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Upslope Contributing Area, Topographic Wetness and Landsliding: A Case study of the Shivkhola Watershed, Darjiling Himalaya

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Abstract

The distribution of landslide in the mountain area can be well understood studying drainage concentration and topographic wetness over the space. In the present study, the saturation of the slope materials were studied with the help of topographic index model (TIM) which incorporate both slope and upslope contributing area. Here nine landslide inducing parameters like slope, amplitude of relief, lithology, drainage density, upslope contributing area, road contributing area, human intervention, presence of thrust, and land use were made to prepare Landslide Susceptibility Zonation Map applying landslide hazard evaluation factor rating approach. The interaction between landslide and different triggering factors were studied separately and ultimately final coordination is made through Landslide Potentiality Index Value (LPIV). To prepare hazard zonation map of the Shivkhola watershed, grid/cell wise weighted index value (WIV) is assigned for each and every classes of individual triggering factors on the basis of landslide potentiality index value. Landslide Susceptibility Index Value (LPIV) is the outcome of the cumulative total of all grid/cell wise assigned Weighted Index Value. Finally, to assess the role of topographic wetness in landslide phenomena of the Shivkhola watershed a relationship was established between landslide susceptibility map and topographic index model.

Keywords: Landslide, landslide susceptibility, factor approach, topographic wetness, Shivkhola watershed.

Introduction

The susceptibility to landslide is analyzed through the interaction of different factors mainly the slope, relief, drainage 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. To prepare hazard zonation map of the Shivkhola watershed the factor-mapping approach has been applied in which various factors viz. Average Slope, Relative Relief, Drainage Density, Dissection Index, Landuse are considered. The National Remote Sensing Agency (NRSA), 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 shiv-khola watershed has been prepared here using factor approach. Landslides and their 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[1]. Landslide hazard zonation 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 degrees and potential hazards from landslides. Landslide hazard is required for developmental planners as scientific tools for efficient management of the land[2]. To constitute the zonation map of slope instability it is necessary to understand the some triggering mechanism of landslides. Soil moisture and surface run-off plays a significant role to cause landslide phenomena[3]. The possible occurrence of landslide is influenced by geology, land use, slope, aspect and terrain roughness. The land use and land cover of a region is the result of both natural as well human interventions[4] which can change the land surface and sometimes introduce slope instability. The assessment of the impact of land use change on climate and atmospheric phenomena provide meaningful insight to understand slope character[5,6]. The preparation of a landslide hazard zonation map is the first major step to combat and to check landslides. The difficulty to prepare the zonation map is the lack of relevant data related to the causative factors of landslide such as topography, climate, geology, hydrology, seismicity and anthropogenic changes. The Shiv-Khola, the right hand tributary of the mighty Mahanadi is located in Kurseong Division of Darjiling District of West Bengal shown in figure-1. It is famously known as Pagla Jhora, the most destructive and torrential hill stream at its upper catchment.

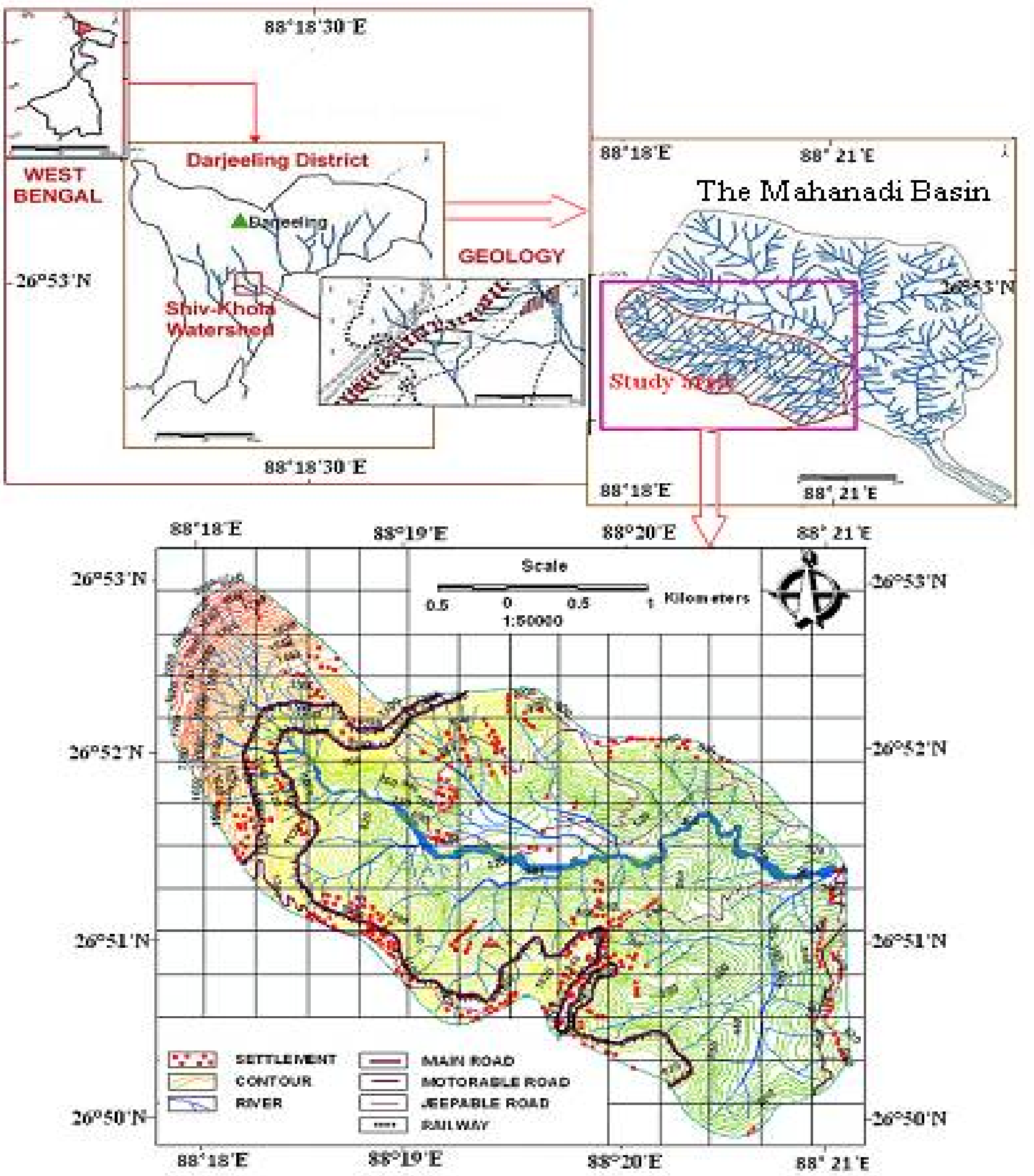

Figure-1
Location map of the Shivkhola Watershed (prepared by author)

Methodology

To prepare the *hazard susceptibility zonation map* the factor-mapping approach has been applied in the present study and various factors viz. average slope, relative relief, drainage density, dissection index, land use, were considered. Average slope is estimated after Wentworth's and it was classified into several slope zones accordingly. 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 Shiv-khola watershed has been obtained from the interpretation of 1:50000 Survey of India Topo-sheet, 1:50000 geo-coded LISS-III Satellite data, existing geological map and extensive field work. The following steps have been taken in to consideration for the preparation of the *landslide susceptibility zonation map.*

To identify the factors/components responsible for slope failure. To arrange various factors according to their significance. To determine variables for each of the factors/components. Preparation of 0.25 sq. Km. grid of the basin. Grid wise assignment of ratings for individual variables. To estimate cumulative landslide hazard evaluation factor by adding all the ratings applied for each components. Preparation of the zonation map putting grid wise LHEF values. Estimation of the degrees of instability based on the map developed. Field validation by comparison with the actual landslide map.

Estimation of Upslope Contributing area (uca): Upslope Contributing Area (uca) is an effective indicator of drainage concentration over space. The places with more upslope contributing area encompass more soil saturation and reduce soil cohesion. The specific contributing area (total contributing area divided by the contour length) is computed by distributing flow from a pixel among its entire lower elevation neighbour pixel[7]. The Fraction of Flow (F_i) allocated to each lower neighbour[8] (i) is determined by using equation-1. An upslope contributing area map was prepared based on calculated contributing area value for each (0.25 sq.km) grid and it was divided into 6 equal classes.

$$Fi = \frac{\mathrm{SiLi}}{\Sigma \mathrm{SiLi}} \qquad (1)$$

[Where, the summation (Σ) is for the entire lower neighbor, S is the directional slope, and L is an effective contour length that acts as the weighting factor. The value of L used here is 10 m of the pixel size of the cardinal neighbour and 14.14 m of the pixel diagonal for diagonal neighbor].

Topographic Index/Topographic Wetness Index: Topography has been a central focus in hydrologic research ever since the introduction of the variable source area concept for storm flow generation· In areas with moderate to steep topography, where elevation potential dominates total hydraulic potential, landform is a key variable in the distribution and redistribution of water[9] as well as for determining the catchment response to precipitation inputs[10-12]. The topographic index, ln(a/tanb), is applied in numerous hydrologic studies[13]. The index is described as I=ln(a/tanb), where 'a' is the upslope contributing area per unit contour length and 'tanb' is the local topographic gradient, and is calculated from a gridded average slope. Research has tended to focus on ways to improve existing algorithms for calculating the topographic index[14, 15]. At present remote sensing technique is used widely to assess water in the soil which can help also to understand landslide in the mountain slope[16].

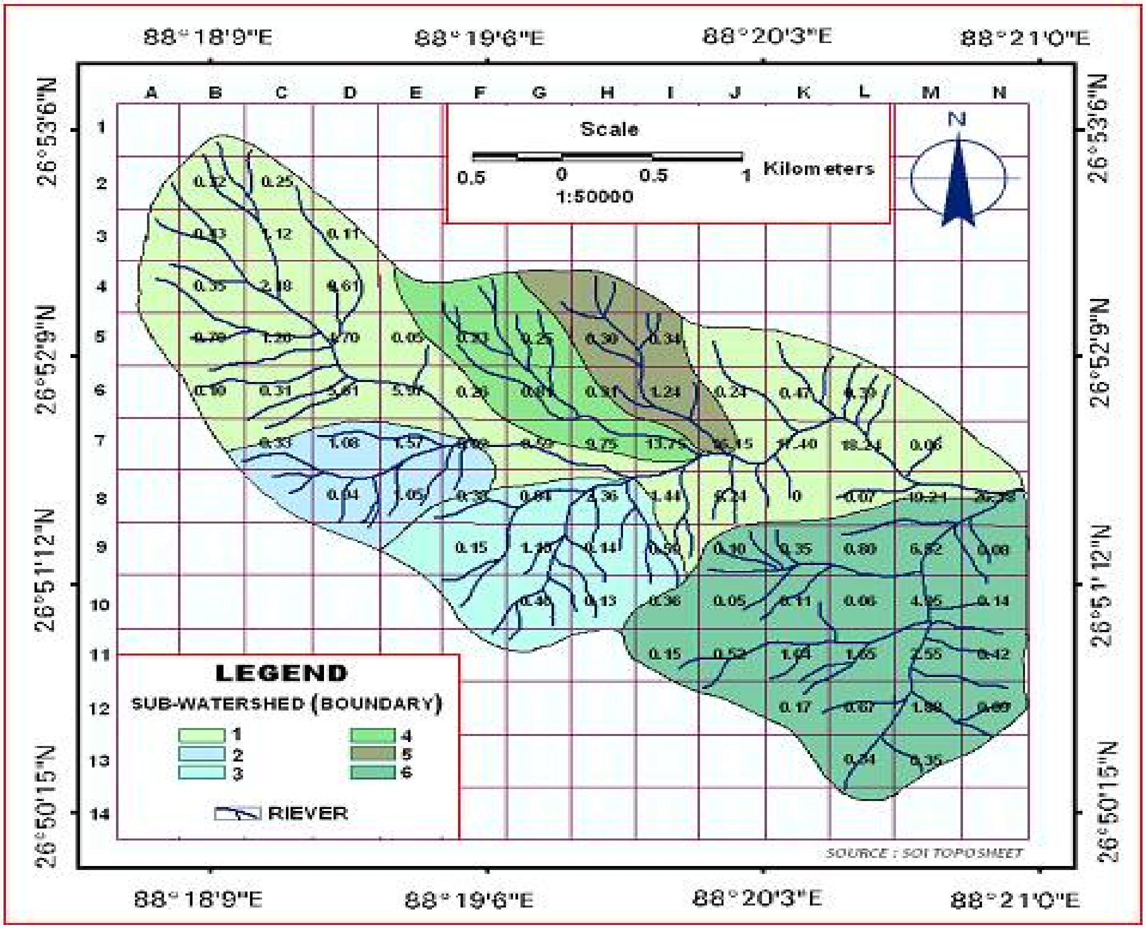

Figure-2
Upslope contributing area of the Shivkhola watershed

Terrain Factors and Landslide Susceptibility Values (LSV) or Maximum LHEF Rating of Different Factors/Components: In the present study 13 landslide inducing factors have been considered and on the basis of these factors 13 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 to relative importance of different factors. Slope is considered as the most 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 11. Upslope contributing area, Depth of soil and land use is assigned with Landslide susceptible values 10 each. Upslope contributing area is the indicator of excess of water and concentration of both surface and sub-surface water and thus helps in the down-slope movement of materials by increasing weight of wet soil, reducing cohesion and increasing lubrication. Land use and land covers are assigned with different rating values according to their importance in soil and slope instability. Drainage channels are rated with maximum rating of 10 where as settlements, agricultural lands; bare lands are rated by 9, 6 and 8 respectively. The dense forest, degraded forest, mixed forest, open forest and jungles are rated with 2,5,3,4 and 4 respectively. Tea gardens are rated with the value of 4. The percentage share of all the land uses of every grid of 0.25 Km^2 are analyzed carefully for calculating the rating value for each of the contributing land uses for those small grids. Ultimately all the rating values for the concerned grid are added for calculating the cumulative rating values and thus Land use Index Values are calculated.

Table-1
Terrain Factors and Landslide Susceptibility Values

No. of Variables	Factors/Variables	Landslide Susceptibility Values(LSV)
1	Slope Inclination	10
2	Road Contributing Area	10
3	Relative Relief	07
4	Drainage Density	06
5	Lithology	06
6	Presence of thrust/fracture	05
7	Dissection Index	07
8	Ruggedness Index	06
9	Constant of Channel Maintenance	08
10	Upslope Contributing Area	10
11	Depth of Soil	10
12	Land use	10
13	Human Intervention	05
Total		100

The Land use Index is assigned with a maximum LSV of 10 and the relative importance of each grid is calculated accordingly. Human interventions are assigned with a maximum value of 9 and the relative importance of the different types of intervention to slope instability is reflected accordingly with assignment of Landslide Susceptibility Values. Ten of such land uses are identified and LSV is assigned to each of them according to potential effect on slope failure. Human intervention on slope is identified as few categories like road, jeepable road, road and settlement, settlement, slope clearance, drainage concentration and are assigned with the values ranging from 4-9 according to their possible effect on slope instability. Upslope contributing area and Topographic Index are two important factors are assigned with LVS ranging from 1-10. The Lithological combinations are also assigned with LSV of a maximum of 6. Depth of the soil is measured at the time of intensive field investigation and LSV ranging from 1to 10 is assigned for each grid according to their relative influence on slope instability.

Results and Discussion

The Total Rating Values or Total Estimated Hazard Values (TEHD) are grouped into 8 Classes stated in table-2 ranging from < 30 to > 54 and assigned with the Susceptibility status accordingly. The lower one is least susceptible to landslide where as the upper one is Very susceptible to catastrophic slope failure. The zone of Very susceptible to catastrophic slope failure is located at PaglaJhora, Gayabari, Tindharia, Northern and central part of Shivitar T.E., Tindharia T.E., and Gitingia T.E.. Maximum of the existing landslides are also located in those areas and thus demanding more attention from the habitants, planners and administrators. Some places along the Hill Cart Road such as Tindharia, Gayabari, Paglajhora etc are very much prone to slope instability. Shivitar T.E. Tindharia T.E. and Gitingia T.E. are affected by huge landslide and so immediate attention is needed for site specific slope management for these regions which is shown in figure-4.

Table-2
Landslide Hazard Zones based on Total Estimated Hazard Values (TEHD)

Zones	TEHD VALUES	Zonal Description
I.	Less than 30	Least susceptible to landslide
II.	30-34	Low susceptible to landslide occurrences
III.	34-38	Fairly susceptible to landslide occurrences
IV.	38-42	Moderate susceptible to landslide occurrences
V.	42-46	Moderately higher susceptible to slope failure
VI.	46-50	Fairly higher potentiality to slope failure
VII.	50-54	Higher potentiality to slope failure
VIII.	Greater than 54	Very susceptible to catastrophic lope failure

Upslope contributing area (uca), Topographic Wetness and landslide Susceptibility: The failure of slope materials occur when it get saturated and reduce cohesion and angle of internal friction. The level of saturation over the space is assessed in the study developing topographic index model where the prepared map is classified into 12 zones. It is observed that the moderate level of wetness with steep slope is critical for landsliding. In the lower segment of the study area as well as along the mid-section of the main river the wetness index value is high where slope angle is moderate to low. Figure-4 depicted that the places of lower Paglajhora, Gayabari, Tindharia, Sepoydhura and Shiviter are dominated by high to very high slope instability where the saturation level is at moderate level. The marginal section of the watershed is characterized by minimum upslope contributing area (uca), low wetness and low landslide activities which indicate the positive relationship between slope wetness and instability. It is also inferred that mid-section of the slope with moderate upslope contributing area provide a suitable condition to saturate the slope materials and ultimately reduce cohesion and increase shearing stress to promote landslip.

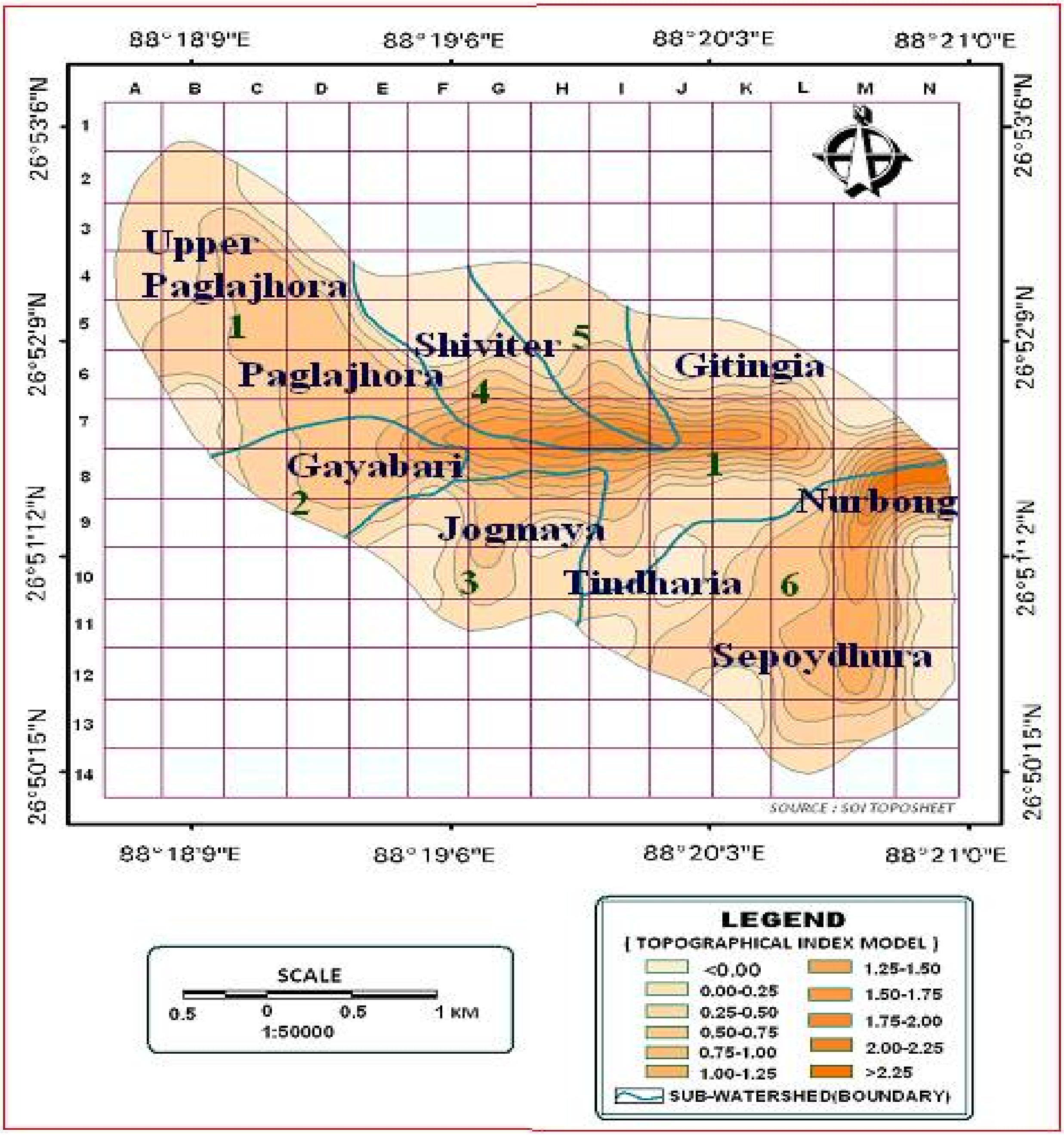

Figure-3
Spatial zonation of Topographic wetness

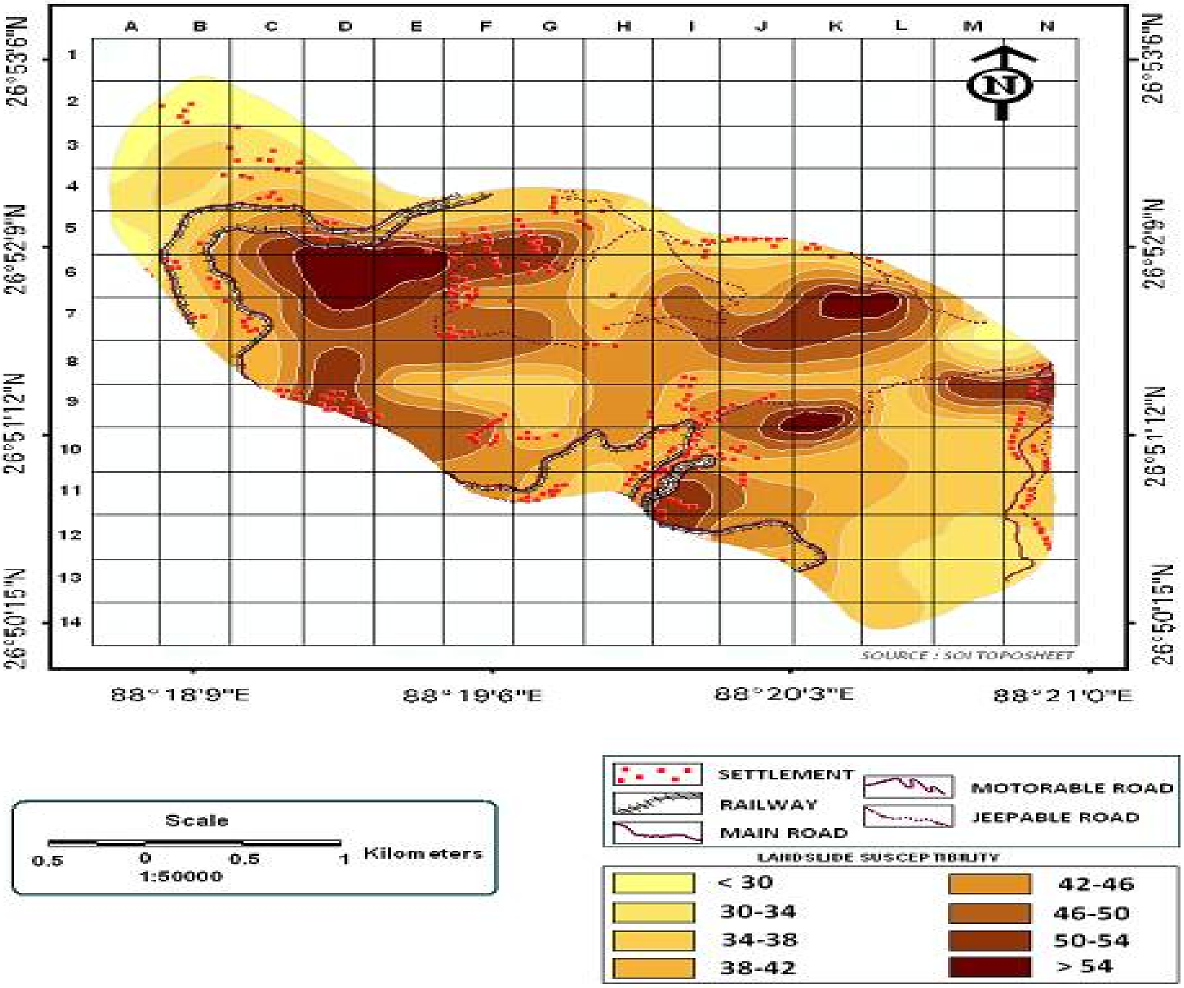

Figure-4
Landslide susceptibility map

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 drainage concentration, topographic wetness and 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.

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