.32	1.30	130	50
1.797-2.546	385	5.02	15671	3.08	1.63	163	63
2.546-3.445	288	3.76	7381	1.45	2.59	259	100
3.445-4.593	96	1.25	3164	0.62	2.01	201	78
4.593-5.991	25	0.33	1599	0.31	1.04	104	40
5.991-7.888	10	0.13	752	0.15	0.88	88	34
7.888-12.732			180	0.04	0.00	0	0
> 12.732			161	0.03	0.00	0	0
Topographic Wetness Index (TWI)							
0.9888-3.049	2281	29.77	98056	19.30	1.54	154	96
3.049-3.683	4468	58.31	346165	30.41	0.86	86	53
3.683-4.396	624	8.14	31974	2.81	1.29	129	81
4.396-5.268	195	2.54	9154	0.80	1.41	141	88
5.268-6.298	59	0.77	3091	0.27	1.27	127	79
6.298-7.486	33	0.43	1367	0.12	1.60	160	100
7.486-8.834	3	0.04	546	0.05	0.36	36	23
8.834-10.656		0.00	160	0.01	0.00	0	0
10.656-13.112		0	54	0.00	0.00	0	0
13.112-21.195		0	17513	1.54	0.00	0	0
Distance from Drainage							
0-75m	6517	85.08	330797	65.11	1.31	130.67	100
75-150m	983	12.83	138584	27.28	0.47	47.048	36
150-225m	134	1.75	28168	5.54	0.32	31.554	24
> 225m	26	0.34	10531	2.07	0.16	16.376	13

The details of the different parameters used for the calculation of final hazard map are described as follows:

The landuse map of the Sindhu Khola watershed is shown in figure 5 and details of landuse pattern of the study area is shown in table 1. The existing landslides are prominent in the cultivated land as 66.25% and 17.33% in the bushes, where as the cultivated land occupies 45.39% of the study area and is followed by the bushes 44.60%. In this context the frequency value was determines taking relation of both the landslide percentages and the area percentages and applied for the final map preparation.
The aspect map of the area is shown in figure 5. The landslide distribution in the different aspect shows that south and south-west facing slopes are 28.40 and 23.72 % of the total area and

maximum aspect area found is North-facing slope as 22.12% where as all other aspect area more or less similar distribution as 10.92 to 13.13% but west northwest and flat lands are found very less amount in terms of percentages.
The slope map of the area is shown in figure 5. The maximum % of landslides presence is in slope angle 25°-35° as 33.39% and followed by angle 35°-45° is 27.99%. On the other hand the maximum percentage area found is 25°-35° is 31.41%, is followed by the 27.05% in 18-25° and 16.77% in 35-45°.

There are all together five different types of formations are found in the study area. They are Gyalthung formation, Hadi Khola schist, Sermathang Formation, Simpani Formation and Dhad Khola formation, figure 5. Among these formations Sermathang formations have most landslides are found as 68.65% is followed by 28.55 % in Simpani formation. If we look the distribution of different formations the Sermathang Formation have 45.91% occupied area is followed by Simpani formation as 43.34%.

The stream power index (SPI) is one of the topographic indices and measures the erosion power of the stream; it also contributes to the stability of the study area. The SPI can be calculated as:

$$SPI = As \times \tan\beta$$

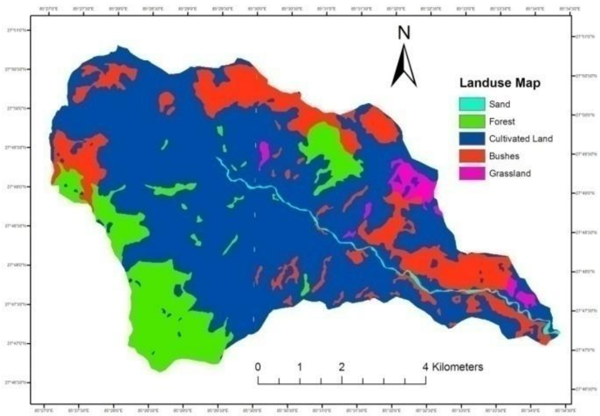
where As is the specific catchment area and β is local slope gradient measured in degree. Map calculating stream power index is shown in Figure 5. From the calculation in table 1 shows that the index value from 0- 0.399 have landslide density as 40.98% and is followed by 36.48% of landslides found in 0.399 to 1.098 index values. On the other hand the index value from 0- 0.399 occupied as 54.46% and is followed 0.399 to 1.098 index values as 30.53%.

The topographic wetness index (TWI) developed by Baven and Kirkby, (1979) within the runoff model is calculated as

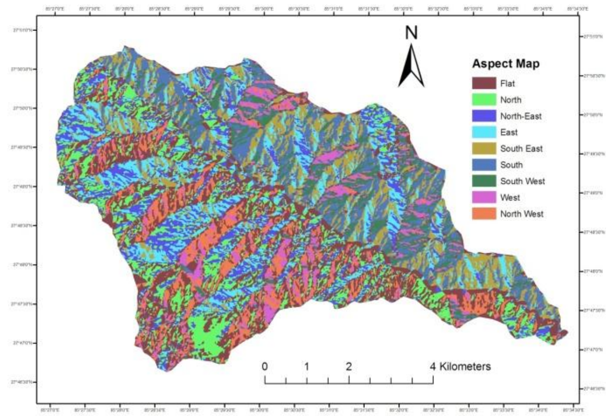
$$TWI = \ln [a / \tan \beta]$$

where a is the cumulative upslope area draining through a point (per unit contour length) and tan β is the slope angle at the point. The ln (a /tan β) index reflects the tendency of water to accumulate at any point in the catchment (in terms of a) and the tendency of gravitational forces to move that water down slope (expressed in terms of tan β as an approximate hydraulic gradient). The water infiltration primarily depends upon the material properties like permeability, pore water pressure and effects on the soil strength. The topographic wetness index map is shown in figure 5. From the calculation in table 1, shows that the topographic wetness index value from 3.049 - 3.683 have landslide density as 58.31% and is followed by 29.77% of landslides found in 0.988- 3.049 index values. On the other hand the index value from 3.049 - 3.683 occupied as 68.13% and is followed by 19.30% of area occupied in 0.988- 3.049 index values.

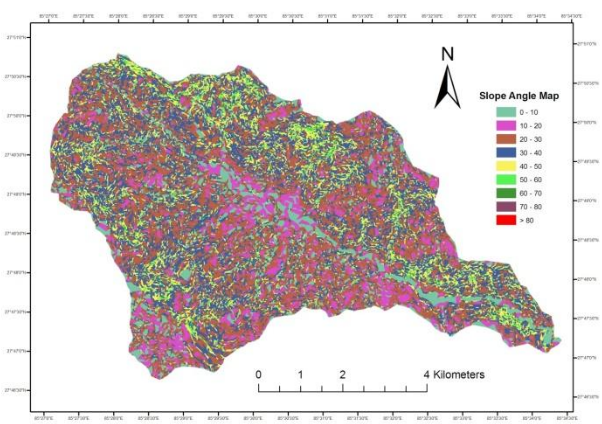
The drainage network is another influencing factor for the occurrence of landslide and the distance from the drainage is also calculated and is shown in figure 5. The different categories of distance from drainage lines are given in table 1. The table shows that the distance from drainage value 0 - 75m have high density of landslide as 85.08% and is followed by 12.83% of landslides found distance 75-150m. On the other hand the distance nearer 0-75m from the drainage line have 65.11% occupied area is followed by 27.28% of area occupied in 75-150m distance.



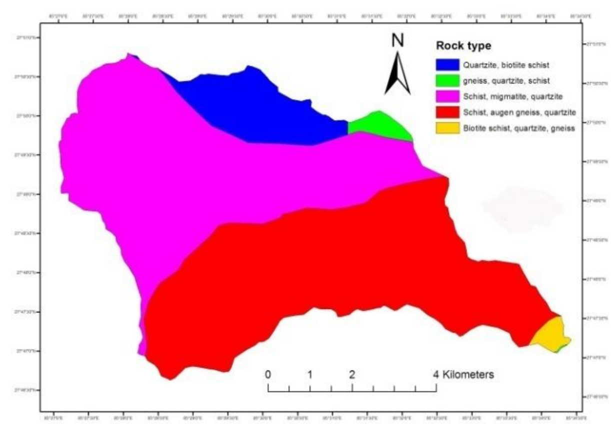
Landuse map



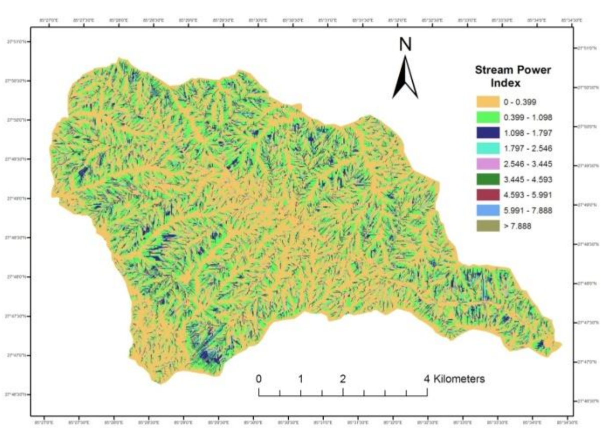
Slope aspect map



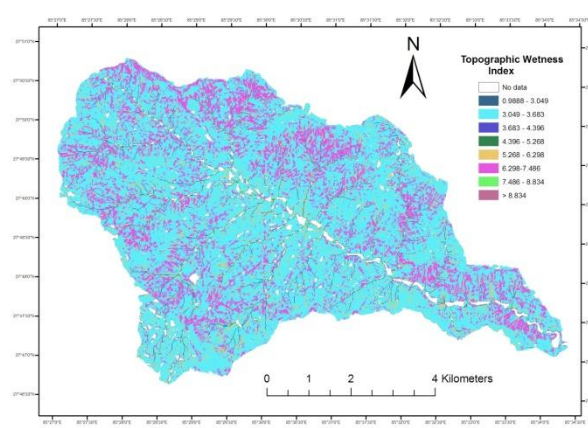
Slope angle map



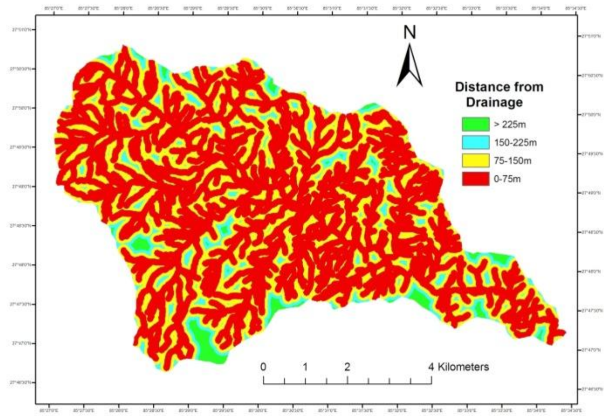
Geological map



Stream power index map



Topographic wetness index map



Distance from drainage

Figure 5. Different factors used to generate Landslide susceptibility map of the Sindhukhola watershed

Landslide Hazard Map

To classify hazard map it was assumed that the different classes are divided into 50% 80% and 90% of low to high level of landslide hazard index values for hazard classification. Total four landslide hazard classes are viz. low (less than 50%), moderate (50% - 80%), high (80% - 90%) and very high more than 90% were used for the classification of landslide hazard map (Fig. 27).

To check capability of landslide susceptibility map produced for the prediction of landslide occurrences were verified by the help of prediction rate curve. Total 70% of landslides were used for testing and 30% for the validation accuracy of produced map. After generating hazard zonation map it was crossed with landslide inventory map and result shown in figure 6 and the area under curve in figure 7. These curves are shows how goodness of fit. To obtain the prediction rate curve for each LHI map, the calculated index values of all pixels in maps were sorted in descending order and then ordered pixel values were categorized into 100 classes with 1% cumulative intervals. The area under curve shows that 50% of landslides are found in the very high hazard zone, 23.64% in high hazard zone, i.e. 73.64% of slides belongs to the high hazard zone and 13.58% in moderately hazard zone. There are around 12% of landslides pixels are found in the low hazard zone; this may be the slope angle at the base of landslide.

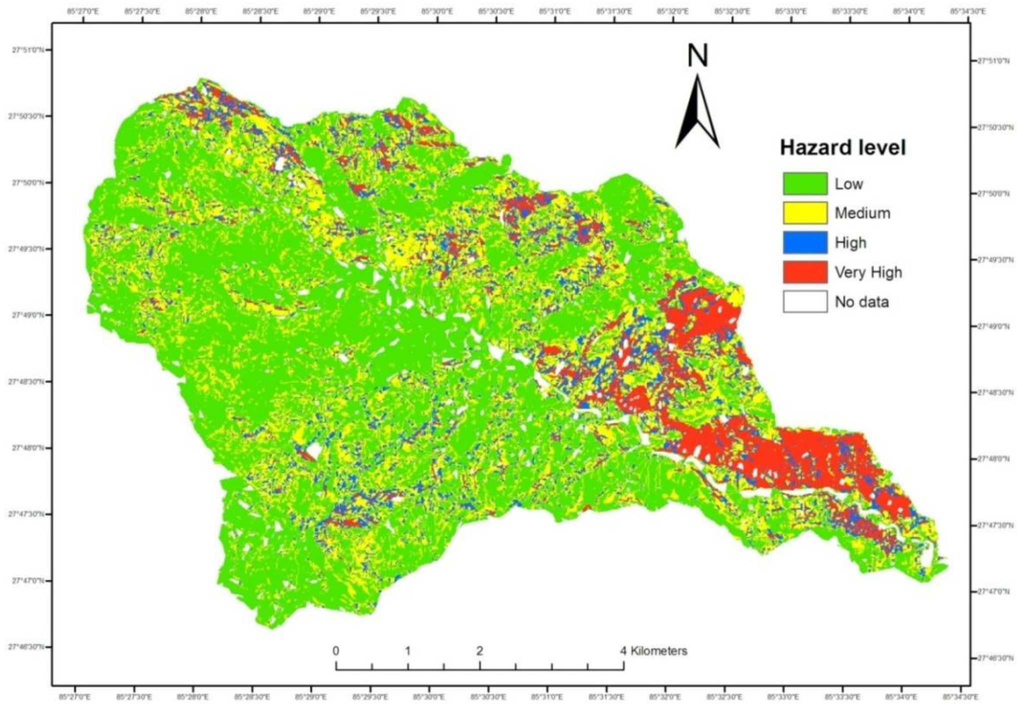


Fig: 6 Landslide Hazard Zonation map of the Sindhu Khola watershed

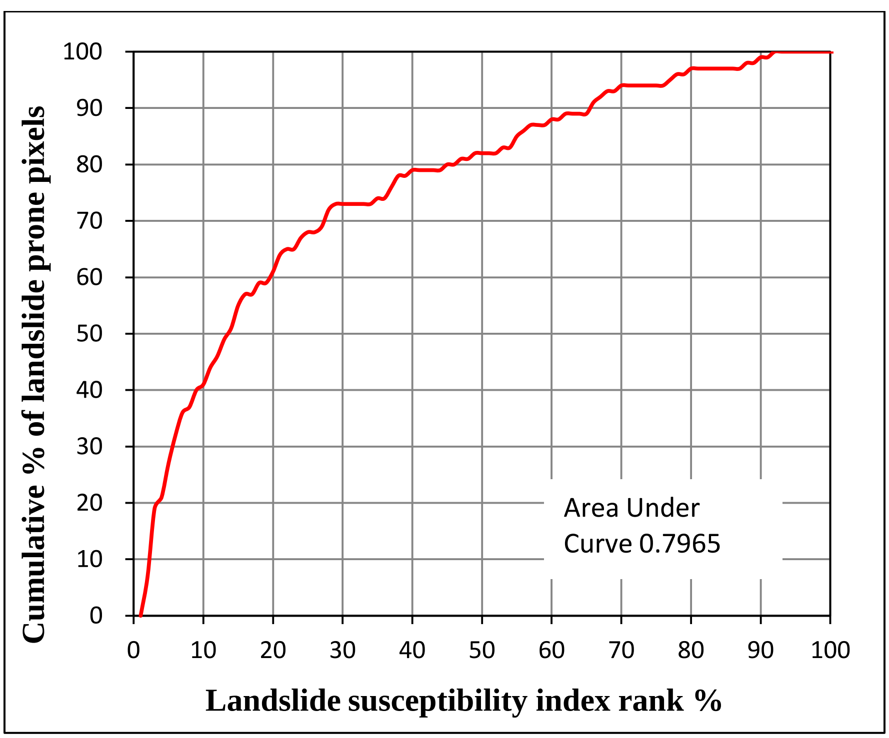


Fig: 7 Computed accuracy of susceptibility attribution by methods used in this study (AUC area under curve)

The curve shows that 40% of higher value of hazard index covers nearly 80% of landslide pixels. The area under the curve is 0.7965. So the accuracy of the implemented statistical model is 79.65%.

CONCLUSIONS

Landslide hazard zonation map is the one which shows the prone zone for the instability in the hilly terrain. There are many methods in practices to determine the hazard mapping and the frequency ratio is used as bivariate method of analysis in present study. There are seven causative factors are used for this analysis and all are based on the digital elevation model (DEM). The conclusions of this study can be explicitly summarized as follows.

The analysis for each factor shows that the geological structure i.e. counterdip and the high slope angle have strongly influence on the slope failure processes. The area also comprises thrust faults which separates most of the rock types and formed due to the sliding of one rock unit with the other. In this sliding process intense shearing occurred which promotes the instability of the area. In this situation of the geological structure and the low grade metamorphic rocks found in the study area have tremendous effect on the stability of terrain. The situation is going worse due to the construction of canal along the slope and most of the places have water percolation due to improper construction of the canal. The percolated water have positive role on the instability of the area. The rainfall is another factor during the monsoon season which affects on the groundwater condition leading the instability. Another major contribution for the instability is the road alignment. The road that construct by the local people is leading role on the stability because of the poor attention on the crack zones, sign of instability due to road construction and the improper management of the drain along the road. As a result, there is huge accumulation of ground water on the mountain base. Similarly, all the surrounded mountains of the selected area consist of large scale landslides and their toe is now extensively disturbed from so called low cost road. As a result, landslide risk is in very alarming situation and whole slope around the selected villages are noticed on high hazard zone.

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