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Assessment and Prediction of Slope Instability in the Lish River Basin of Eastern Darjiling Himalaya using RS and GIS

Mandal Sujit and Mandal Biplab
Department of Geography, University of Gour Banga, Malda-732103, West Bengal, INDIA

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Abstract

The present study area, the Lish River basin of eastern Darjiling Himalaya shows extensive tea cultivation, deforestation, expansion of communication and settlement, shifting cultivation, unscientific and unplanned land use practices. All these activities have brought a tremendous threat to the population living in the Lish river basin causing devastating landslip. Although, various attempts were being taken to combat and check the landslide phenomena but a systematic and quantitative assessment and prediction of landslides are to be made in detail for planning and development. The assessment and prediction of the landslide phenomena are the prime concern of landslide mitigation. The present study is dealt with the assessment and prediction of landslide prone area in the Lish River basin. To make the landslide susceptibility map of the Lish river basin, some landslide inducing factors i.e. slope angle, slope aspect, slope curvature, drainage, lithology, geomorphology, soil, land use and land cover, and NDVI were taken into account and all the data layers were developed using RS and GIS tools. To integrate all the data layers Overlay analysis method on GIS platform were performed and landslide susceptibility map of the Lish river basin were prepared.

Keywords: Landslide susceptibility, RS and GIS, Frequency ratio, Lish River Basin.

Introduction

The approaches to mitigate landslide risk are made through studying the history of management of landslide terrain by constructing protective structures or monitoring and warning systems, or through the ever-increasing sophisticated methods for mapping and delineating areas prone to landslides[1]. Landslide analysis is mainly done by assessing Susceptibility, Hazard and Risk[2]. Risk analysis is a valid technique for combating the landslide hazards for formulation and application of the proper management proposal. Recently many studies have been done to assess landslide risk using the GIS tools[3]. The application of probabilistic model for landslide risk and hazard analysis is one of the sophisticated and scientific approach in landslide studies[4-9]. The logistic regression model for landslide hazard mapping is the most significant statistical approach[10]. The landslide hazard and risk analysis could be accomplished using geotechnical model and the safety factor analysis[11]. Recently, landslide hazard evaluation using fuzzy logic, and artificial neural network models have been mentioned in the various literature[12]. In the present study area remote sensing Technique and GIS tools are used on nine landslide inducing parameter like lithology, geomorphology, soil, relief, slope angle, slope aspect, slope curvature, drainage density, NDVI, land use and land cover to assess the magnitude of susceptibility to landslide and its spatial distribution.

The quantitative analysis of landslide inducing attributes like slope, aspect, amplitude of relief, drainage density, lithology, Geomorphology and land use is of great significance for the scientific management of mountain river basin. Preparation of Landslide Zonation Map is an important technique which figure out spatial distribution of landslides and helps to take site specific proper remedial measures in a rational manner. In the present study the interaction of different factors are studied separately and ultimately final coordination is made through *landslide potentiality index value* (LPIV) and *landslide susceptibility index value* (LSIV). For the preparation of the hazard zonation map of the Lish River Basin, grid/cell wise weighted index value (WIV) is assigned for each and every classes of individual attributes on the basis of the magnitude of landslide potentiality index value. To prepare the zonation map of the Lish river basin, *weighted overlay analysis* was performed on GIS platform and finally a relationship was established between the prepared susceptibility map and all the thematic data layers.

The susceptibility to landslide is analysed through the interaction of different factors mainly the slope map, aspect map, curvature map, relative relief, drainage density, and land use and land cover. The spatial distribution of these factors is analysed separately and ultimately final coordination is made through integration of these variables by making composite index. For the preparation of the hazard zonation map of the Lish river basin the factor-mapping approach has been applied in which various factors viz. Slope, aspect, curvature, Relative Relief, lithology, geomorphology, soil, drainage Density, Land use were considered.

Landslide hazard assessment involves the division of an area in to several zones, which indicates progressive levels of landslide hazard. The term zonation implies the categorization of the land surface in to areas and arranges them according to potential hazards from landslides and other mass movements on slope[13]. Landslide susceptibility map is required for developmental planners as scientific tools for efficient management of the land.

To constitute the zonation map of slope instability it is necessary to understand the some triggering mechanism of landslides. The preparation of a landslide hazard zonation map is the first major step for combating such disaster and also is the major objective of my study. The difficulty to prepare landslide susceptibility map is the lack of information related to the factors responsible for slope failure.

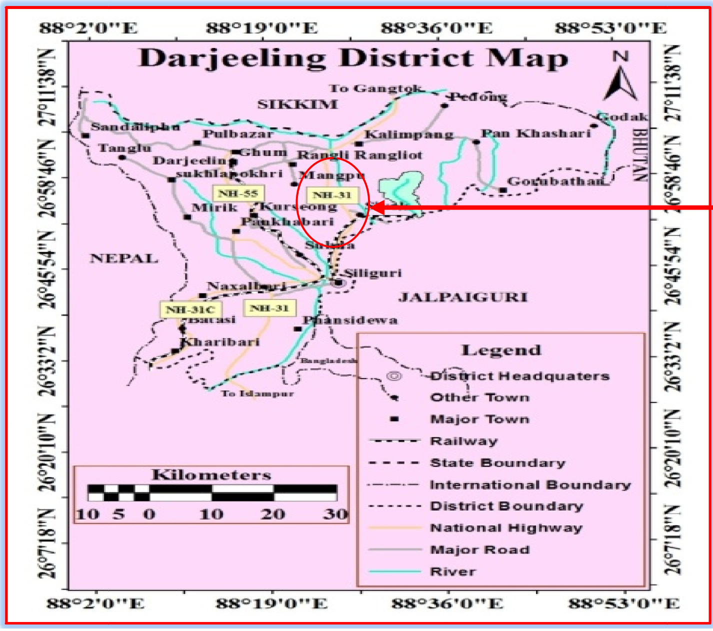

Figure-1
The Lish River Basin in Darjiling District

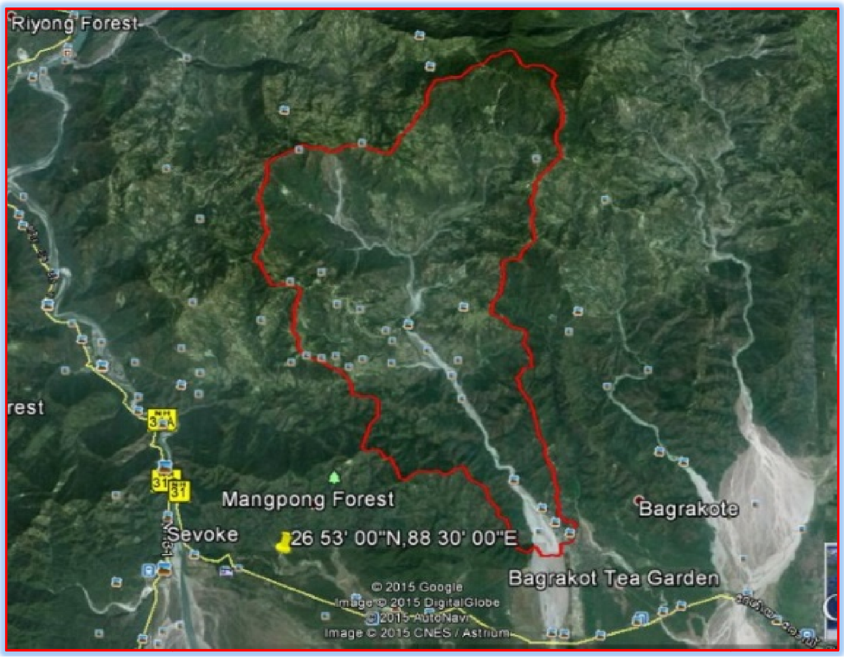

Figure-2
The Lish River Basin in Google Earth Image

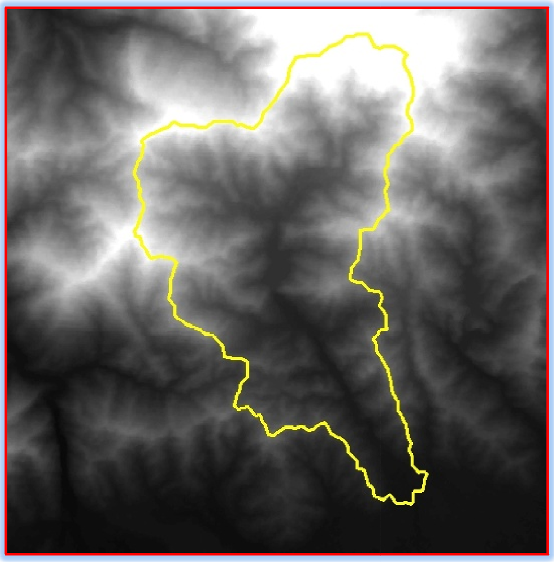

Figure-3
DEM Image of the Lish River Basin

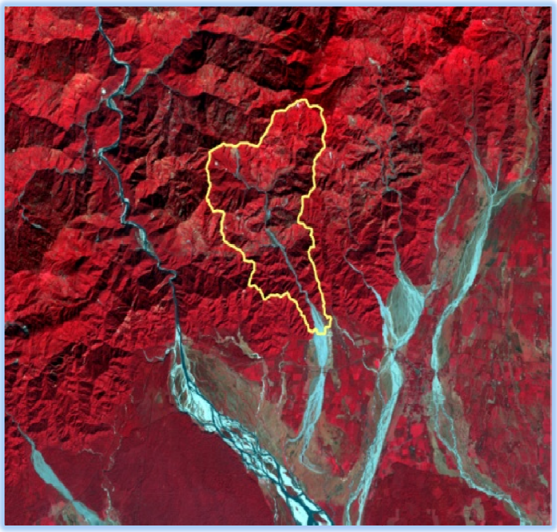

Figure-4
LANDAST Image of the Lish River Basin

The landslide hazard zonation mapping can be accomplished using various factors which promote hill slope unstable[14]. Various topographic models, hydrologic models and digital elevation modes were also applied in the present day to assess landslide[15-17]. The study on changing land use character over the land surface is a great challenge in geographical research[18].

Landslides and floods are the most serious natural problems that undermine the economic and cultural development of the Lish basin. Records since 1929 show a sharp acceleration in the rate of devastating slide occurrences (total no. 135 covering an area of 1.5 sq.km) along with lesser slips leading to great loss of life and heavy damage to land and property. The situation has deteriorated further in recent times, the last two decades having witnessed the worst landslides on hill-slopes (total no. 64 covering an area of 4.52 sq.km). The River Lish originating from Lalegoan (lat. 26^{0}59' N and long. 88^{0}33' E) at the altitude of 1820 m traverses a distance of about 21.20 km to join the mighty river Tista at Shaugoan (lat. 26^{0}49'N and 88^{0}33'E). On the way it receives at least 75 tributaries; important among them are the Chun-Khola, Phang-Khola, Lish-Nadi, Turung-Khola and the Rato-Khola etc[19]. The total catchment or geographical area of the river Lish is about 51.72 sq.km. The highest and lowest elevation of this basin ranges from 200 metre to 1800 metre. It becomes clear that fragile lithology, high intensity rainfall, steep slope, are supposed to be the major causes of landslide in the study area in Darjeeling Himalayan region shown in figure-1and figure-2. Lihologically the Lish river basin is made of mainly sandstone shale/clay; slate, schist, quartzite and crystallines (mainly gneisses). Most of the area, basically whole middle section of the basin which characterised by the existence of slate, schist and quartzite. The extreme southern portion of the basin is registered with very fragile lithology that is sandstone, shale and clay. Geomorphology of the Lish river basin is divided into three categories such as- folded ridge, highly dissected hill slope and piedmont fan plain. About 51% area of the basin is covered with highly dissected hills, 31% by folded ridge and remaining 18% dominated by piedmont fan plains.

Material and Methods

Landslide susceptibility map was prepared using remote sensing and GIS in the present work. The digitization of all the landslide inducing factors are made and the concerned data layers are prepared based on SOI Topo-sheetusing Arc View and ARC GIS Software. Firstly, SRTM Digital Elevation Model was derived at 30×30 m resolution of the corresponding Satellite Image LANDSAT (2015) depicted in figure-3 and figure-4. Finally, slope map, curvature and aspect maps are prepared from Digital Elevation Model and designed in value domain using filtering technique. The *lithological map* of the concerned study area is prepared after NATMO Kolkata (Eastern Region). Drainage density map was prepared on the grid resolution of 30×30 m.

Land use and land cover map is prepared evaluating LANDSAT image data, SOI Topo-Sheet using supervised classification technique and following *maximum likelihood method*. To bring out the degree of importance of the triggering factors, *Landslide Potentiality Index Value [LPIV]* for each range of the concerned factors is calculated following eq-1.

$$LPIV = \frac{F_2}{F_1} \times 100 \text{ (equation-1)}$$

F_2= number of pixels/cells or grid without landslide.

F_1= number of pixels/cells or grid with landslide.

To extract the number of pixels with and without landslide, a *landslide occurrence map* is prepared evaluating SOI Topo-sheet, Google earth image (2014) and Satellite Image in Figure-

5. All the generated maps are reclassified with weighted values depending on their degree of magnitude to landslide occurrences. Finally, a landslide susceptibility map is carved out applying *Weighted Overlay Analysis Model* using the following algorithm.

Landslide Susceptibility = [Lithology*21 + Drainage Density *14+Slope Angle*13 + Elevation*12 + Slope Curvature*10 + Relative Relief*08 +Slope Aspect*07 +NDVI*06+Soil*05+Geomorphology*04].

To prepare landslide hazard zonation map of the Lish river basin the weighted overlay analysis has been applied in which various factors viz. slope inclination, slope aspect, slope curvature, relative relief, drainage density, NDVI, elevation, lithology and geomorphology are considered. This approach offers tremendous flexibility to the whole mapping system because specialist team can work on different parameters independently or collectively.

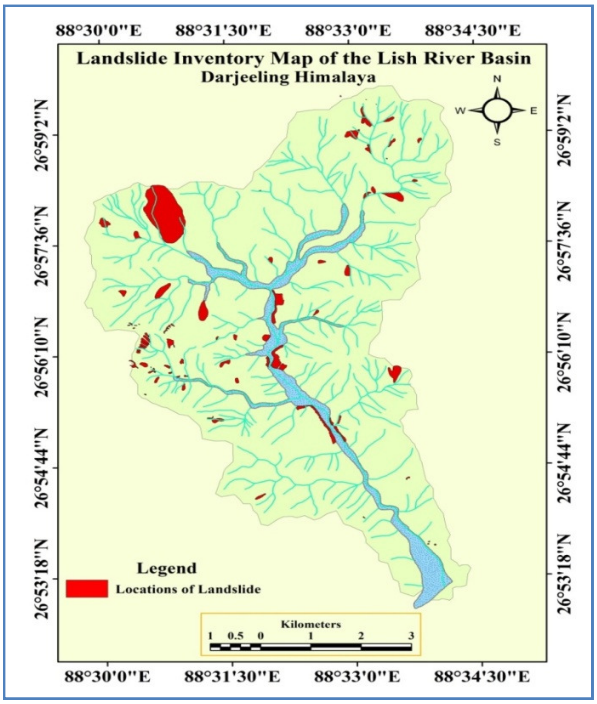

Figure-5
Landslide distribution in the Lish river basin

The information regarding landslides hazard evaluation factor (LHEF) of the Lish river basin has been obtained from the interpretation of Aster GDEM, 1:50000 Survey of India 78 B/9 Topo-sheet, existing geological map, Google Earth image and extensive field work. The following steps have been taken in to consideration for the preparation of the zonation map. i. To identify the factors/components responsible for slope failure. ii. To arrange various factors according to their significance. iii. To determine variables for each of the factors/components. iv. Class wise and factor wise assignment of ratings based on frequency ratio and the relative importance of landslide inducing factors prevalent. v. Preparation of landslide susceptibility map using weighted overlay analysis on GIS Platform.

Terrain Factors and Maximum LHEF Rating of Different Factors/Components: In the present study 10 landslide inducing factors have been considered and on the basis of these factors 10 thematic maps have also been prepared following suitable method. Maximum *Landslides Hazard Evaluation Factor* (LHEF) value or *Landslide susceptible values* (LSV) are assigned to every factor according the apprehended importance of different factors. To accomplish weighted overlay analysis and to prepare susceptibility map of the study area, each factor was rated in different way considering the relative significance in terms of landslides. The landslide factor maps such as slope angle in figure-7, slope aspect in figure-8, slope curvature in figure-9, lithology in figure-10, relative relief in figure-11, geomorphology in figure-12, drainage density in figure-13, soil in figure-14 and land use in figure-15 were prepared and studied to assign the factor rating values. Slope was considered as the important factor for slide as the rate of the release of kinetic energy directly depends on the steepness and this energy is responsible for the mass transfer with the help of gravity and so is assigned with 13. Drainage channels are rated with maximum rating of 14. The factor wise distribution of landslide susceptibility value is stated in table-1.

Table-1
Terrain Factors and Landslide Susceptibility Values

No. of Variables	Factors/Variables	Landslides Hazard Evaluation Factor (LHEF)
1	Lithology	21
2	Drainage Density	14
3	Slope Angle	13
4	Elevation	12
5	Slope Curvature	10
6	Relative Relief	08
7	Slope Aspect	07
8	Normalised Differential Vegetation Index(NDVI)	06
9	Soil	05
10	Geomorphology	04
Total		100

To generate landslide susceptibility map of the Lish river basin, each class of the individual factor was also rated considering the relative significance of each class in landsliding. Higher the relative relief, maximum is the rating value for each class. In terms of drainage density, moderately high drainage density was rated high which is depicted in table-2. There is a positive relationship between slope and landslide and considering it each class was rated accordingly. High positive and high negative curvatures of the slope invite slope saturation and slope failure. So high positive and negative slope curvature was assigned as high class rating value.

Table-2
Assignment of theme weight and class weight

Factors/components	Variables	Theme weight	Feature Class weight
1.Relative Relief (meters)	64.48- 225.18	21	1
	225.18 - 332.31		2
	332.31- 399.86		3
	399.86- 465.07		4
	465.07– 658.07		5
2. Drainage Density.	0 – 396.43	14	3
	396.43 – 729.44		4
	729.44 – 1094.17		7
	1094.17 – 2077.33		6
	2077.33 – 4043.67		4
3. Slope Angle	0 - 13.37	13	1
	1.3.37 – 21.96		2
	21.96 – 29.84		3
	29.84 – 38.43		4
	38.43 – 60.63		5
4. Elevation	116 – 447	12	1
	447 – 655		2
	655 – 872		3
	875 – 1107		5
	1107 – 1405		6
	1405 - 1870		4
5. Slope Curvature	Concave	10	5
	Flat		1
	Convex		4
6. Lithology	1. Sandstone, shale/ Clay.	08	2
	2. Slate, Schists, Quartzite.		3
	3. Unclassified Crystallines (Mainly Gneisses)		4
7. Slope aspect map	Flat(-1)	07	1
	North(0-22.5)		1
	Northeast(22.5-67.5)		1
	East(67.5-112.5)		3
	Southeast(112.5-157.5)		4
	South(157.5-202.5)		5
	Southwest(202.5-247.5)		2
	West(247.5-292.5)		2
	Northwest(292.5-337.5)		1
	North(337.5-360)		1
8. NDVI	-0.014-0.107	06	4
	0.107-0.180		6
	0.180-0.224		3
	0.224-0.303		2
	0.303-0.360		1
	0.360-0.501		
9. Soil	1.W002	05	01
	2.W004		03
	3.W008		02
10. Geomorphology	1. Folded Ridge.	04	05
	2. Highly Dissected Hill Slope.		03
	3. Piedmont Fan Plain.		01

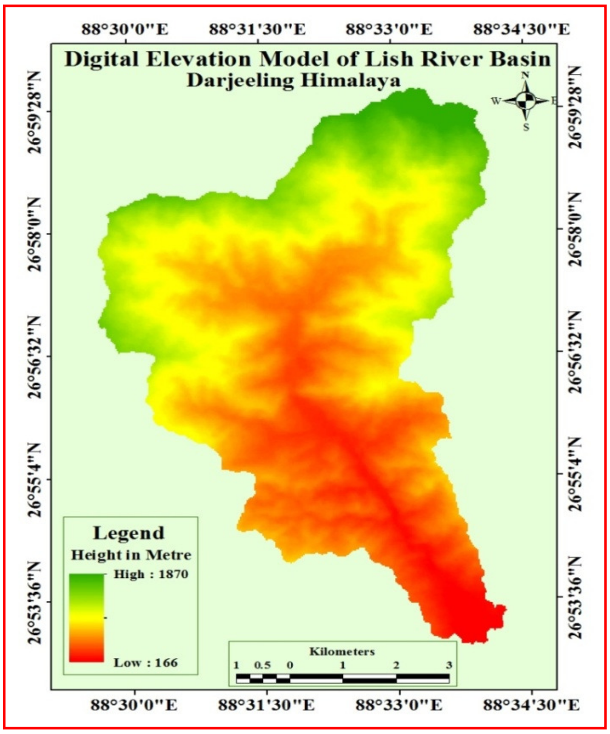

Figure-6
DEM of the Lish Basin

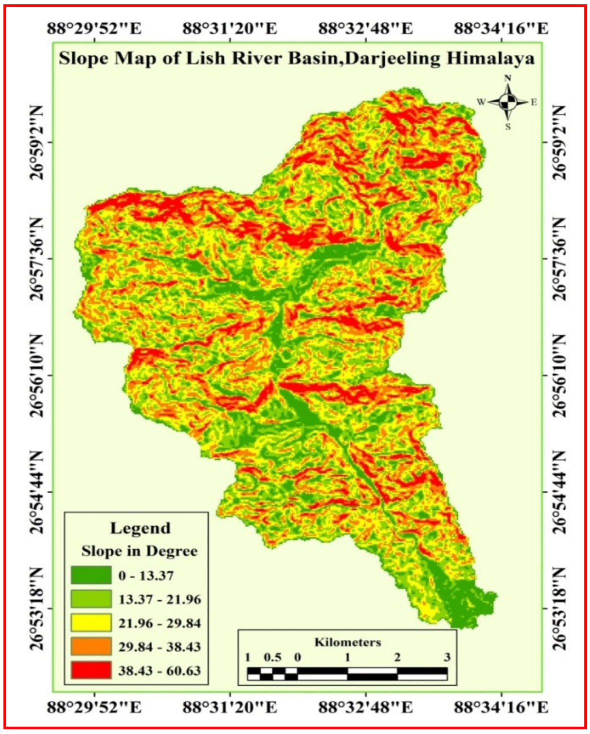

Figure-7
Slope map

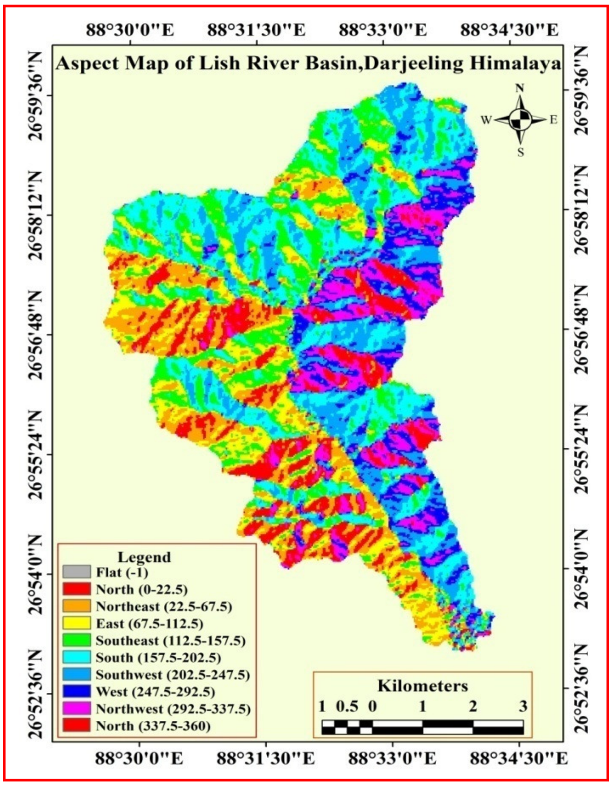

Figure-8
Slope Aspect map

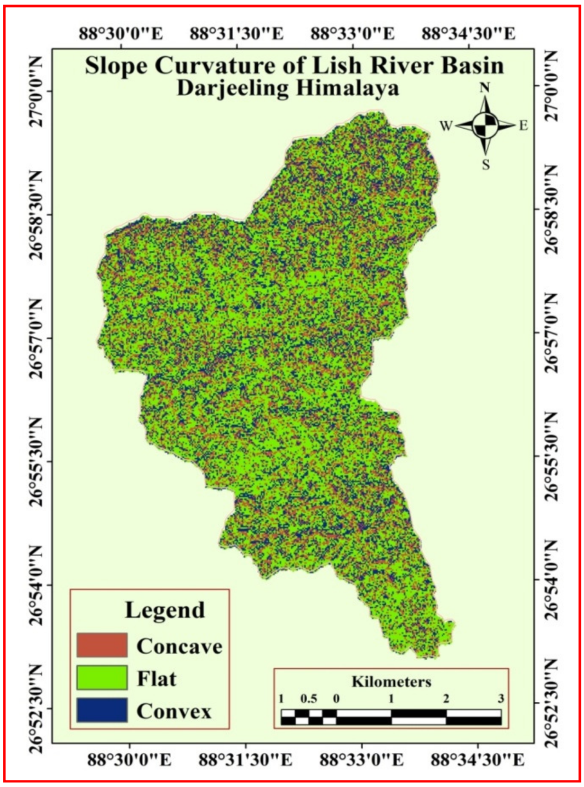

Figure-9
Slope Curvature Map

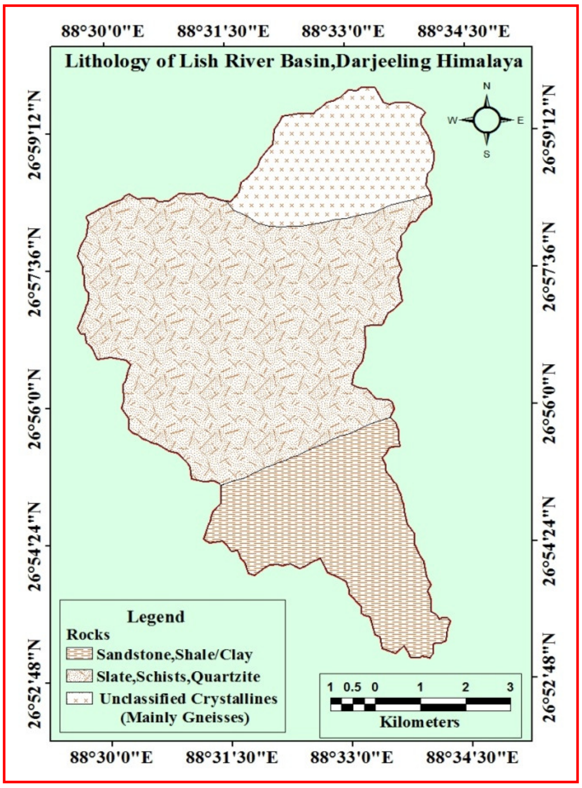

Figure-10
Lithology of the Lish basin

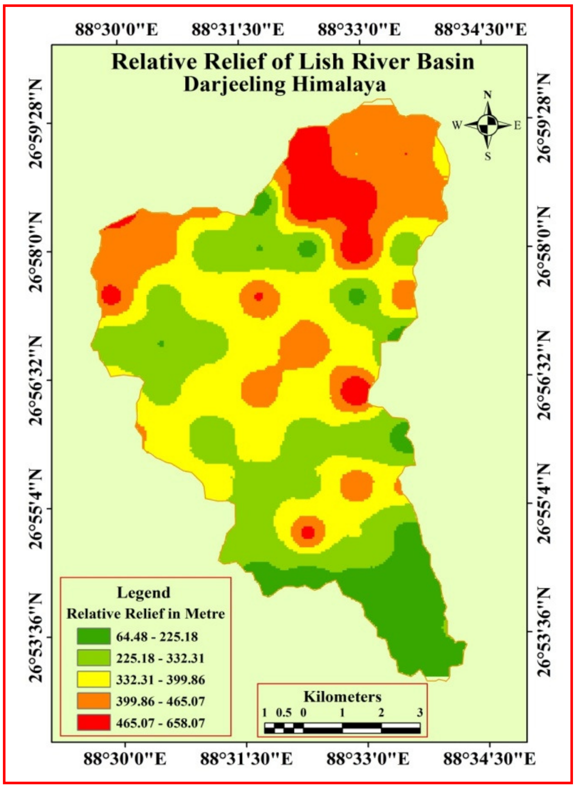

Figure-11
Relief map

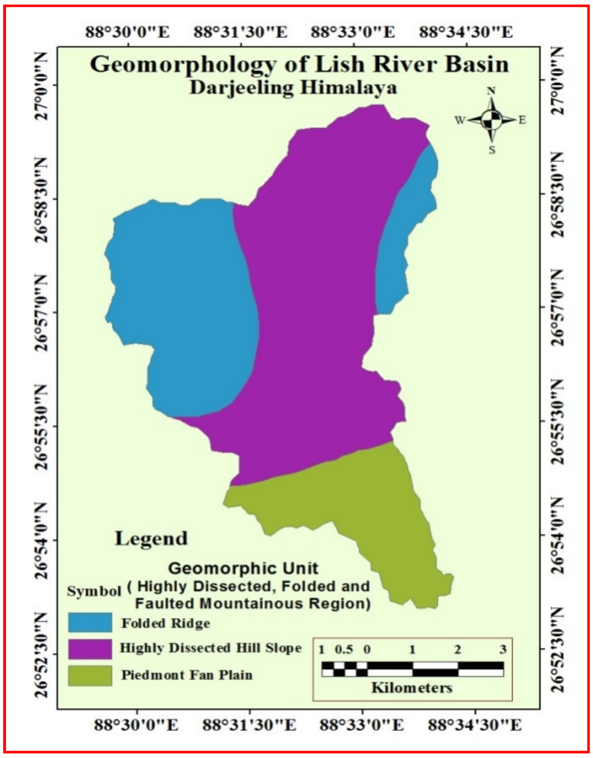

Figure-12
Geomorphology map

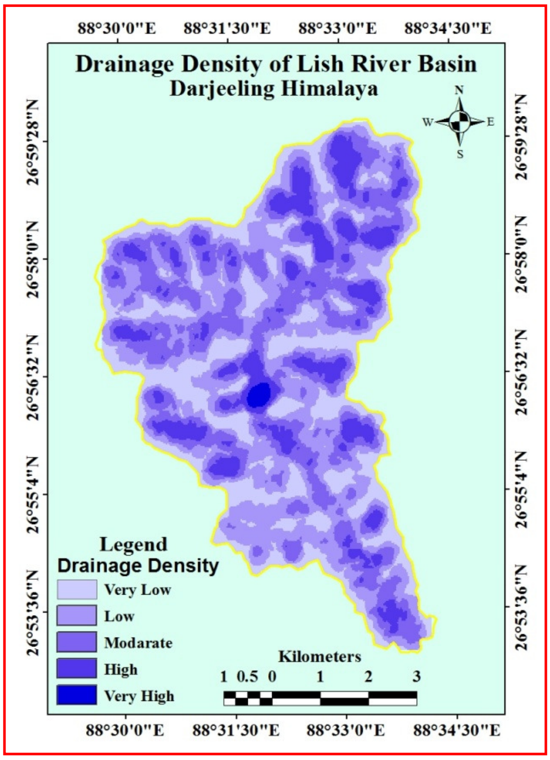

Figure-13
Drainage density map

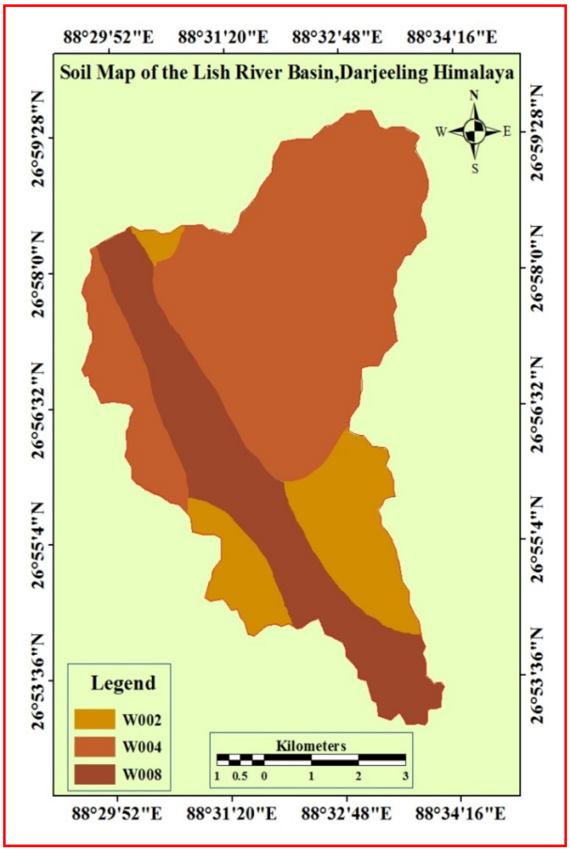

Figure-14
Soil Map

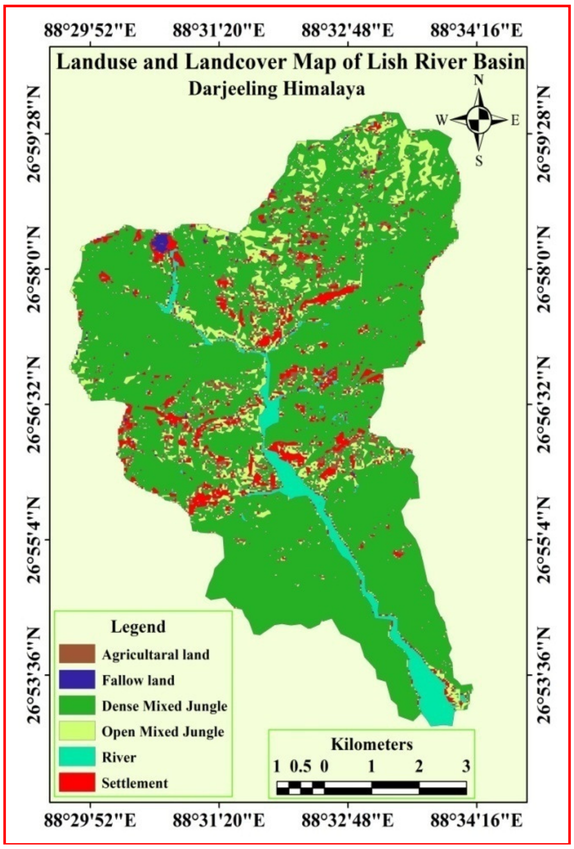

Figure-15
Land use map

Results and Discussion

Landslide zonation: The Lish river basin is classified into 4 landslide hazard zones i.e. low, moderate, high and very high which is shown in figure-16. The Total Rating Values or Total Estimated Hazard Values (TEHD) are grouped into 4 Classes like 2, 3, 4 and 5 and assigned with the Susceptibility status accordingly. The low value is least susceptible to landslide whereas the high value is very susceptible to catastrophic slope failure. The zone of very susceptible to catastrophic slope failure is located at Northern part of the Lish river basin Maximum of the existing landslides are also located in those areas and thus demanding more attention from the habitants, planners and administrators. The area already affected by huge landslide and so immediate attention is needed for site specific slope management for these regions.

To determine the probability or chances of landslide occurrences phenomena in each landslide susceptibility class a frequency ratio is being calculated by means of a ration between landslide susceptible area (%) and landslide frequency (%). Frequency ratio value approaching towards ‘0’ indicates lower the chances of landslide activities and reverse condition is the outcome when the value approaching towards ‘1’. Study shows that around 22% area of the Lish river basin is attributed with frequency ration value of more than ‘1’ which indicates greater the chances of landslide probability in the same area. 56.55 % are of the basin is registered with moderate landslide susceptibility with frequency ration value of 1.03. High landslide susceptible area of 25.59 % is registered with the frequency ratio of 1.22 which shows high landslide probability in table-3.

Slope and Landslide susceptibility: The positive relationship between slope and landslide susceptibility is found in the Lish river basin. The slope angle ranges from 30^0 to 60^0 is dominated by moderate to high landslide susceptibility. Table-4 depicts that 35 degree slope the area is less and landslide susceptibility is high and the slope angle of less than 20 degree shows the maximum area of low landslide susceptibility.

Drainage and landslide susceptibility: Basically moderate drainage density in the study area is registered with high to very high landslide susceptibility. In the moderate drainage density zone minimum area is dominated by less landslide susceptibility whereas low drainage density depicts the maximum area of low landslide probability. High drainage density prone area with steep slope did not allow the concentration of drainage and finally promote low landslide probability and depicted in table-5.

Table-3
Landslide Hazard Zone on the Basis of Total Estimated Hazard Values (TEHD) and Frequency Ratio Study

Landslide Susceptibility	Total pixels	% of Total Area	Landslides pixel	% of Land Slide	Frequency Ratio
Low	6754	11.08	114	7.69	0.69
Moderate	34473	**56.55**	867	58.50	**1.03**
High	15596	**25.59**	464	31.31	**1.22**
Very high	4131	6.78	37	2.50	0.37
Total	60954	100	1482	100	1

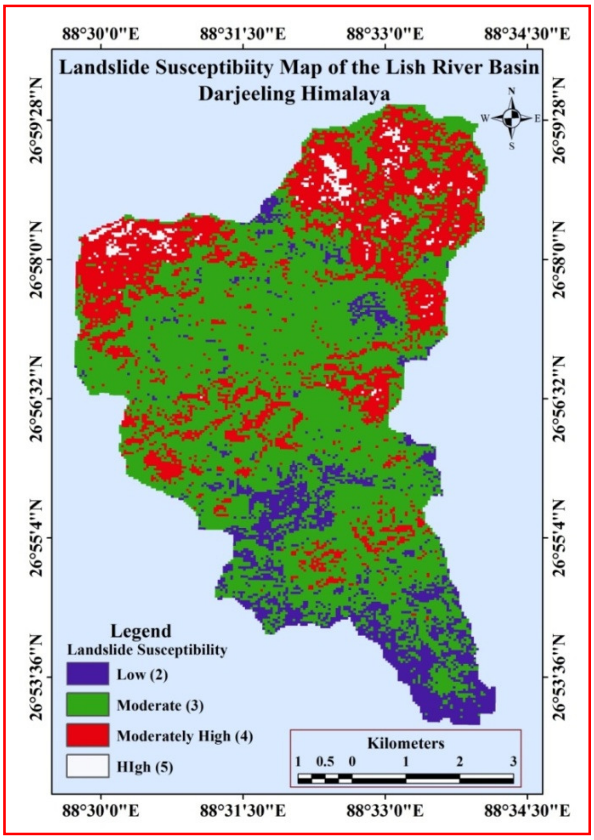

Figure-16
Landslide susceptibility Zones of the Lish river basin

Table-4
Slope Angle and Landslide Susceptibility.

Slope Angle	Landslide susceptibility								
	Low	% of low	Moderate	% of moderate	High	% of high	Very High	% of very high	Total
0-13.6	1963	19.89	6207	62.89	1699	17.22	0	0	9869
13.6-22.19	2163	17.56	7829	63.53	2262	18.35	70	0.57	12324
22.19-30.07	1788	12.64	8955	63.28	3201	22.62	207	1.46	14151
30.07-38.67	1217	0.09	7978	55.99	4529	31.79	524	3.68	14248
38.67-60.86	1011	7.04	9203	64.08	3167	22.05	981	6.83	14362

Geomorphology and landslide susceptibility: Large area characterised by highly dissected hill slope showed high to very high landslide susceptibility in the Lish River Basin. Besides the folded ridges also depicted the larger area with high slope instability. Table-6 showed the area dominated by piedmont fan plain shows less susceptible to slope failure. 56.65% area of the geomorphic unit of folded ridge, 58.09% of piedmont fan plain and 61.26% of highly dissected hill slope are dominated by moderate level of slope instability. 28.63 % of folded ridge and 21.76 % of dissected hills are characterised by high landslide hazards.

Soil and landslide susceptibility: Soil having coarse texture with taxonomy of W002 reveals higher probability of landslide susceptibility. The taxonomy of W008 is registered with landslide susceptibility in the Lish river basin. It is also found that greater area of the basin is dominated by coarse texture soil and less cohesion which finally introduce slope instability in the study area which is analysed in table-7.

Lithology and landslide susceptibility: Large area of the lithological composition of crystalline rocks and slate, schists and quartzite are dominated by high landslide susceptibility. On the other hand the area covering sandstone, shale and clay reveals the less area with high landslide susceptibility described in table-8. The study revealed that the maximum area (43.05 %) of unclassified crystallines lithological unit is dominated by high and very high landslide susceptibility.

Table-5
Drainage Density and Landslide Susceptibility

Drainage Density	Landslide Susceptibility								
	Low	% of low	Moderate	% of moderate	High	% of high	Very high	% of very high	Total
0-396.43	2008	15.59	9016	70.06	1758	13.65	94	0.73	12876
396.43-729.44	2172	10.70	13989	68.92	3962	19.52	173	0.85	20296
729.44-1094.17	1439	8.59	9634	57.51	5283	31.53	397	2.37	16753
1094.17-2077.33	1635	17.57	3307	35.55	3260	35.04	1101	11.83	9303
2077.33-4043.67	0	0	1108	64.38	613	35.62	0	0	1721

Table-6
Geomorphology and Landslide Susceptibility

Geomorphology	Landslide Susceptibility								
	Low	% of low	Moderate	% of moderate	High	% of high	Very High	% of very high	Total
Folded Ridge	2115	10.04	11932	56.65	6030	28.63	984	4.67	21061
Piedmont Fan Plain	3527	31.07	6593	58.09	1230	10.84	0	0	11350
Highly Dissected Hill Slope	3186	11.16	17486	61.26	6210	21.76	1661	5.82	28543

Table-7
Soil and Landslide Susceptibility

Soil	Landslide Susceptibility								
	Low	% of low	Moderate	% of moderate	High	% of high	Very high	% of very high	Total
W002	1959	14.28	8211	59.86	3412	24.88	134	0.98	13716
W004	1486	4.47	20027	60.28	10297	30.99	1415	4.26	33225
W008	2683	19.15	8773	62.61	2061	14.71	496	3.54	14013

Table-8
Lithology and landslide susceptibility

Lithology	Landslide susceptibility								
	Low	% of low	Moderate	% of moderate	High	% of high	Very High	% of very high	Total
Unclassified Crystallines	1114	9.29	4455	37.14	5164	43.05	1261	10.51	11994
Slate, Schists, quartzite	2860	8.73	20321	62.06	8980	27.42	584	1.78	32745
Sandstone Shale/Clay	6054	37.34	8835	54.49	1326	8.18	0	0	16215

Conclusion

The Lish river basin is dominated by moderate level of slope instability and which is followed by moderately high, low and high landslide susceptibility. The north eastern and north western part of the basin is experienced with high landslide susceptibility where further constructional activities are to be avoided to check the destruction from the landslide phenomena. Further slope failure is expected in near future in the north eastern and north western part of the basin and may cause havoc destruction by destroying tea garden area and human settlement. Moderate level of landslides can be expected in the middle most section of the slope facet on the both sides of the trunk streams and pre-slide management strategies are to be taken at all those places. Extreme marginal part of the basin where drainage concentration is less is characterised by moderately high landslide susceptibility. The slope angle ranges from 30^0 to 60^0 is dominated by moderate to high landslide susceptibility. Beyond 35 degree slope the area is less and landslide susceptibility is high. Slope angle of less than 20 degree shows the maximum area of low landslide susceptibility. Extreme lower southern part of the basin is registered with low landslide where the possibility of landslip is very low. In the mid-section of the basin, the active erosional process of the trunk stream steepens the side slope and introduces slope failure at greater magnitude. Soil having coarse texture with taxonomy of W002 reveals higher probability of landslide susceptibility. The taxonomy of W008 is registered with landslide susceptibility in the Lish river basin.

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