Applied GIS

ISSN: 1832-5505
Vol-2 Issue-02 April 2014

Lish River Basin, Eastern Darjiling Himalaya: Remote Sensing and Geographic Information System Assessment and Prediction of Slope Instability

Biplab Mandal[1] & Sujit Mondal[1],

Abstract

Planners and policymakers have been paying close attention to the landslide prone region in the mountainous terrain as a result of the tragic loss of life and property that has occurred there. Extensive tea planting, deforestation, growth of connectivity and habitation, shifting cultivation, and other unscientific and unplanned land use activities may be seen in the Lish River valley of the eastern Darjiling Himalaya. All of these things have increased the danger for the people who live in the Lish river basin by making landslides more likely. A systematic and quantitative evaluation and forecast of landslides have to be done for optimal planning and development, despite the fact that different measures were made to battle and control the landslide phenomenon. This was one of the goals of this study. Landslide prevention focuses mostly on improving our ability to identify and anticipate landslide occurrences. In this study, we analyzed and predicted landslide-prone areas in the Lish River valley. Some landslide inducing factors were considered while making the Lish river basin's landslide susceptibility map, including slope angle, slope aspect, slope curvature, drainage, lithology, geomorphology, soil, land use and land cover, and normalized difference vegetation index (NDVI). Class rating values were given for each class and factor based on the frequency ratio of each class across all thematic data layers. In order to combine several data sets After performing an overlay analysis model on a GIS platform, we were able to anticipate the geographical distribution of slope instability and create a landslide zonation map for the Lish river basin. Landslide hazard was found to be very high to extremely high in the Lish river basin.

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

1. Introduction

The attempts to reduce 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 (Dai et al., 2002). Landslide analysis is mainly done by assessing Susceptibility, Hazard and Risk (Einstein, 1988). Risk analysis is a valid technique for combating the landslide hazards for formulation and application of the proper management proposal. Varne (1984) studied the landslide hazard zonation. Recently many studies have been done to assess landslide risk using the GIS tools. Guzzetti et al. (1999) have summarized many landslide hazard evaluation studies. Jibson et al. (2000); Luzi et al. (2000); Praise and Jibson (2000); Rautelal and Lakheraza (2000); Donati and Turrini (2002); and Zhou et al. (2002) have applied the probabilistic model for landslide risk and hazard analysis. Atkinson and Massari (1999) applied the logistic regression model for landslide hazard mapping. The landslide hazard and risk analysis with the help of the geotechnical model and the safety factor was done by Gokceoglu et.al. (2000); and Zhou et al. (2003). Recently, landslide hazard evaluation using fuzzy logic, and artificial neural network models have been mentioned in the various literature of Ercanoglu and Gokceoglu (2002); Pistocchi (2000) and Lee et al. (2004a). In the present study area remote sensing Technique and GIS tools are used on nine landslide inducing parameter like like lithology, geomorphology, soil, relief, slope angle, slope aspect, slope curvature, drainage density, NDVI, landuse and land coverto 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, aspect, curvature, relative relief, drainage density, and land use. 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. Average Slope, Relative Relief, Drainage Density, Landuse are considered. The first good paper on *landslide hazard zonation* in India was published by Majumder (1980). The National Remote Sensing Agency (NRSA), Dept. of Space of the Govt. of India, Hyderabad, has recently published an Atlas on Landslide hazard zonation in two parts, Atlas vol. 1 refers to Uttaranchal, and Atlas vol.2 refers to Himachal Pradesh. The centre of disaster mitigation and management, Chennai, and the Building Materials Technology

Promotion Council, New Delhi, are now together preparing the first, small scale landslide hazard map of India. Bureau of Indian Standards (BIS-1998), proposed a guidelines for landslide hazard zonation map on 1:25,000 or 50000 scales. The zonation map of the Lish river basin has been prepared here using factor approach (landslide hazard evaluation factor-LHEF) rating scheme. Generally the location of the landslide and its behavior is governed by the hydrology of the sub-catchment in which it is located rather by the characteristics of the catchment as a whole. Without a thorough mapping of the sub-catchment and without assigning the weightage accordingly, the match between the inferred hazard rating and the observed hazard rating will remain elusive (Bhandari-1987). Landslide hazard zonation involves the division of an area in to several zones, which indicates progressive levels of landslide hazard. According to Varnes (1984), "the term zonation implies in the general sense to categorize the land surface in to areas and arranges them according to degrees and potential hazards from landslides and other mass movements on slope. Landslide hazard maps are 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 in preparing the zonation map is the lack of collected data related to the causative factors such as topography, climate, geology, hydrology, seismicity and anthropogenic changes.

Figure1: The Lish River Basin in Darjiling District.

Figure 2: The Lish River Basin in Google Earth Image.

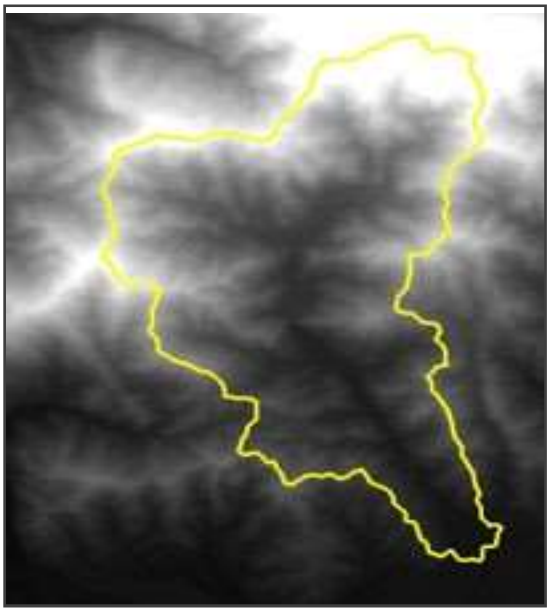

Figure 3: DEM Image of the Lish River Basin.

Figure 4: LANDAST Image of the Lish River Basin.

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 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 (**Basu**). 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 the nature of weak, young set of rocks, predominance of monsoonal climate with high intensity and long duration rainfall and steep mountain escarpment slope are supposed to be the major problems associated with landslide in the study area in Darjeeling Himalayan region. 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.

Materials and Methodology to prepare landslide susceptibility map

A landslide susceptibility map is prepared applying remote sensing technique and GIS tool to show the spatial distribution of the interactions of causative factors, and to draw two decades having witnessed the worst

are preparedbased on SOI Topo-sheetusing ArcViewandARC GIS Software. Firstly, the *contour map* is prepared and digitized fromthe SOI Topo-sheet and is subsequently transformed to Digital Elevation Model or toGRID/Raster Surface at 30×30 m resolution of the corresponding Satellite Image LANDSAT (2015). Finally, slope, curvature and aspectmaps are prepared from DEM and designedin value domain using filtering technique.The *lithological map* of the concerned study area is prepared after NATMO Kolkata (Eastern Region). Drainage density map (the length of drainage in km/sq.km) is prepared on the grid resolution of 30×30 m.

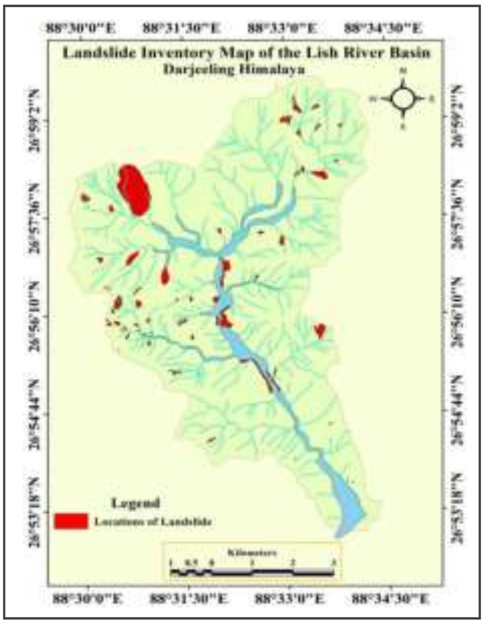

Figure 5: Landslide Inventory Map of the Lish river basin.

Land use/land cover map is prepared evaluating LANDSAT image data, SOI Topo-Sheet using supervised classification technique and following *maximum likelihood*

a relationship between range of individual factors and mag

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 (eq.3).

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

F_2 = number of pixels/cells or grid without lands

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

To extract the number of pixels with and without landslide, a *landslide occurrence map* (Figure.2) is prepared evaluating SOI Topo-sheet and Satellite Image LANDSAT digitized and converted into raster values through ARC GIS Software. All the generated maps are reclassified with weighted values (Table-1) depending on their degree of magnitude to landslide occurrences. Finally, a landslide susceptibility map is carved out applying *Weighted Overlay Analysis Model and*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].

For the preparation of the 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. 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.

a) To identify the factors/components responsible for slope failure.
b) To arrange various factors according to their significance.
c) To determine variables for each of the factors/components.
d) Class wise and factor wise assignment of ratings based on frequency ratio and the relative importance of landslide inducing factors prevalent in the study area.
e) Development of landslide susceptibility map applying 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. Here lithology was ranked first and assigned 21 as LHEFRV which is followed by drainage density, slope angle, elevation, slope curvature, relative relief, slope aspect, NDVI, soil and geomorphology. 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 the table 1.

Table 1: Terrain Factors and Landslide Susceptibility Values.

Sl. No	**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. 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: Landslide Hazard Evaluation Factor Rating Scheme.

Factors/components	**Variables**	**Theme weight**	**Feature Class weight**

Relative Relief (m)	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
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
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
Elevation	116 - 447	12	1
	447 - 655		2
	655 - 872		3
	875 - 1107		5
	1107 - 1405		6
	1405 - 1870		4
Slope Curvature	Concave	10	5
	Flat		1
	Convex		4
Lithology	Sandstone, shale/ Clay.	08	2
	Slate, Schists, Quartzite.		3
	Unclassified Crystallines (Mainly Gneisses)		4
Slope Aspect	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
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		
Soil	1.W002	05	01
	2.W004		03
	3.W008		02
Geomorphology	Folded Ridge.	04	05
	Highly Dissected Hill Slope.		03
	Piedmont Fan Plain.		01

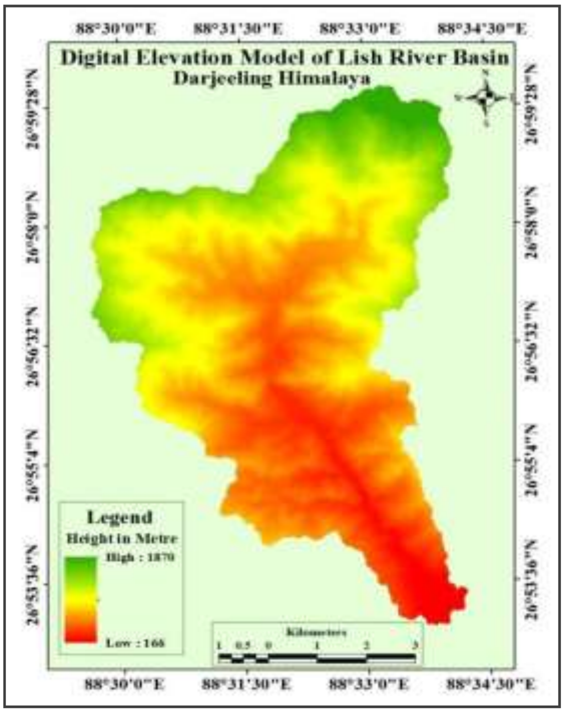

Figure 6: DEM of the Lish Basin.

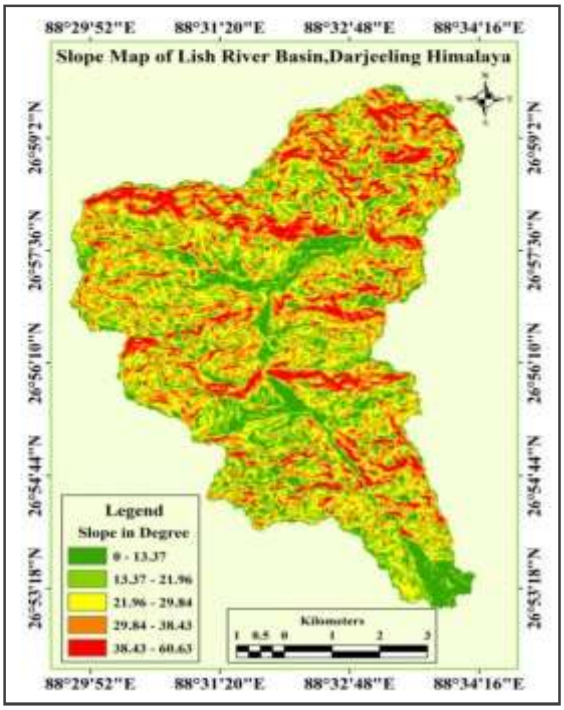

Figure 7: Slope angle map.

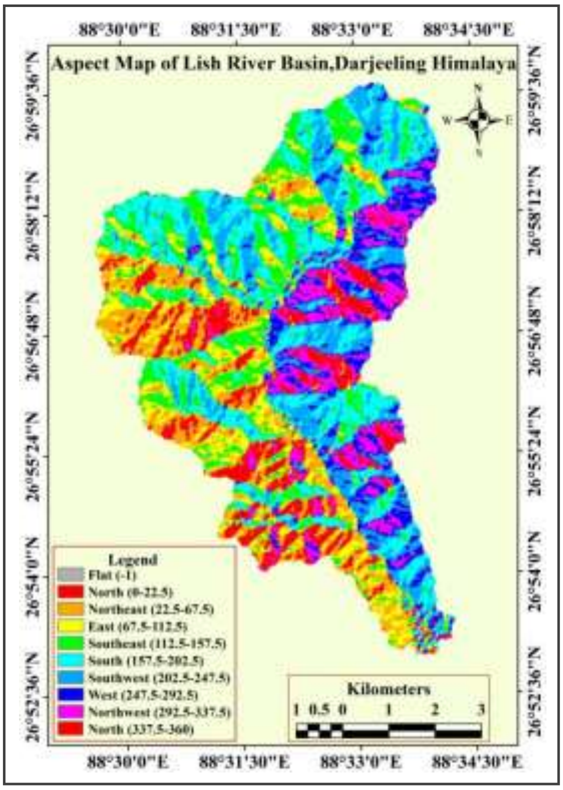

Figure 8: Slope Aspect map.

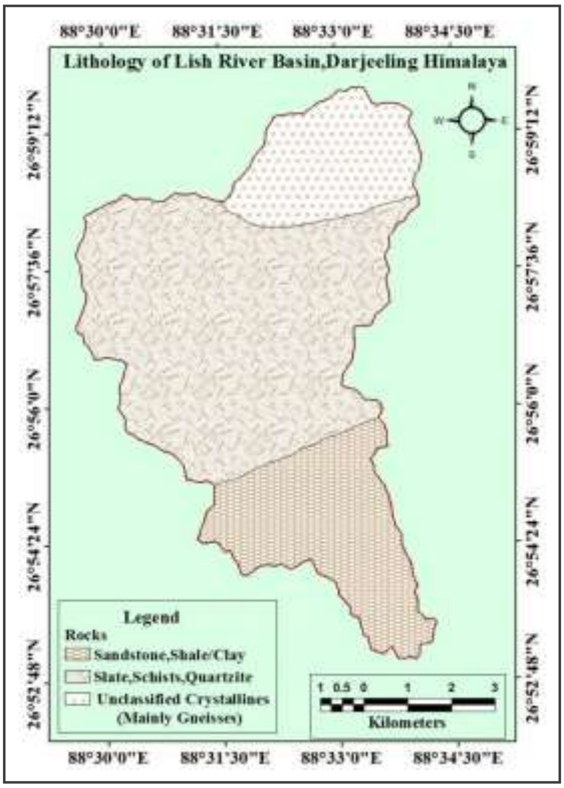

Figure.10: Lithology of the Lish basin.

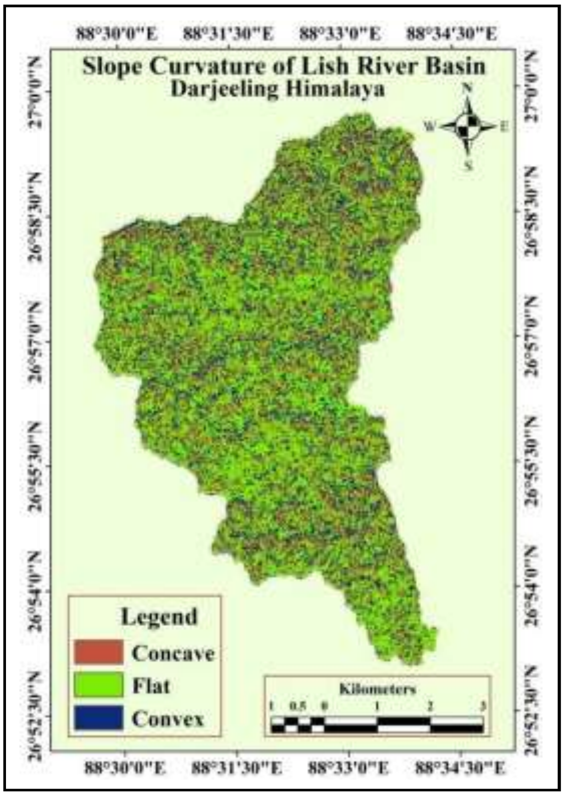

Figure 9: Slope Curvature Map.

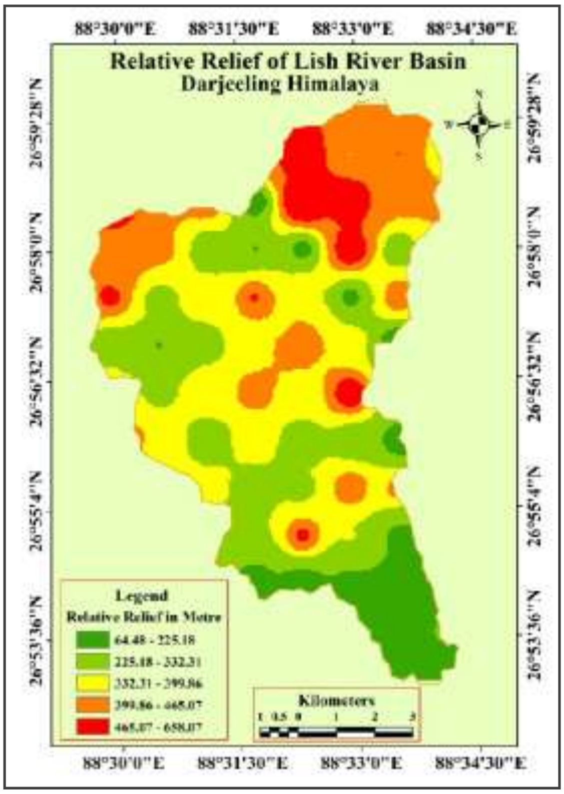

Figure 11: Relief map.

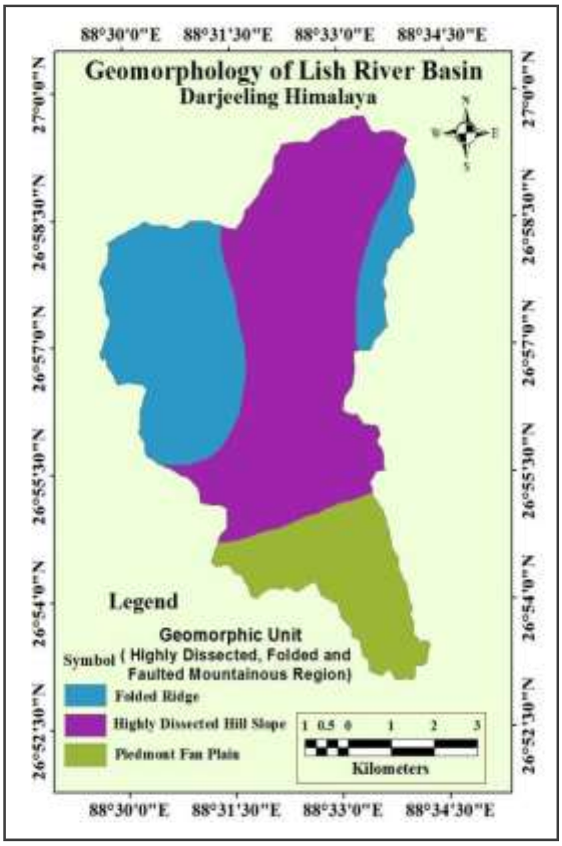

Figure 12: Geomorphology map.

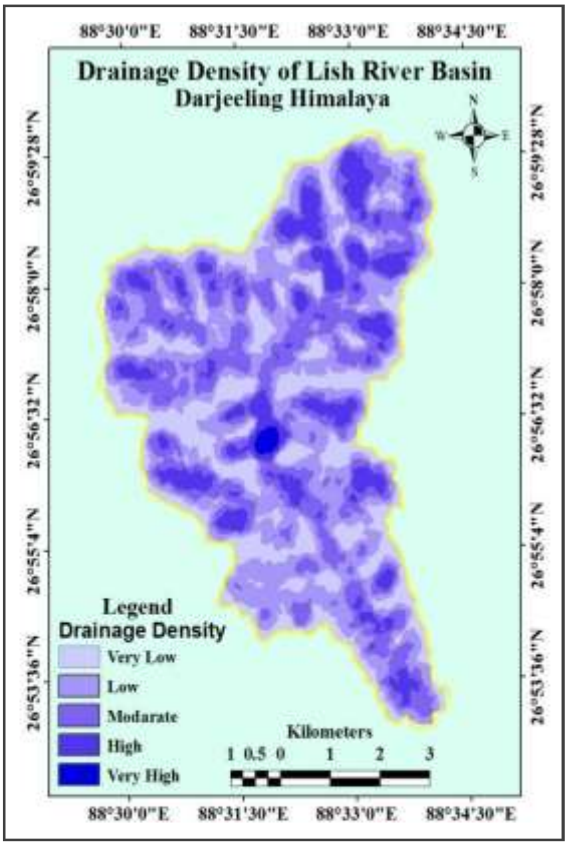

Figure 13: Drainage density map.

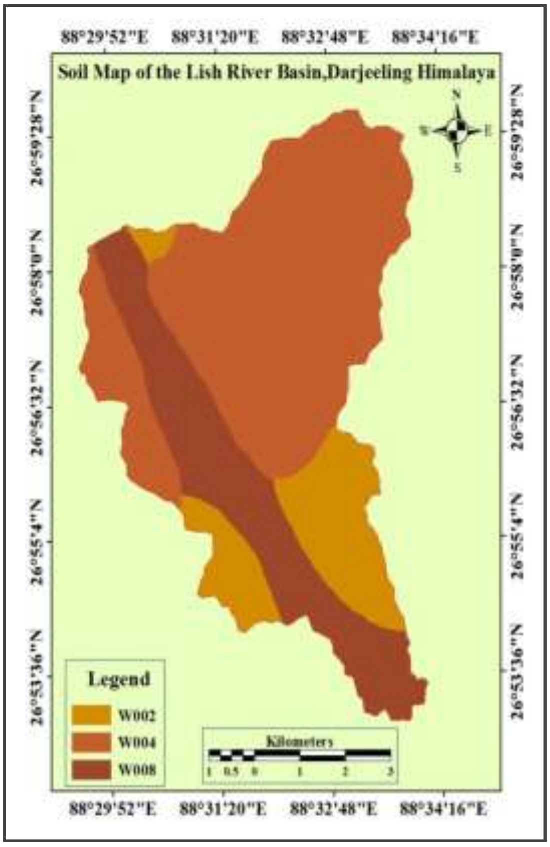

Figure 14: Soil Map.

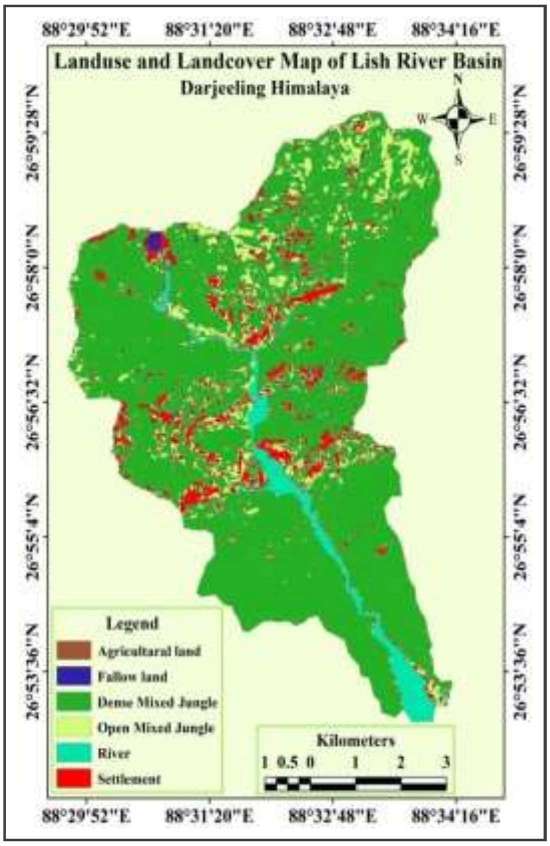

Figure 15: Land use map.

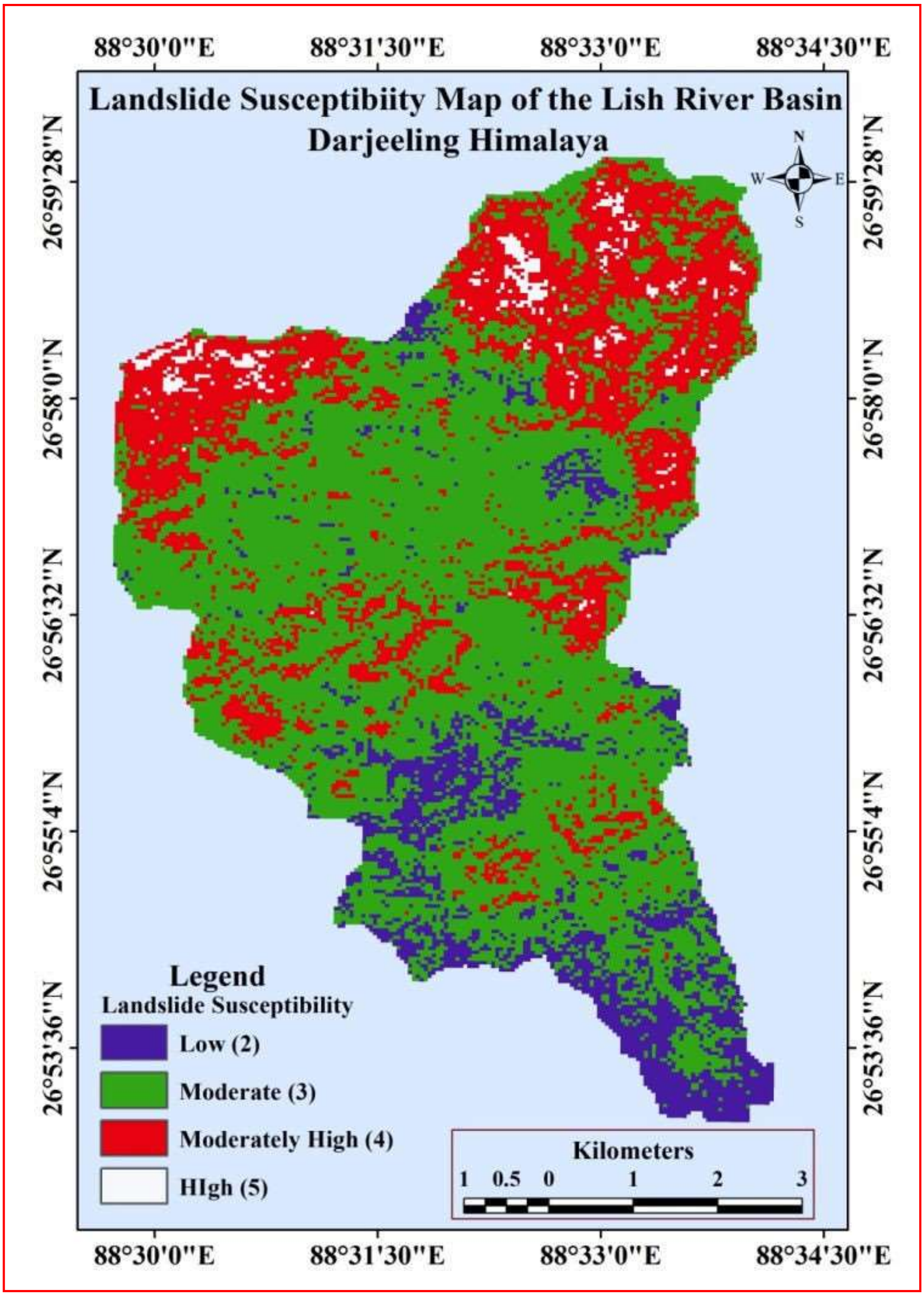

Figure 16: Landslide susceptibility Zones of the Lish river basin.

Result and Discussion

Landslide susceptibility Zones of the Lish river basin:

The Total Rating Values orTotal 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.

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

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 (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. Beyond 35 degree slope the area is less and landslide susceptibility is high (Table.4). Slope angle of less than 20 degree shows the maximum area of low landslide susceptibility.

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

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 (Table.5).

Table 5: Drainage Density and Landslide Susceptibility.

Drainage Density	Landslide Susceptibility								
	Low	% of low	Mode rate	% of mode rate	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

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. Area dominated by piedmont fan plain shows less susceptible to slope failure (Table. 6).

Table 6: Geomorphology and Landslide Susceptibility.

Geomorphology	Landslide Susceptibility								
	Low	% of low	Mode rate	% of mode rate	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

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 (Table.7).

Table 7: Soil and Landslide Susceptibility.

Soil	Landslide Susceptibility								
	Low	% of low	Mode rate	% of mode rate	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

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 (Table.8).

Table 8: Lithology and landslide susceptibility.

Lithology	landslide susceptibility								
	Low	% of low	Mode rate	% of mode rate	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 present work reveals that rational management of potential slope failure zones, where the danger is not exposed yet, is of most important and to be considered as emergency as that of immediate response to a fresh landslide. Pre-slide management of slope requires the identification of susceptible zones. The present work identifies such vulnerable zones of varied priority applying functional, systematic and metastable approach of slope evolution where the stability is expressed as a function of a numbers of factors. The site specific management of slope is necessary along with the general treatment recommended above and timely response to this instability problem only can save the region from potential destruction and the proper execution of the suggestion made may save the resources and ultimately the society and thus the present work will find social relevance. 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 levelof landslides can be expected in the middlemost 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.

References:

Bharatwaj, A.K., C, Pradeep., Thirumalaivasan,D., Shankar, C.P, Madhavan, N., -“Morphometric Analysis of Adyar Watershed” Institute of Remote Sensing, Anna University, Guindy, Chennai, India-600025, pp 71-77, 2014.

Partnerships for Reducing Landslide Risk: Assessment of the National Landslide Hazards Mitigation Strategy, http://www.nap.edu/catalog/10946.html.

S. Mandal and R. Maiti, Semi-quantitative Approaches for Landslide Assessment and Prediction, Springer Natural Hazards, DOI 10.1007/978-981-287-146-6_1.

R. Saha, D. Mondal and J.S. Bisen-'Tea soils of Darjeeling.'

Landslide hazard zonation between Noney-Nungba along NH-53 and geotechnical investigation for two slides.

National Atlas & Thematic Mapping Organisation (NATMO), Dept. of Science & Technology, Ministry of Science & Technology,Govt. of India.

Atkinson P M and Massari R (1998) Generalized linear modeling of susceptibility to landsliding in the central Apennines, Italy; *Computer & Geosciences* 24, pp. 373-385

Carrara A, Cardinali M, Guzzetti F and Reichenbach P (1995) GIS-Based techniques for mapping landslide hazard in Geographical Information System in Assessing Natural Hazards. Academic Publication, Dordrecht, Netherland.

Dai FC and Lee CF (2002) Landslide characteristics and slope instability modeling using GIS; Lantau Island, Hong Kong; *Geomorphology* (42), pp. 213-228

Donati L and Turrini M C 2002 An objective and method to rank the importance of the factors predisposing to landslides with the GIS methodology, application to an area of the Apennines (Valnerina; Perugia, Italy); *Engineering Geology* (63), pp. 277-289

Einstein HH (1988) Landslide risk assessment procedure. Proceedings of the Fifth International Symposium on Landslides. pp. 1075-1090.

Gokceoglu C, Sonmez H and Ercanoglu M (2000) Discontinuity controlled probabilistic slopefailure risk map of the Altindag (Settlement) region in Turkey. *Engineering Geology* (55), 277-296

Guzzetti F, Carrara A, Cardinali M, and Reichenbach P (1999) Landslide Hazard Evaluation: A review of current techniques and their application in a multi-scale study, Central Italy. *Journal of Geomorphology*. 31. Elsevier, London, pp. 181-216

Jibson WR, Edwin LH and John AM (2000) A method for producing digital probabilistic seismic landslide hazard maps. *Engineering Geology* (58) pp. 271-289

Lee S, Ryu J H, Won JS and Park HJ (2004a) Determination and Publication of the weights for landslide susceptibility mapping using an artificial neural network. *Engineering Geology*(71) pp. 289-2.

Parise M and Jibson WR (2000) A seismic landslide susceptibility rating of geologic units based on analysis of characteristics of landslides triggered by the 17 January, 1994 Northridge, California earthquake; *Engineering Geology* 58, pp. 251-270

Rautelal P and Lakhera RC (2000) Landslide risk analysis between Giri and Tons Rivers in Himachal Himalaya (India); *International Journal of Applied Earth Observation and Geoinformation* 2, pp. 153-160

Varnes DJ (1984) Landslide Hazard Zonation: a review of principles and practice. *UNESCO, Natural Hazard,* No. 3, pp 61

Zhou C H, Lee C F, Li J and Xu ZW (2002) On the spatial relationship between landslide and causative factors on Lantau Island, Hong Kong. *Geomorphology* 43, pp. 197-207

Atkinson P M and Massari R (1998) Generalized linear modeling of susceptibility to landsliding in the central Apennines, Italy; *Computer & Geosciences* 24, pp. 373-385