# Analysing spatial interrelationship between landslides with various thematic Geofactors and quantitative validation of landslide susceptibility maps – A case study from Sikkim Himalaya

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**Abstract**

The Sikkim and Darjeeling Himalayas experience frequent land sliding events triggered by monsoon rainfall and intermittently by earthquakes. An inventory of 474 landslides has been prepared covering 1130 km of major road corridors in parts of Sikkim. Out of 474 landslides, 236 are rockslides and 238 are debris slides. Out of 474 landslides, 177 are active, 42 are reactivated landslides, 241 landslides are dormant/ suspended whereas 14 landslides are stabilized/ relict. Out of the inventoried landslides, 116 have been triggered due to the earthquake of 18$^{th}$ September, 2011 (6.9 Mw), rest is rainfall-triggered. Spatial correlation of these landslide incidences with the geofactors revealed that the landslide density (i.e., number of landslide incidences per sq. km.) is maximum (0.66) within 35°-45° slope category, followed by 25°-35° slope category (0.60); highest landslide density (0.96) is within high grade schistose rock mass and the least (0.38) is within quartzites. Within the overburden material, the younger loose material has the maximum landslide density of 1.33 and the insitu soil has the least landslide density (0.101). Within land-use and cover, the barren land has the maximum landslide density (0.85), whereas the thickly vegetated land and agricultural land have lower densities of 0.16 & 0.25 respectively. Hydro-geologically, the flowing category has the maximum landslide density (1.87), followed by dripping category (0.87). Out of all the inventoried landslides, 257 spatially belongs to the High landslide susceptibility Zones (HSZ) with landslide density of 0.76; 159 landslides belong to the Moderate landslide susceptibility Zone (MSZ) with density of 0.41 and the remaining 58 landslides are in Low landslide susceptibility Zones (LSZ) having landslide density of 0.24. Further the relative abundance (%) of earthquake triggered landslides in low, moderate and high susceptibility zones are13%, 37.5% & 49.5% respectively; these abundances are almost similar to that of earlier landslide incidences (12%, 33% and 55%) which are largely rainfall triggered. The above results validate the landslide susceptibility maps prepared along the road corridors of Sikkim during 2006-2009. The above analysis and synthesis of the landslide incidences reveal further that the occurrences of landslides along the roads of North Sikkim is higher and same may be explained by relative higher abundance of high grade schist, younger loose material, fluvio-glacial material, dripping and flowing

conditions of the slope forming material and relatively lower abundance of agricultural land along the roads of North Sikkim compared to other districts. This work successfully presents an analytical method to study the empirical relationships between landslides and their major causal factors and also proposes a simple quantitative technique of validation of the existing landslide susceptibility maps.

## 1. Introduction:

Landslides/ land subsidence are the major and perennial geo-environmental hazards in the Sikkim Himalayas during the active monsoon period (July to September). The phenomenon is triggered due to heavy and continuous rainfall for a considerable duration, earthquakes and ill planned anthropogenic activities. Recurring landslides and incidences of slope instability have played havoc causing snapping of important communication corridors and arterial roads, destruction of agricultural land, houses, loss of human life and properties, posing threat to some major civil structures like dams, bridges, ropeways, power transmission lines and towers. Moreover, the nature (state, activity & style), type (material involved & movement), intensity and distribution of landslides and related phenomenon across the region are highly variable. During the monsoon period the problem aggravated many fold and the major road communications of the state get severely damaged. Earthquake of varying intensity also intermittently shaked this part of the Himalayas causing loosening of slope mass and results in subsequent slope failures. However the seismically induced landslide events are much more devastating in comparison to the rainfall induced landslide.

Though lots of spatial data of landslides along the major road of Sikkim have been generated in the last Century but there has been no systematic inventory database in the country from which both spatial and temporal prediction of this disaster can be made to holistically help the planners in developing the effective strategy to mitigate this hazard. With the aid of advanced GIS software, Paul & Ghoshal (2009) prepared a GIS-based inventory along the major road corridors of Sikkim-Darjeeling Himalayas. That inventory database included the incidence data up to April, 2006. The present authors continued with similar endeavour and collected further detailed field-based landslide inventory data following the international norms of landslide classification (Cruden & Varnes, 1996) and according to the national need to update the landslide inventory database along the roads of the Sikkim on GIS platform using *Arc*GIS 9.2. This updated inventory is stored in the national archive and will become a part of the much-awaited National Landslide Inventory Database of GSI for this particular terrain. The inventory data has various attributes like spatial, temporal, classification attribute, damage, cause and remedial measures. The spatial attributes, the damage details and the suggested remedial measure will help the planners and the stakeholders / end-users to develop effective preventive and mitigation measures. On the other hand the classification details, temporal data and the details of causal factors will help in understanding the landslide process and development of effective spatial / temporal prediction followed by the development of hazard and risk map along the communication network of this defence-strategic state of India.

In the present work, an attempt has been made to spatially correlate the landslide inventory by determining its density metrics with different thematic geodata for examining their spatial relationships with major causal factors such as topography, geology, land-use and cover, water saturation etc. Simultaneously, similar type of spatial interrelationship has also been established with the macro-scale (1:50000) landslide susceptibility map of the terrain prepared in 2009 for validating and examining the susceptibility status of the terrain. An attempt has also been made to compare the vulnerability of roads of different districts of Sikkim as well as to compare the characteristics of rainfall triggered landslide incidences (data collected between the year 2006 to the year 2009) with the seismically induced landslide incidences (data collected after the Sikkim earthquake of $18^{th}$ September).

## 2. The Study area:

The inventory of the landslides has been made along the major communication road (1130 line km) encompassing all districts of Sikkim. The state of Sikkim is characterized by mountainous topography encompassing parts of Lesser Himalayas, Higher Himalayas and the Trans Himalaya and hosts some of the highest mountain peaks of the this active fold-thrust-belt. The study area mainly falls in Lesser and Higher Himalayas with an elevation ranging from 350 m (around Singtam, Melli, Jorethang, Rongpo) through 800-1200 m around Dharamdin, Tashiding, Rongli, Ranipool, Mangan, 1800-2200 m around Gangtok, Soreng, Yaksum, Namchi, Pelling, Ravangla) to 2800 – 3200 m in Lachung, Lachen, Kyangsla areas with elevation increasing gradually from south to north. In Sikkim-Darjeeling Himalayas, the Lesser Himalaya starts from Kalijhora and continues upto Singhik. In the formidable ranges of the Lesser Himalayas, the slopes are gentler and in the undulating stretches, numerous streams and rivulets flow along the depression and finally join with the trunk streams. All these have made extremely rugged landscapes with fine drainage network and stream dissections. In the Higher Himalayan terrain, the topography is highly rugged, characterized by steep slopes with prominent gully erosion. The thickness of overburden on soil cover is considerable in the Lesser Himalayan zone which sharply decreases as one goes towards Higher Himalaya which exposes the rocks on the slope. The slope morphometry drastically changes from Lesser Himalayan zone to Higher Himalayan Zone. In the former it is $16^0$-$25^0$ with rounded to sub-rounded spurs whereas in case of latter it is $25^0$-$45^0$ in with sharp truncated ridge and spurs. The Tista-Rangit water divide is the main north-south water divide within the Sikkim Himalayas. Tista is the trunk river in Sikkim Himalayas. Within Sikkim, Dikchu, Rangnichu and Rangpochu are the main left bank tributaries where as Talung Chu and Rangit rivers are main right bank tributaries.

The lesser Himalayas in Sikkim exposes a thick pile of meta-sedimentary rocks of the Daling Group comprising of Phyllites /phyllitic quartzite and low grade schists of the Gorubathan Formation, dominantly metapsammites of the Reyang Formation and dominantly carbonates of the Buxa Formation. Further north in the higher Himalayas, granite gneiss and high grade meta-sediments (high grade schists and quartzites) belonging to the Central Crystalline Gneissic Complex (CCGC) are thrusted over the low grade metamorphics of Daling Group along the Main Central Thrust (MCT). Beside these, the Gondwana sediments – coarse, greyish black sandstone, carbonaceous shale, coal beds and Rangit pebble slate are well exposed in the Rangit window zone. Along MCT, a strongly lineated, coarse to medium grained granite gneiss and granite mylonites (Lingtse Gneiss) in the form of sheets are conspicuously disposed as thrust wedges.

As per Seismic Zonation Map of India (BIS: IS: 1893, Part-I, 2000) and the map published by IMD, the state of Sikkim comes under Seismic Zone IV – a zone of considerable vulnerability. In this area most of the earthquakes are shallow focus (< 40 km) and are commonly of 4.5 to 5.5 magnitude range on the Richter scale The regional distribution pattern of earthquakes and lineament / fault patterns in Sikkim and adjoining region indicates that a number of high (5.0 to 5.9) and medium magnitude earthquakes are clustered around and related to Tista Lineament along NW-SE direction. One more NW-SE trending lineament, marked as a fault along Tista River between Lachen and Chungthang (and further southeast) appears to have been one of the influencing locales of some high magnitude earthquakes (GSI, 2000).

## 3. Methodology:

The study was carried out mainly along the road stretches: the study area restricted up to the nearest ridge line in the uphill and the nearest river edge in the downhill side resulting in mapping of nearly 857 $km^2$ area. Along the road, thematic mapping of various geofactors (lithology, structure, slope morphometry, relative relief, land use & land cover and hydrogeology) has been carried out as per the BIS guideline, 1998, where as mapping of landslide incidences are based mainly on field observations. Spatial information on each landslide was taken up broadly on location (Latitude/ Longitude, village, road etc.), landslide classification (attributes such as type of movement, material involved, state etc. as per Cruden and Varnes, 1996), damage details, causes, mitigation measures etc.

The landslide susceptibility map (LSM) used for this work has been prepared by superimposing the thematic maps of different causative factors through preparation of primary and derived coverages, assignment of LHEF ratings and estimation of TEHD values (facet-wise) in GIS platform following BIS Guidelines (IS: 14496, Part-II, 1998) (Bhattacharya *et al.*, 2009). Facet, the unit area of study was prepared using Digital Elevation Models. In this study, the LSM of the study area has been validated with the landslide incidences. Further to understand the relative role of various geofactors, landslide densities (no. of landslide incidences per sq.km.) of various sub-classes of a geofactor have been calculated followed by the participation of these subclasses in various susceptibility classes. Again a comparison of landslide susceptibility of roads of various districts of Sikkim has also been made through comparison of landslide density and relative abundances of susceptibility classes in these districts. An effort has been made to understand the reasons of the landslide susceptibility of these districts through the role of varied geofactors. Finally a comparison of relative abundances of landslides triggered mainly by rainfall and earthquake in different susceptibility zones has been attempted to understand the role of different triggering factors in land sliding of the Sikkim Himalayas.

## 4. Results & Discussion:

The landslide incidences have been categorized as per classification of *Cruden and Varnes1996.* Out of 474 landslides, 236 are rockslides and 238 are debris slides (Plate I). Out of 474 landslides, 177 are active, 42 are reactivated, 241 are dormant/ suspended, whereas 14 landslides are stabilized/ relict. Out of the inventoried landslides, only 116 have been triggered due to the earthquake of $18^{th}$ September, 2011 (6.9 Mw), rest are mainly rainfall-triggered. Details of the slide incidences are given in the Table 1.

Table1
Categorization of the landslide incidences (*Cruden and Varnes, 1996*)

| **Material** | | **State** | | **Activity** | | **Style** | |
|---|---|---|---|---|---|---|---|
| Rock Slide | 236 | Active | 177 | Advancing | 6 | Single | 331 |
| Debris Slide | 238 | Reactive | 42 | Retrogressing | 157 | Complex | 10 |
| | | Dormant | 14 | Confined | 174 | Multiple | 6 |
| | | Suspended | 227 | Enlarging | 47 | Composite | 110 |
| | | Stabilised | 6 | Moving | 48 | Successive | 17 |
| | | Relict | 1 | Widening | 41 | | |
| | | Abandoned | 7 | Diminishing | 1 | | |

The Lithological map (Plate II) of the studied area shows different varieties of slope forming material which include eight varieties of rock and five varieties of overburden materials. The landslide densities of different categories of litho types have been determined and the result is shown in figure 1a. The analysis of figure shows that within the overburden material, younger loose material has maximum landslide density (1.33) followed by fluvioglacial deposits where as *insitu* soil has least density (0.101). Within the rock categories high grade schistose rock mass have highest landslide density (0.96) and the quartzites have least density (0.38). The same is reflected in the relatively higher abundance of younger loose material and fluvioglacial deposits in higher susceptibility classes as depicted in figure 1b. A comparison of the spatial distribution of various litho covers in different districts of Sikkim has been analyzed, result of which is shown in figure 1c.

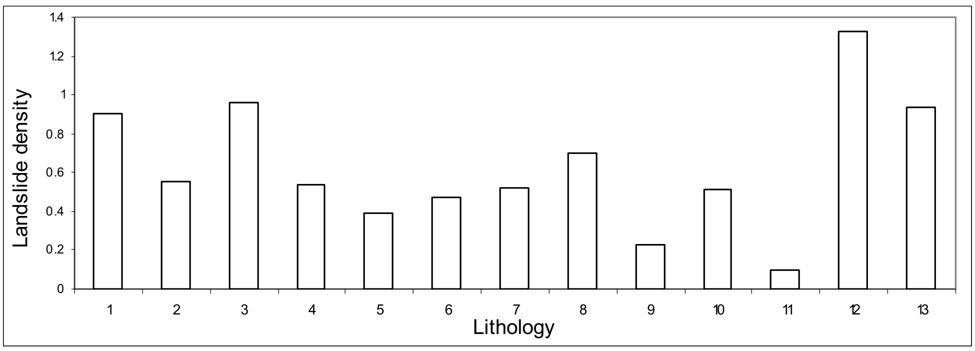



Figure 1a Comparison of landslide density in different litho type

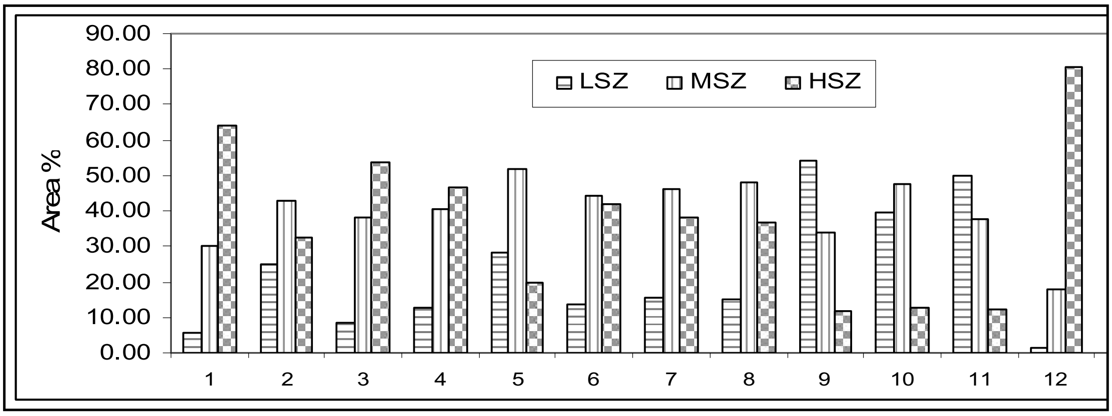



Figure 1b Comparison of areas of Landslide Susceptibility classes in different litho type

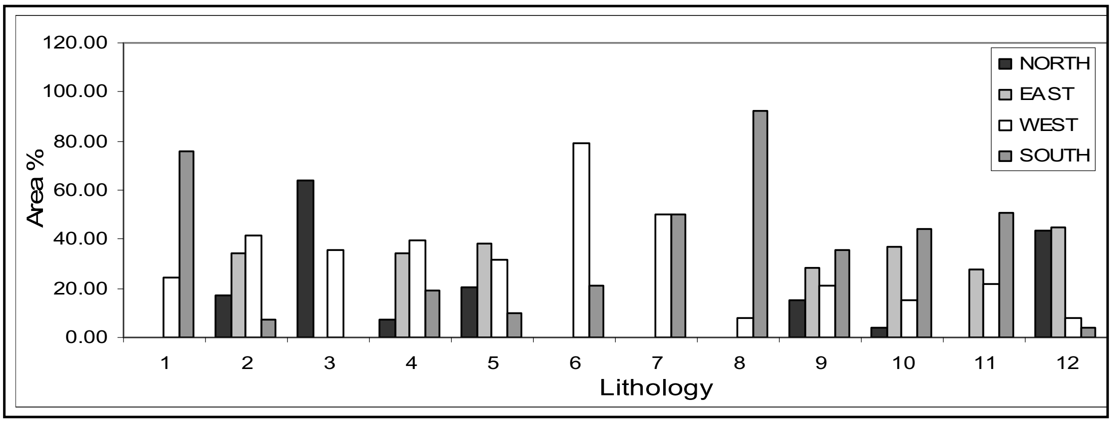



Figure 1c Comparison of areas of various litho type in different district of Sikkim

1.*Dolomitic quartzite, chert, phyllites, slate 2.Banded migmatite, garnet biotite gneiss, mica schist 3.High grade schist 4.Low grade schist & Phyllites 5.Quartzite 6.Sandstone 7.Shaly Sandstone 8.Slate 9. Older Alluvium 10.Older well compacted debris 11.Soil 12.Younger loose material 13.Fluvioglacial deposit*

The slope-morphometry map (Plate-III) of the studied area shows five categories of hill slope *viz* i) escarpment / cliff (>45°), ii) steep slope (35°-45°), iii) moderately steep slope (25°-<35°), iv) gentle slope (15°-<25°) and v) very gentle slope (<15°). The landslide densities of different categories of slope have been determined separately for rock slides, debris slides and the total slides (both rock slide & debris slide and the result is shown in figure2a.

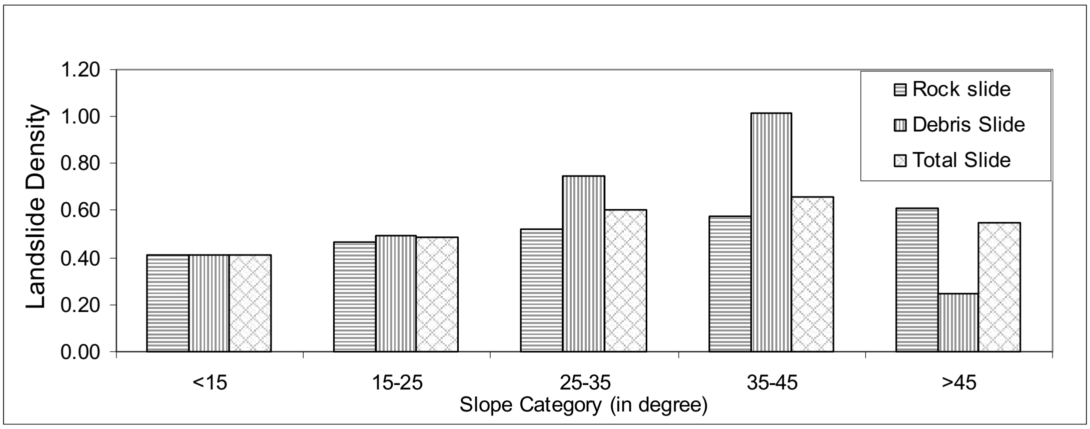



Figure2a Comparison of landslide density in different slope categories

*Landslide density of rock slide= No. of rockslides per sq.km of the rock covered area*
*Landslide density of debris slide= No. of debris slides per sq.km of the rock covered area*
*Landslide density of total slide= No. of both rock & debris slide per sq.km of both the rock &debris covered area*

The figure shows that the density of rock slide increases with the slope angle where as the density for debris slides increases with the slope angle up to 45° after which it decreases with slope angle. This is due to the fact that the debris material cannot present on the escarpment/ cliff due to their low angle of repose (φ value). This fact indicates need for revision of rating system of BIS guideline on Macro-scale Landslide Hazard Zonation for the slope parameter. The increase of landslide susceptibility with the slope is also reflected in the relatively higher abundance of higher susceptibility classes in steeper slopes as depicted in figure 2b.

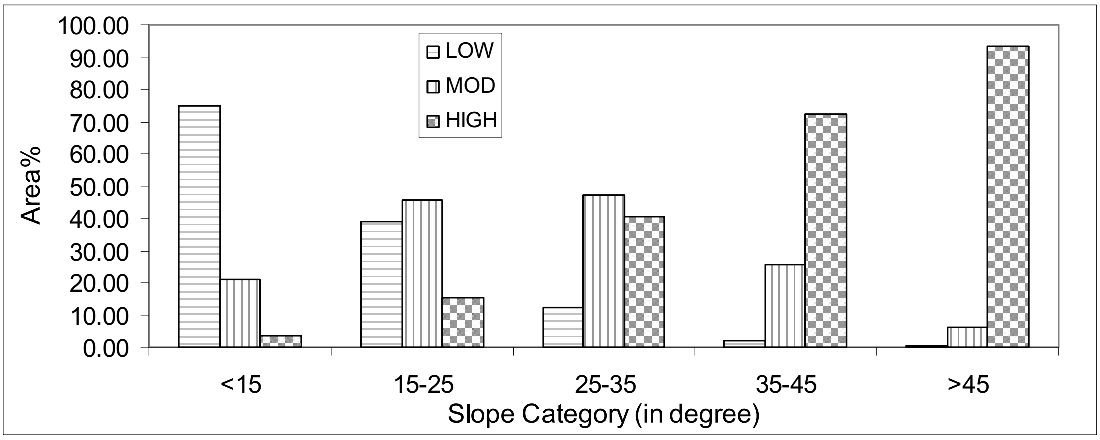



Figure 2b Comparison of areas of Landslide Susceptibility classes in different slope categories

A comparison of the spatial distribution of various slope categories in different districts of Sikkim has been analyzed, result of which is shown in figure 2c.

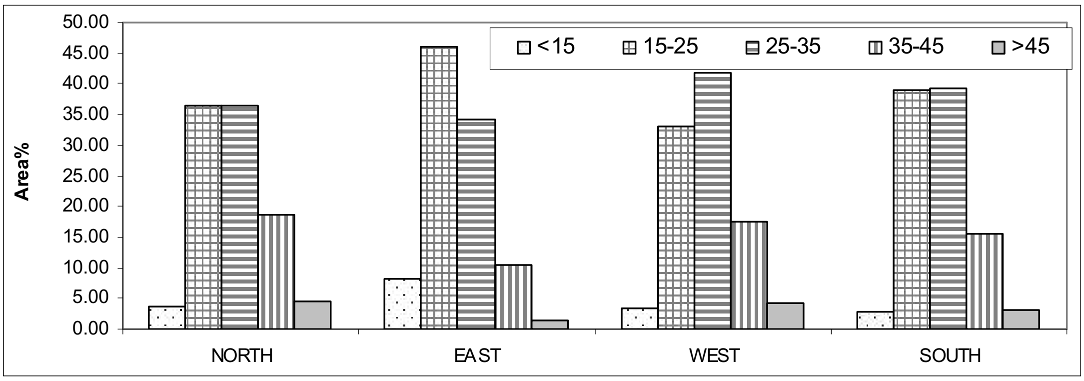



Figure 2c Comparison of areas of various slope categories in different district of Sikkim

The above figure indicates relatively higher abundance of steeper slopes in North and West districts of Sikkim in comparison to other two districts.

The Relative Relief map (Plate-IV) of the studied area shows three categories of relative relief *viz* i) Low (<100m) ii) Medium (101-300m) and iii) High (>300m). The landslide densities of different categories of relative relief have been determined and the result is shown in figure 3a.

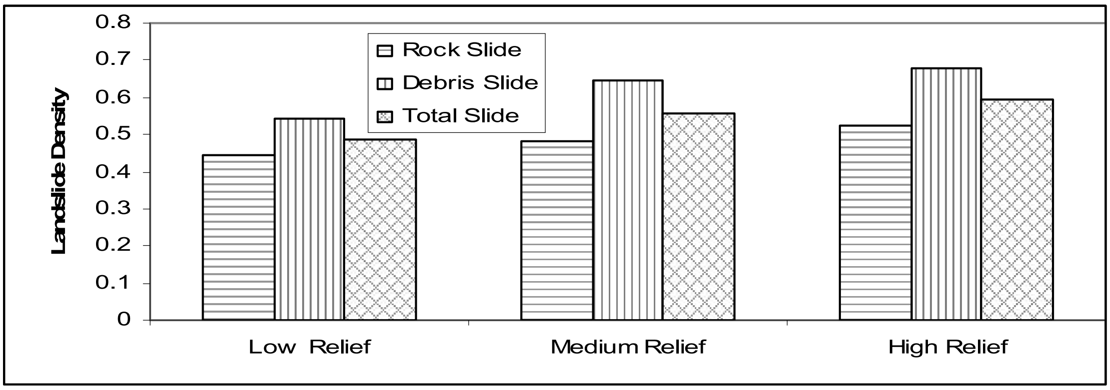



Figure 3a Comparison of landslide density in different relative relief categories

The figure shows that the density of rock slide increases with the relative relief. The increase of landslide susceptibility with the relative relief is also reflected in the relatively higher abundance of higher susceptibility classes in higher relief categories as depicted in figure 3b.

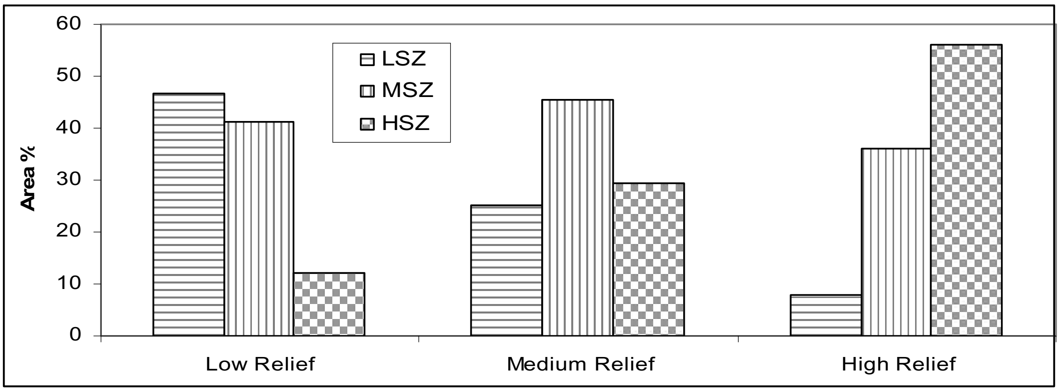



Figure 3b Comparison of areas of Landslide Susceptibility classes in different relative relief categories

A comparison of the spatial distribution of various relief categories in different districts of Sikkim has been analyzed, result of which is shown in figure 3c.

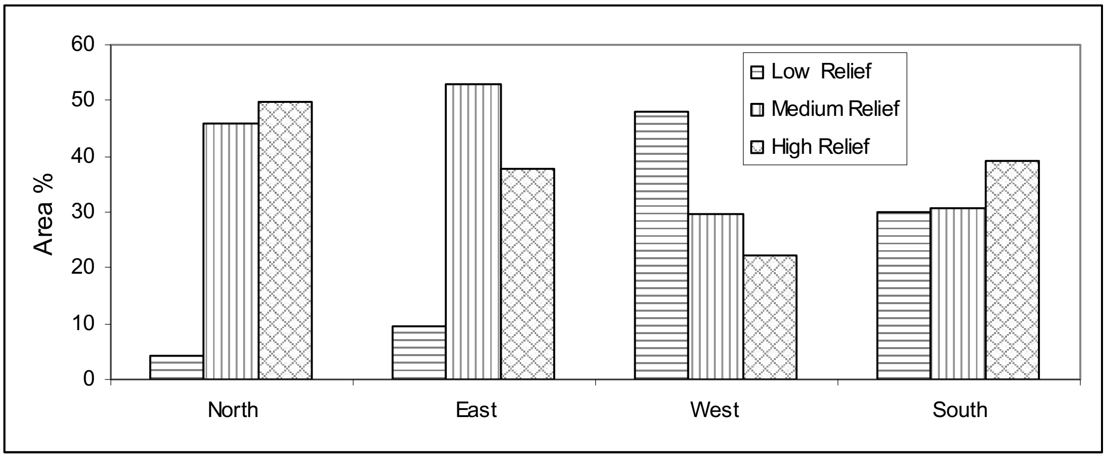



Figure 3c Comparison of areas of various relative relief categories in different district of Sikkim

The overburden thickness map (Plate-V) has been prepared on the basis of estimation of overburden thickness. The areas having overburden thickness <2m represent either the bare rock or the rock present under thin (<2 m.) overburden cover. The landslide susceptibility for this category has been calculated on the basis of relationship of the attitude of structural discontinuities of exposed/ underlying rocks. The landslide susceptibility of areas having overburden thickness more than 2m have been decided on the basis of their landslide densities and the result is shown in figure 4a.

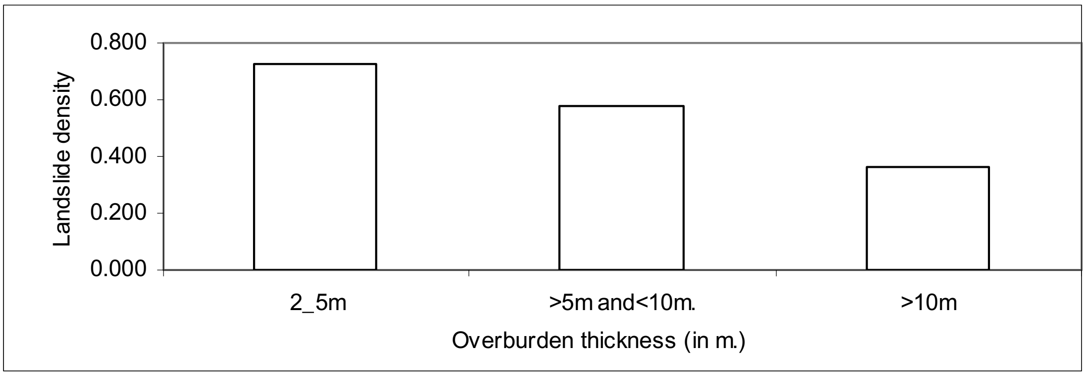



Figure 4a Comparison of landslide density in different overburden thickness categories

The landslide density distribution reflect true picture for the Eastern Himalaya where shallow translational debris slide within '2-5m' thickness category is most common and occurs after the onset of monsoon causing huge loss of life and property due to their suddenness. On the other hand the areas having more than 10m. of overburden are generally older alluvial fill materials and are not very prone to landslide. However they may occasionally cause devastating landslides at the end of the monsoon period. The comparison of landslide susceptibility with the various susceptibility classes has been shown in figure 4b.

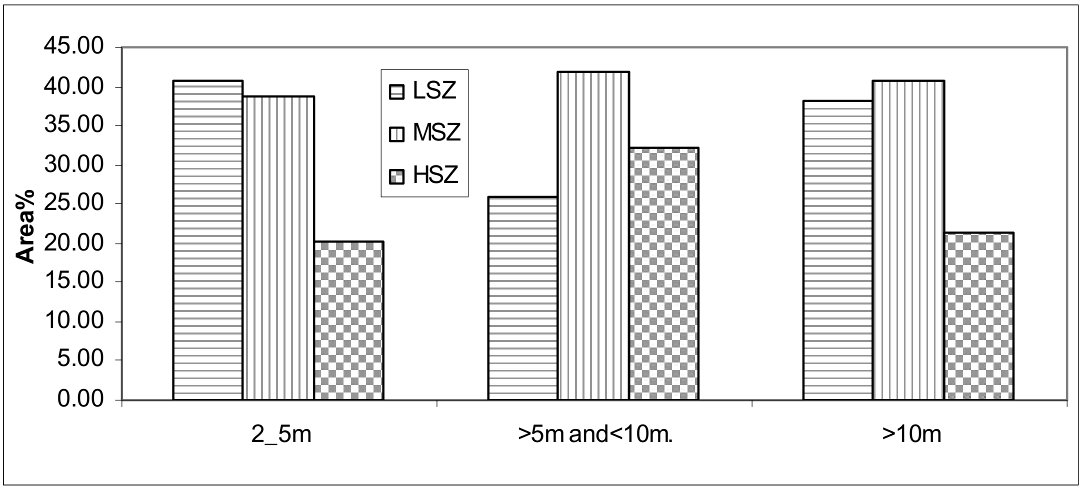



Figure 4b Comparison of areas of Landslide Susceptibility classes in different overburden thickness categories

The result of the above figure does not corroborated with the landslide density. This may be due to the fact that higher rating has been assigned to more overburden thickness as per BIS guideline contrary to the landside density variation across the thickness categories.

Land use- land cover map (Plate-VI) of the studied area shows five categories of hill slope *viz* i) agriculture/ populated land ii) thickly vegetated iii) moderately vegetated areas iv) sparsely vegetated areas and v) barren land. The landslide densities of different categories of Landuse-landcover have been determined and the result is shown in figure 5a.

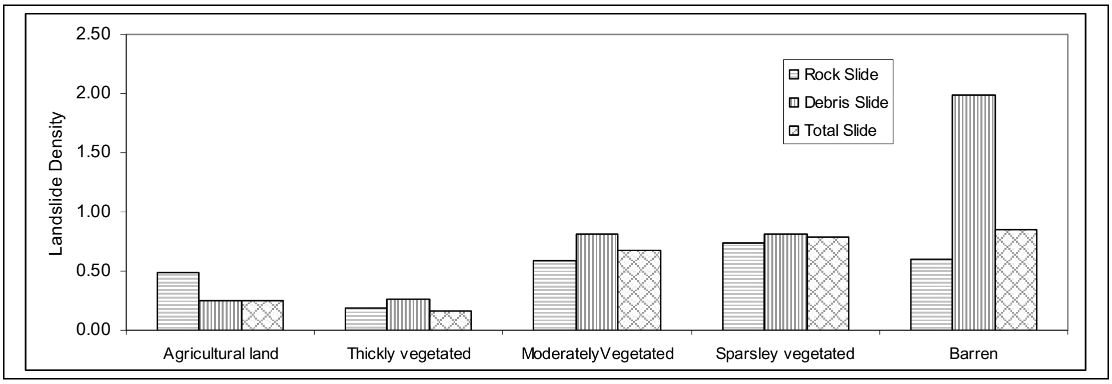



Figure 5a Comparison of landslide density in different Landuse-landcover categories

The figure 5a shows that in general the density of landslide increases with the reduction of vegetation cover; considering all inventoried landslide, the barren land has the maximum landslide density (0.85), whereas the thickly vegetated land and agricultural land have lower densities of 0.16 & 0.25 respectively. Though there is steep increase of density of debris slide in barren slopes, there is no clear relation of density of rock slides with this geo-factor in the study area. It can be interpreted that for rocky slopes there is little role of this geo-factor in terms of landslide susceptibility. The comparatively lower density for the agricultural land is due to the fact that most of the agricultural lands are on gentle to very gentle slope. The increase of landslide susceptibility with the depletion of land-cover is also reflected in the relatively higher abundance of higher susceptibility classes in lesser vegetation cover areas as depicted in figure 5b**.**

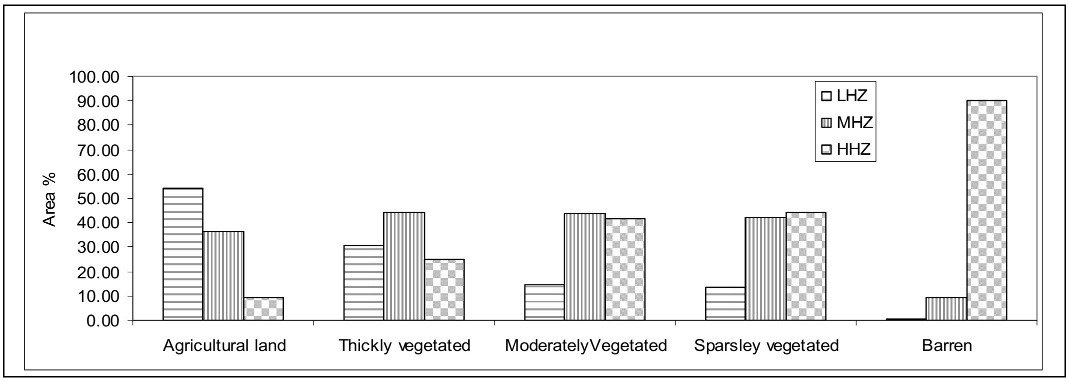



Figure 5b Comparison of areas of Landslide Susceptibility classes in different land use-land cover categories

A comparison of the spatial distribution of various Landuse-landcover categories in different districts of Sikkim has been analyzed, result of which is shown in figure 5c.

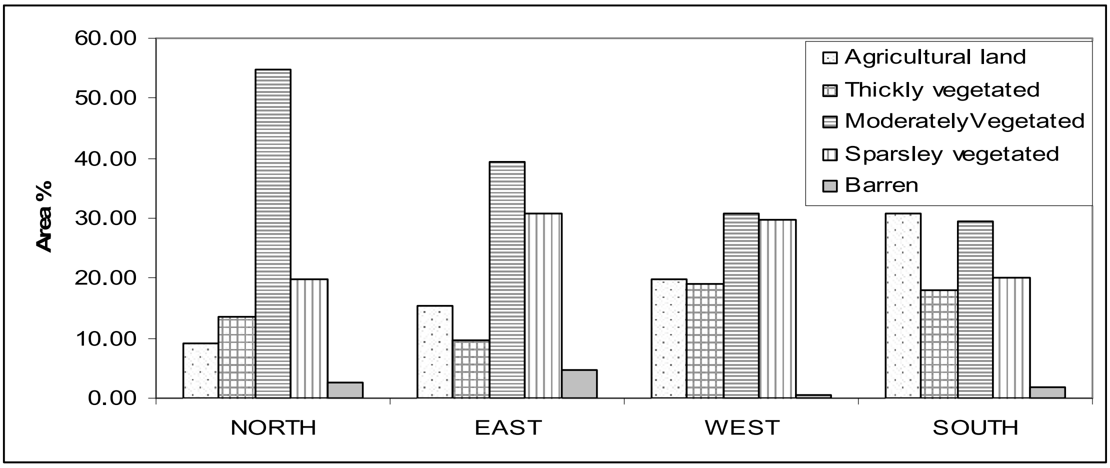



Figure 5c Comparison of areas of various Landuse-landcover categories in different district of Sikkim

The above figure indicates relatively higher abundance of moderately thick vegetation and lesser abundance of agricultural land slopes in North district of Sikkim in comparison to other two districts.

The hydro-geological map (Plate-VII) of the studied area shows four categories of water saturation of the slope forming material *viz.,* i) damp, ii) wet, iii) dripping and iv) flowing The landslide densities of different hydro-geological condition have been determined and the result is shown in figure 6a.

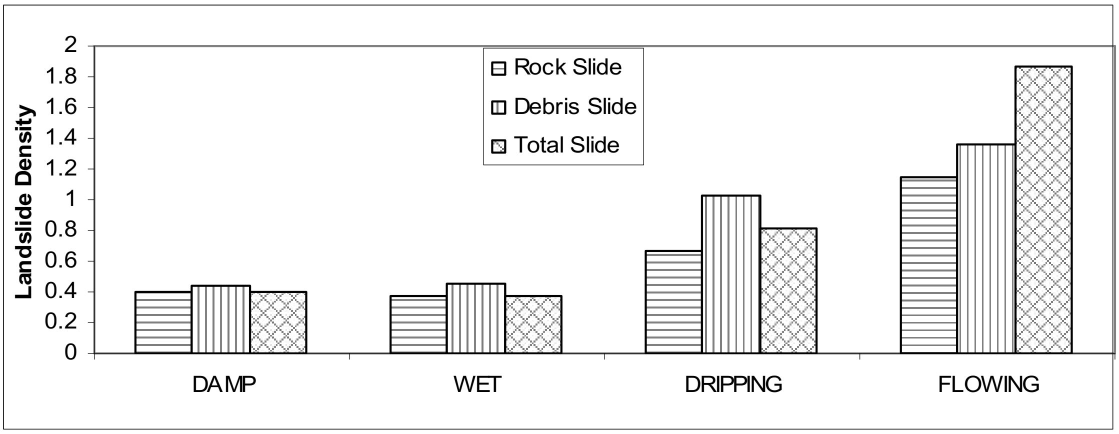



Figure6a Comparison of landslide density in different hydro-geological categories of the studied area

The figure shows that considering all inventoried landslide, the flowing category has the maximum landslide density (1.87), followed by dripping category (0.87). The landslide density of both rock & debris slide increases with the water saturation of slope forming material, though the increment of density with saturation is more for debris slide. The landslide density of both the damp and wet category is almost similar; this may be either due to collection of data during different months (before or after the rain) or during different time of the day (morning, noon or afternoon) or due to the variation of subjective visual interpretation of the saturation condition of slope forming material. The increment in difference between the landslide density of rock & soil slide in dripping category than that of wet and damp category is due to the greater role of piping action in debris material than in rock. Again in case of flowing category the difference in density of tock & debris slide is lesser than that of dripping category: This is due to the more dominant role of erodibilty / toe cutting in comparison to the piping action in case of rock slide.

In a nutshell, we can conclude that the effect of water saturation on rock & debris slide is different due to the fact that the water saturation of debris material depends on it's primary permeability, where as water saturation of a rock is mainly due to its secondary permeability. Hence the existing rating system for hydro-geological factors in BIS guideline needs some modification.
The increase of landslide susceptibility with the water saturation is also reflected in the relatively higher abundance of higher susceptibility classes in more saturated slope forming material as depicted in figure 6b.

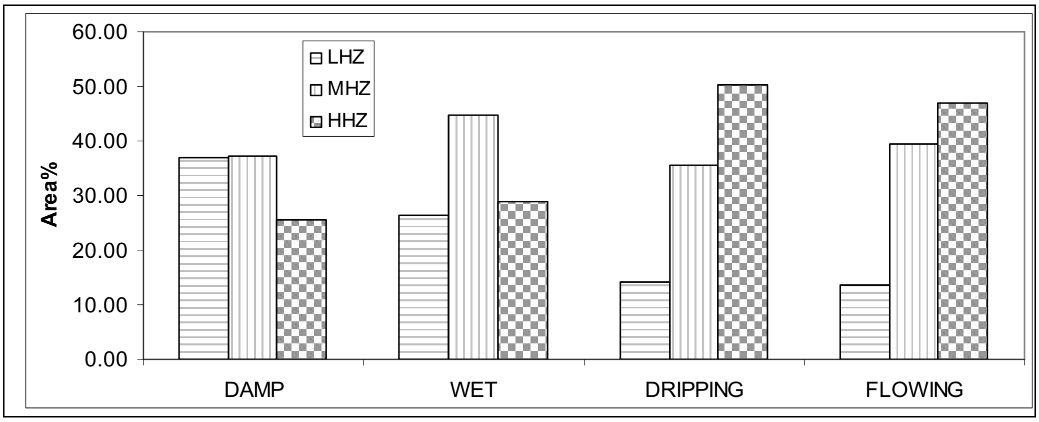



Figure 6b Comparison of areas of Landslide Susceptibility classes in different hydro-geological categories

A comparison of the spatial distribution of various hydro-geological categories in different districts of Sikkim has been analyzed, result of which is shown in figure 6c.

The above figure indicates relatively higher abundance of dripping and flowing categories in North district of Sikkim in comparison to districts.

The landslide susceptibility map (Plate-VIII) of the studied area shows three susceptibility zones viz i) Highly susceptible zone, ii) moderately susceptibility zone and iii) low susceptibility zone. The comparison of landslide density of mainly rainfall triggered landslides and the landslides triggered due to the earthquake of 18th September, 2011 in various landslide susceptibility classes has been made in the figure 7a. Out of all the inventoried landslides, 257 belongs to the High landslide susceptibility Zones with landslide density of 0.76 ; 159 landslides belong to the Moderate landslide susceptibility Zone with density of 0.41 and the remaining 58 landslides fall in Low landslide susceptibility Zones having landslide density of 0.24. Again the variation of densities for rainfall triggered landslide and earthquake triggered landslide in various susceptibility classes are almost similar.

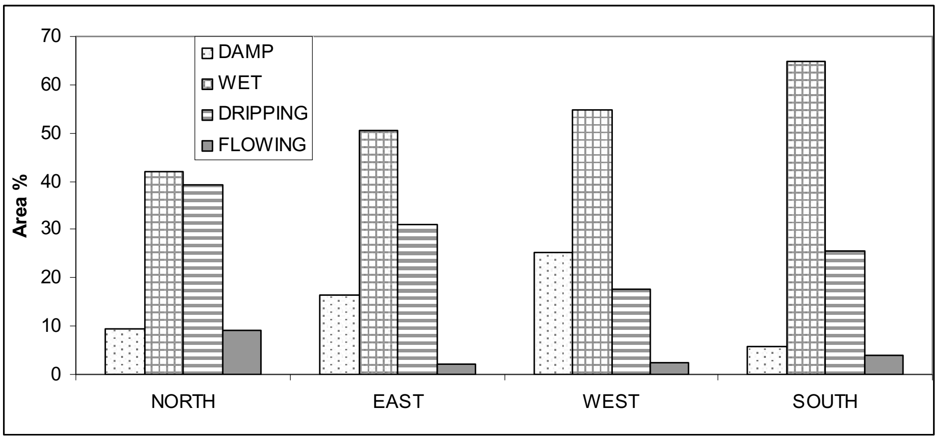



Figure 6c Comparison of areas of various hydro-geological categories in different district of Sikkim

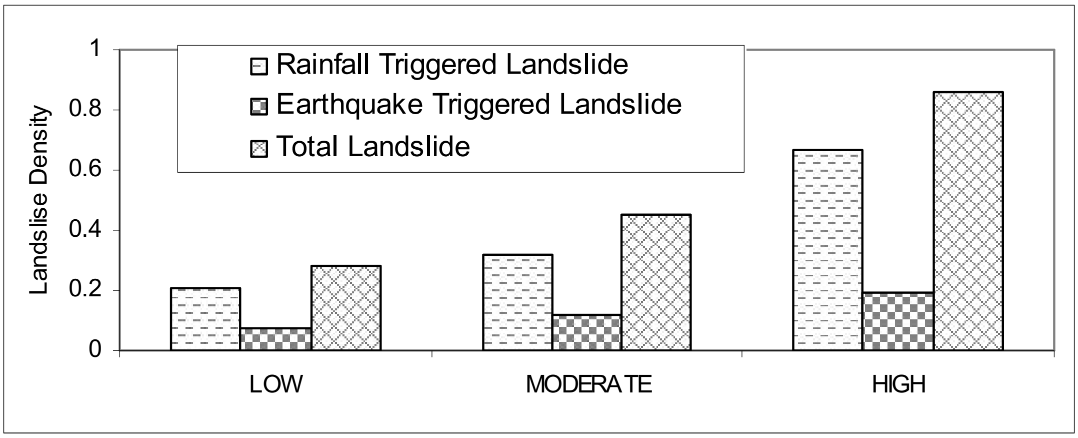



Figure 7a Comparison of density of Rainfall induced and Earthquake induced landslides in different landslide susceptibility classes

The comparison of the relative abundances (%) of mainly rainfall triggered landslides and the landslide triggered due to the earthquake of 18$^{th}$ September, 2011 in various landslide susceptibility classes has been made in the figure 7b. The figure shows that the trend of relative abundance of earthquake triggered landslides (13% in low, 37.5% in moderate & 49.5% in high susceptibility zones) is almost similar to that of earlier (data collected during 2006 to2009) landslide incidences (12%, 33% and 55%) which are largely rainfall induced.

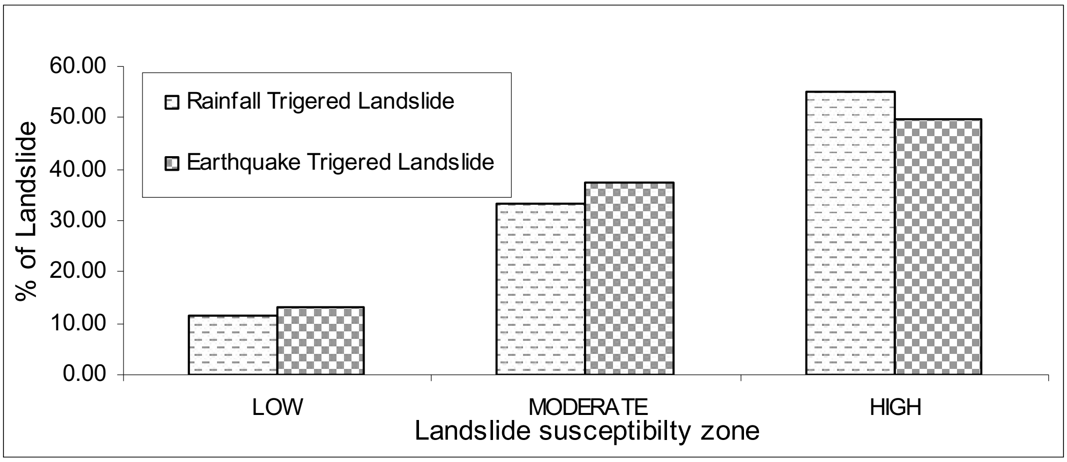



Figure 7b Comparison of abundance of Rainfall induced and Earthquake induced landslides in different landslide susceptibility classes

The above results (figure 7a & 7b) validate the landslide susceptibility maps prepared along the road corridors of Sikkim during 2006-2009.

The comparison of the density of mainly rainfall triggered landslides and the landslide triggered due to the earthquake of 18th September, 2011 in various districts of Sikkim has been made in the figure 7c. The figure shows that the density of both these types of landslides is maximum in North district of Sikkim followed by East Sikkim in comparison to South and West districts. The causes of the higher density of this district have been discussed in the previous discussions.

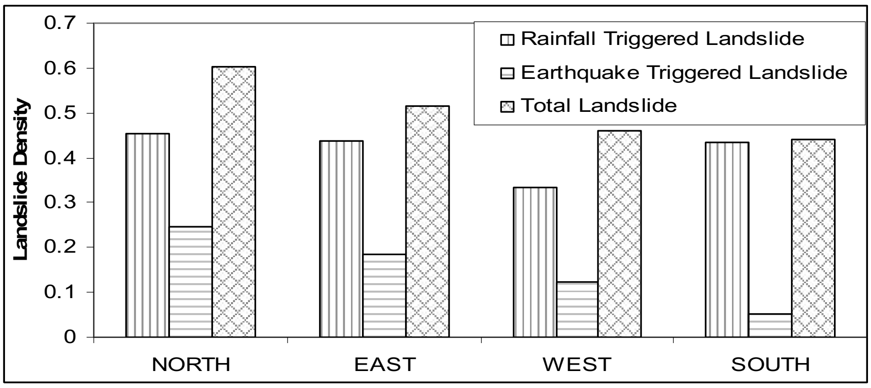



Figure 7c Comparison of abundance of Rainfall induced and Earthquake induced (September, 2011) landslides in different districts of Sikkim

The higher landslide density of North district of Sikkim has also been reflected in figure 7d in which maximum part of North district falls within highly susceptible zone.

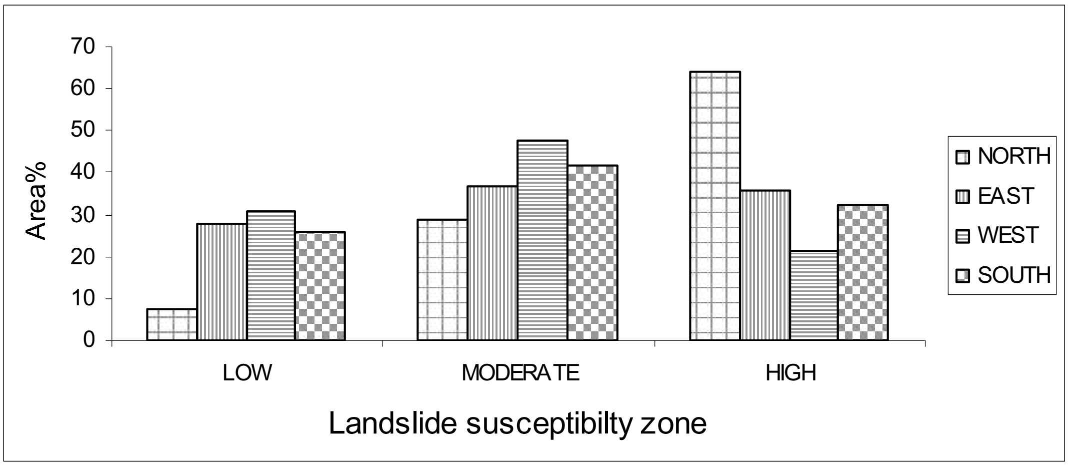



Figure 7d Comparison of areas of various susceptibility zones in different district of Sikkim

## 5. Conclusion:

The inventory of 474 landslide incidences has been prepared along the major corridors (total 1130km) of Sikkim Himalaya. Out of the inventoried landslides, only 116 have been triggered due to the earthquake of 18$^{th}$ September, 2011 (6.9 Mw), rest are rainfall-triggered and collected during the year 2006-2009. Spatial correlation of these landslide incidences with the geofactors using landslide density revealed the role of these geofactors causing landslide. The relative roles of the geofactors have again corroborated by their spatial distribution in the three landslide susceptibility classes. It has been observed that the relative importance of the geofactors determined through the landslide density differs from the importance given in BIS guideline for landslide macrozonation. The main reason for this deviation is relative importance of geofactors in rock slide and overburden slide are different and should be treated separately during macrozonation where as in BIS guideline they have treated together. Another important reason for the deviation is the more qualitative and subjective description of the subclasses of the geo-factors especially in case of Land use-Land cover and hydro-geological factors. The visual estimation of soil thickness in case of macro-zonation sometimes leads to erroneous data and the alternative to this factor may be work out.

The comparison of density and relative abundance of Rainfall induced and Earthquake induced landslides in different landslide susceptibility classes shows almost similar pattern which validate the landslide susceptibility maps prepared along the road corridors of Sikkim during 2006-2009.

The above analysis and synthesis of the landslide incidences reveals further that compared to that of other districts, the occurrences of landslides along the roads of North Sikkim is higher and same may be explained by relative higher abundance of high grade schist, younger loose material, fluvio-glacial material, dripping and flowing conditions of the slope forming material and relatively lower abundance of agricultural land along the roads of North Sikkim compared to other districts.

This work successfully presents an analytical method to study the empirical relationships between landslides and their major causal factors and also proposes a simple quantitative technique of validation of the existing landslide susceptibility maps.

PLATE- II: LITHOLOGICAL MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM

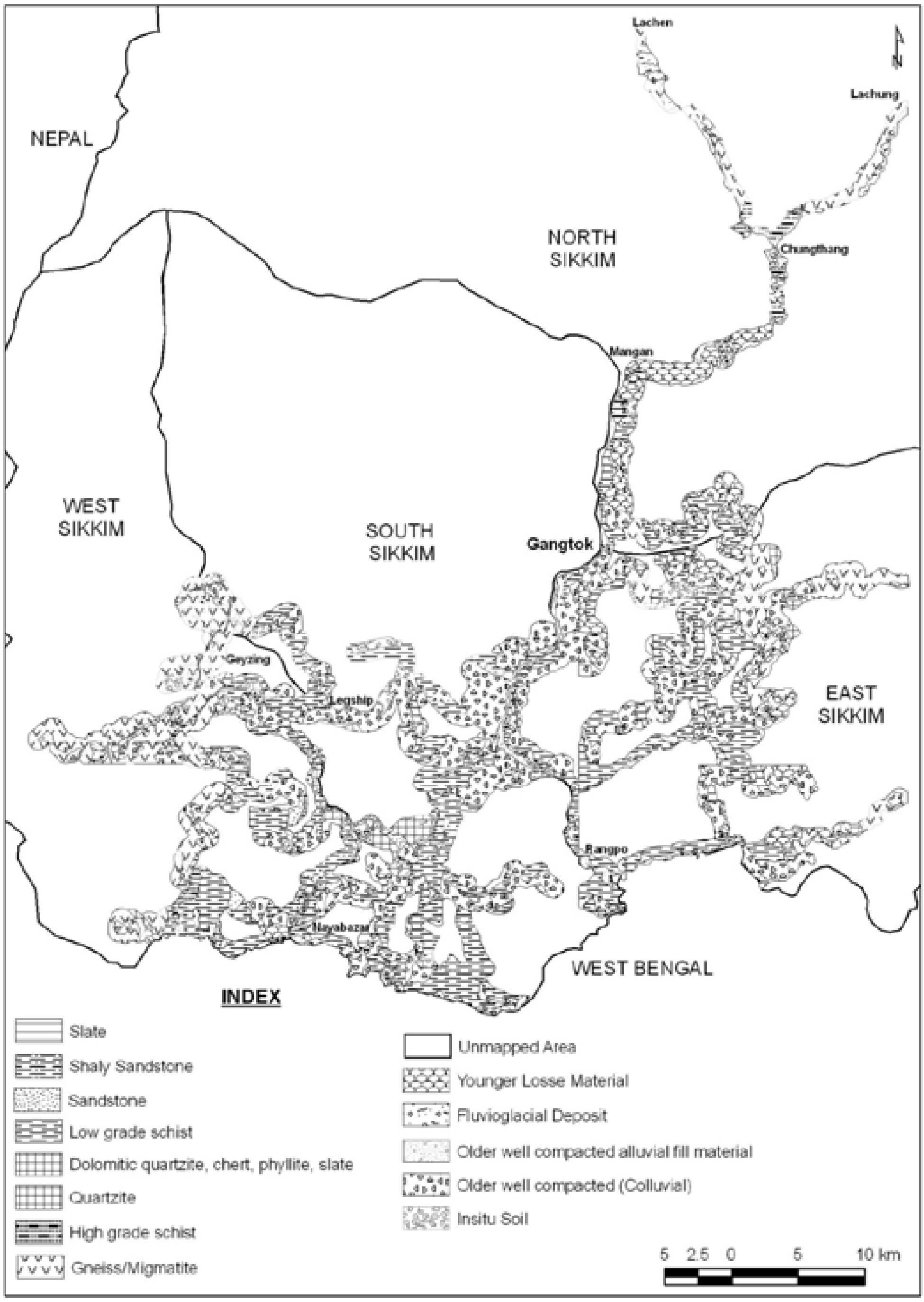


**PLATE- III: SLOPE MORPHOMETRY MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM**

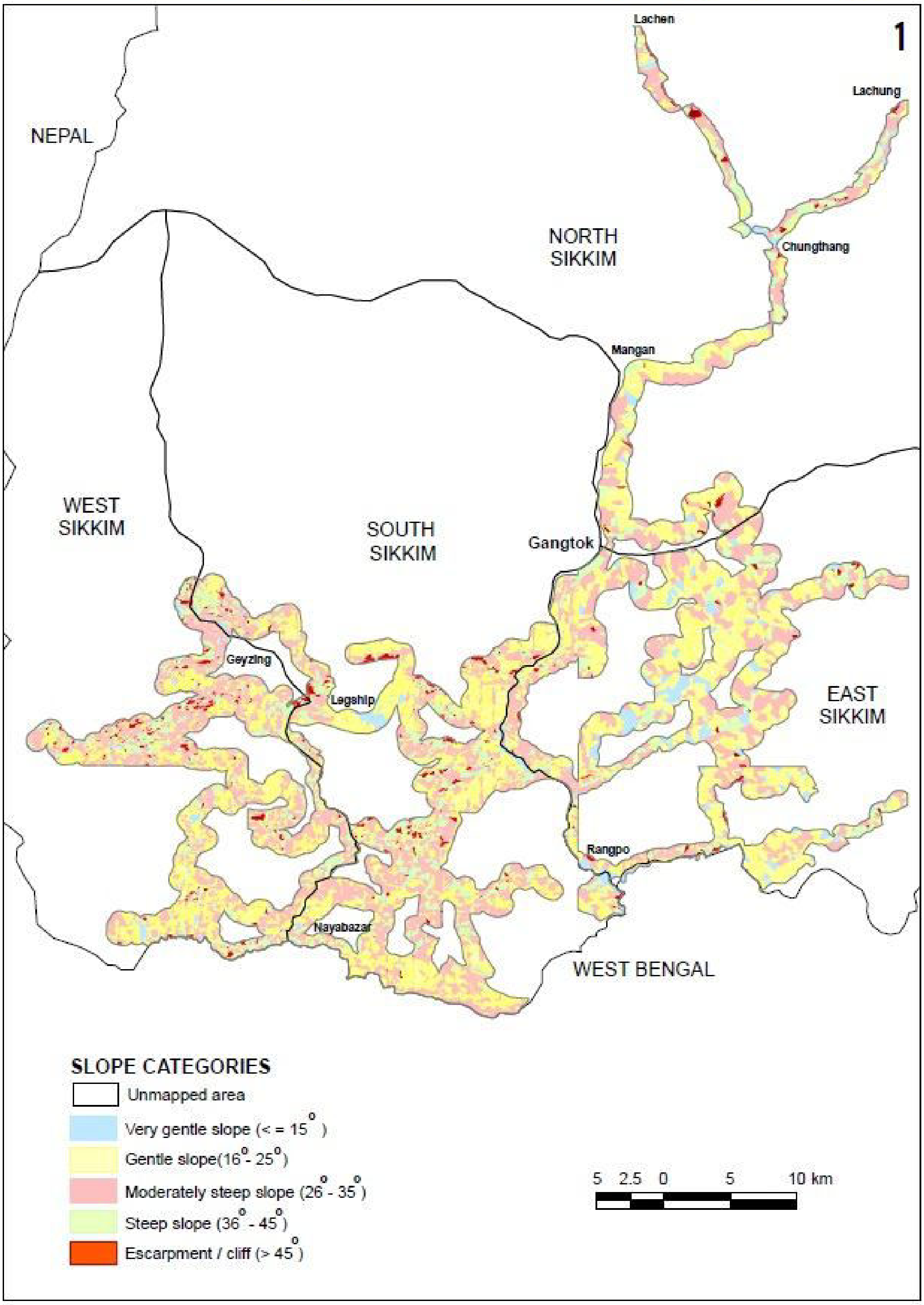


PLATE- IV: RELATIVE RELIEF MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM

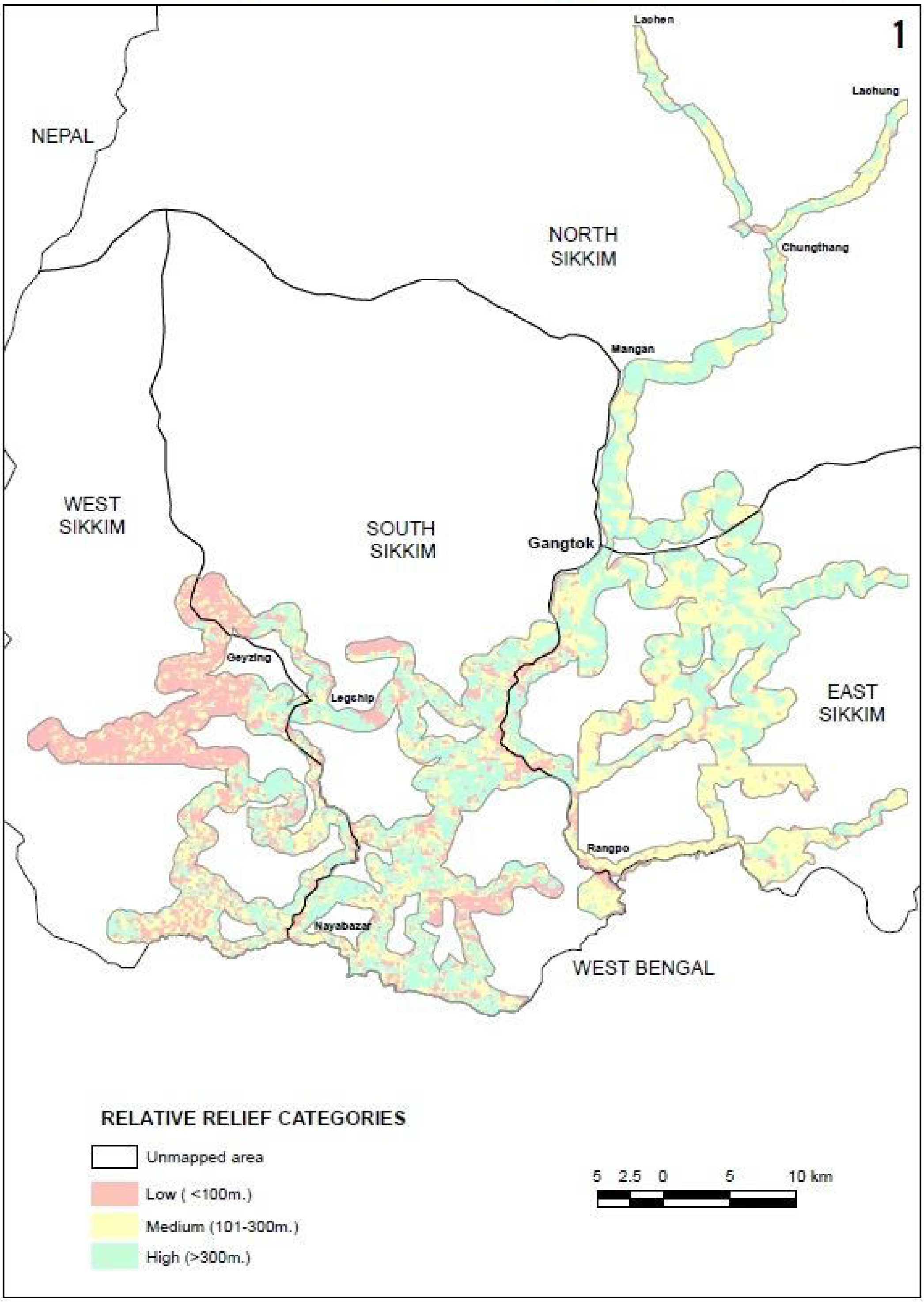


**PLATE- V: OVERBURDEN THICKNESS MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM**

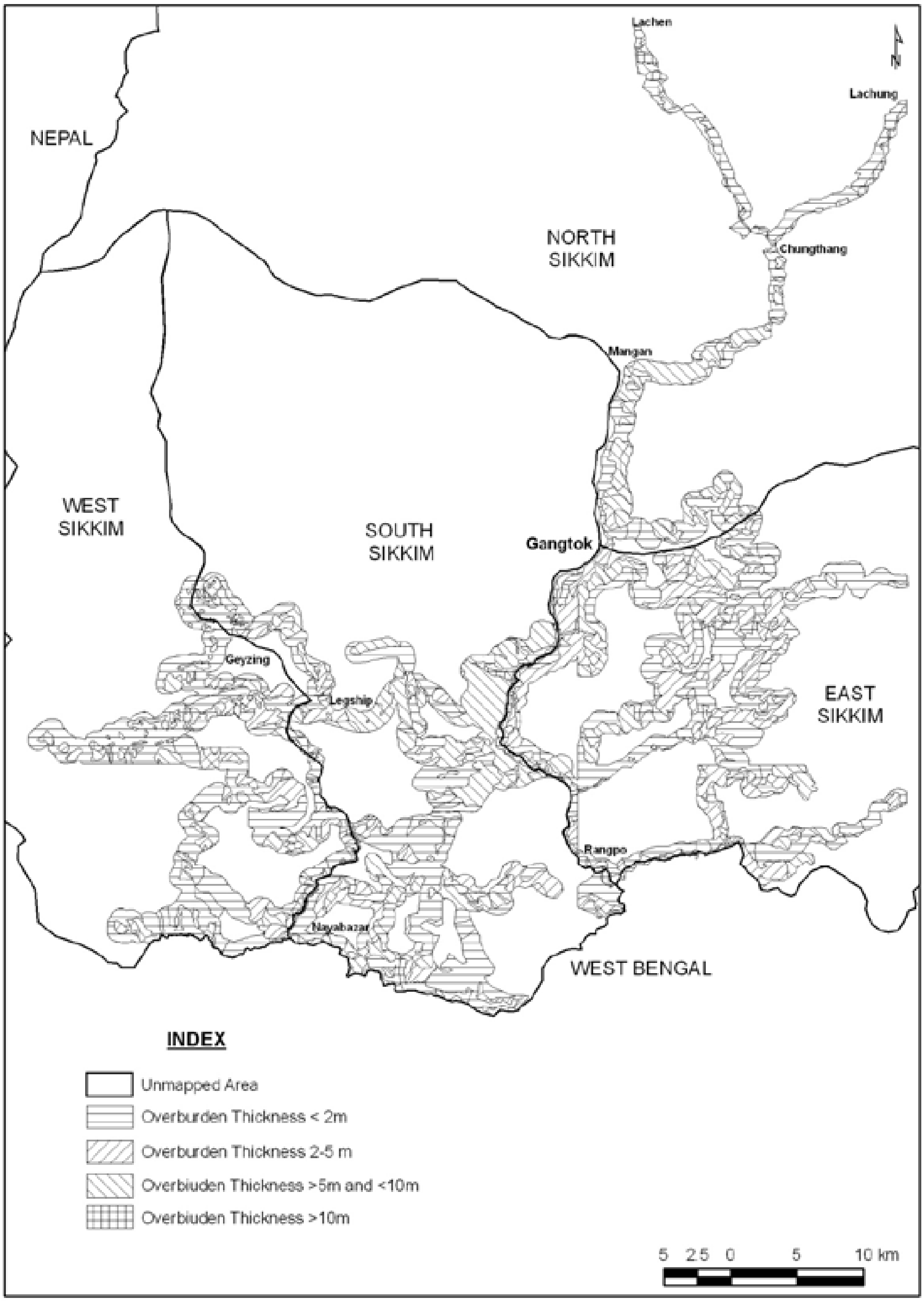


**PLATE- VI: LANDUSE- LANDCOVER MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM**

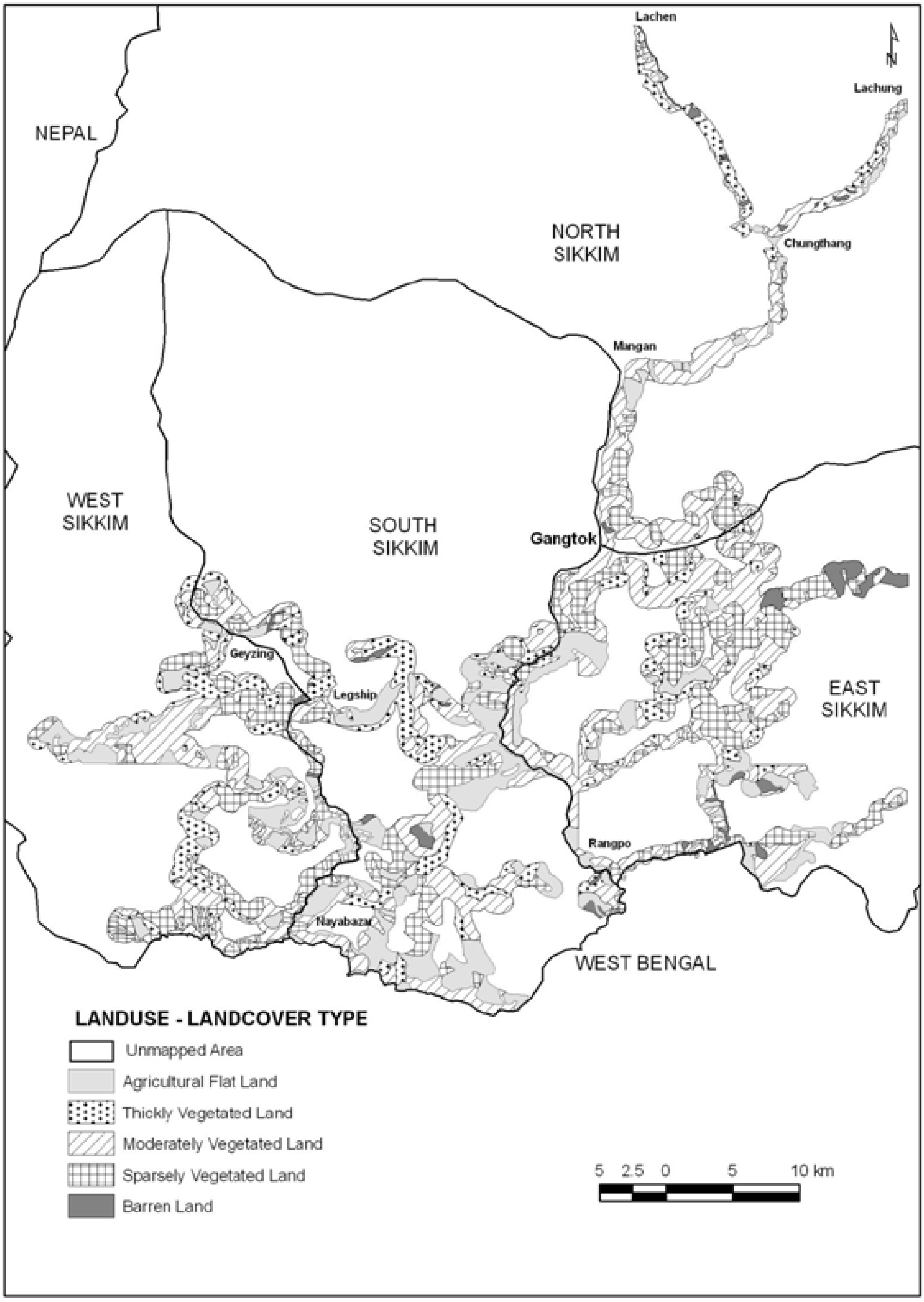


**PLATE- VII : HYDRO-GEOLOGICAL MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM**

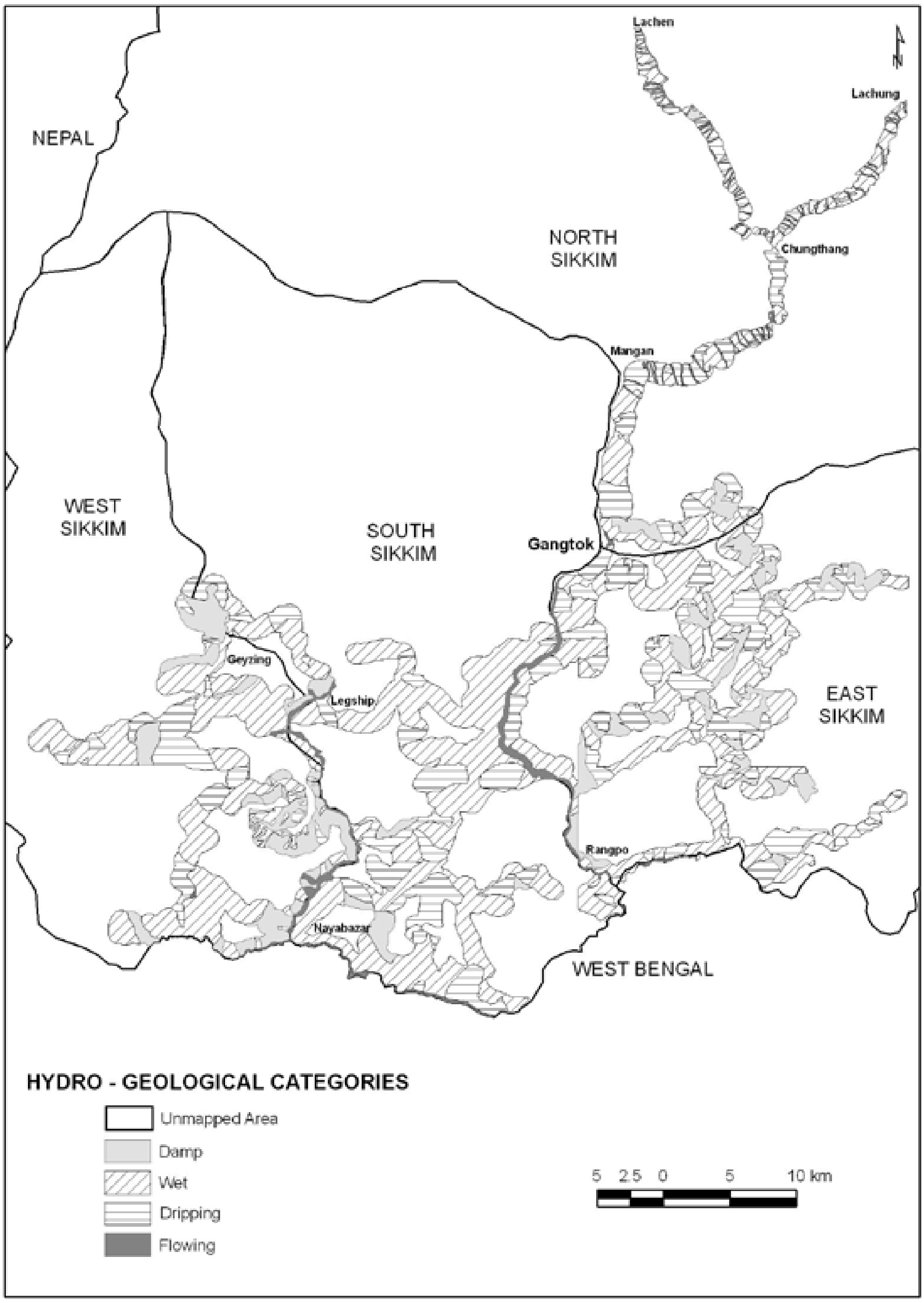
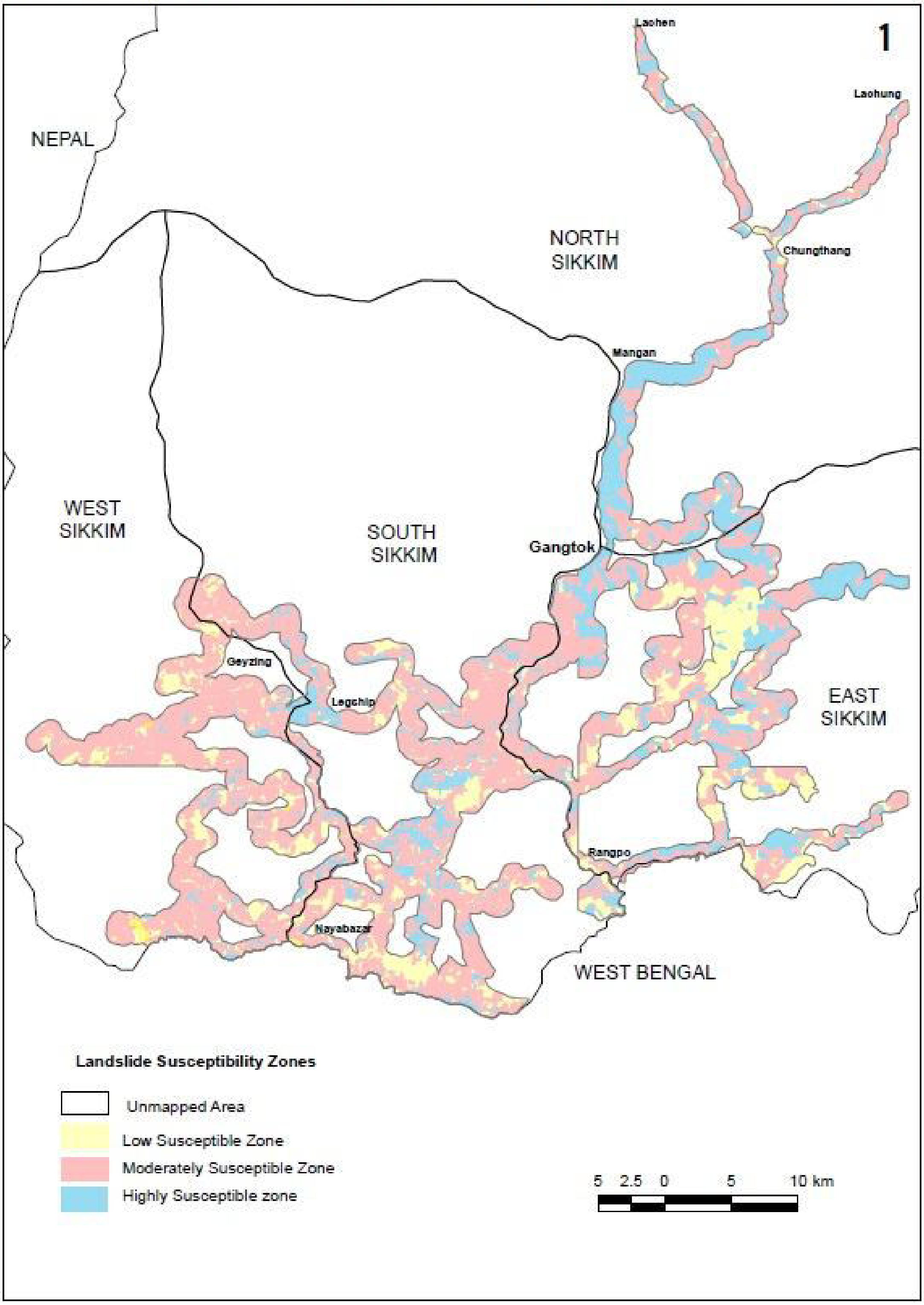


PLATE- VIII: LANDSLIDE SUSCEPTIBILTY MAP ALONG THE MAJOR ROAD CORRIDORS OF SIKKIM



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