International Journal of Research in Social Sciences
Vol. 8 Issue 6, June 2018,
ISSN: 2249-2496 Impact Factor: 7.081
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

LANDSLIDE RISK ASSESSMENT IN THE REGION ALONG NH 10, SIKKIM

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Keywords:
Landslide;
Susceptibility;
Physical Exposure;
Risk;
AHP.

Abstract

Landslides are a combined result of weak geology and geomorphology and human destruction with the development activities only for human ease. Landslide is one of the most devastating natural hazards in all the Himalayan states specially Sikkim. A case study was carried out in a region along NH 10. The people in the area are the most affected as their only means of economy and communications are disrupted and totally destroyed by this malice and atleast 100 crore was lost in the last 5 years. The study was focused on landslide monitoring, landslide susceptibility mapping and landslide risk mapping. The method used in this study was AHP (analytical hierarchical process) and quantitative raster maps were integrated to produce landslides susceptibility map and risk map and for this geospatial techniques were used.

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1. Introduction

Slope destabilisation or landslide or landslip occurs in most of the slopes once, because of causal factors of the particular area, triggered even more by earthquakes and extreme rainfall (Van Westen, 1993). Although it is a natural process, but gets accelerated due to anthropogenic controls such as road construction and mining operations which have quickened the speed of mass wasting specially when done without attention to scientific engineering and environmental aspects. To keep the roads operational year round, the situation gets worst when the builders resort to rolling the accumulated landslide debris down-slope, which triggers new landslides not only leading to deforestation, but also reducing productivity from agricultural terraces and affects water availability along with overall quality of life. Moreover, the single highway connecting the whole of Sikkim, is most important difficulty faced by people in the state, gets closed in many areas due to landslides causing stop to local livelihood.

Study Area

The study area of landslide hazard is a part of Sikkim comprising the NH 10 highway servicing North, South and East Sikkim. The capital of Sikkim, Gangtok and secondary towns Pakyong, Ranipool, Singtam, Mangan, and Chungthang falls in this route. The state elevation varies from 300 m to 8000 m from the m.s.l. and is primarily a mountainous state with a climate varying from tropical to alpine.

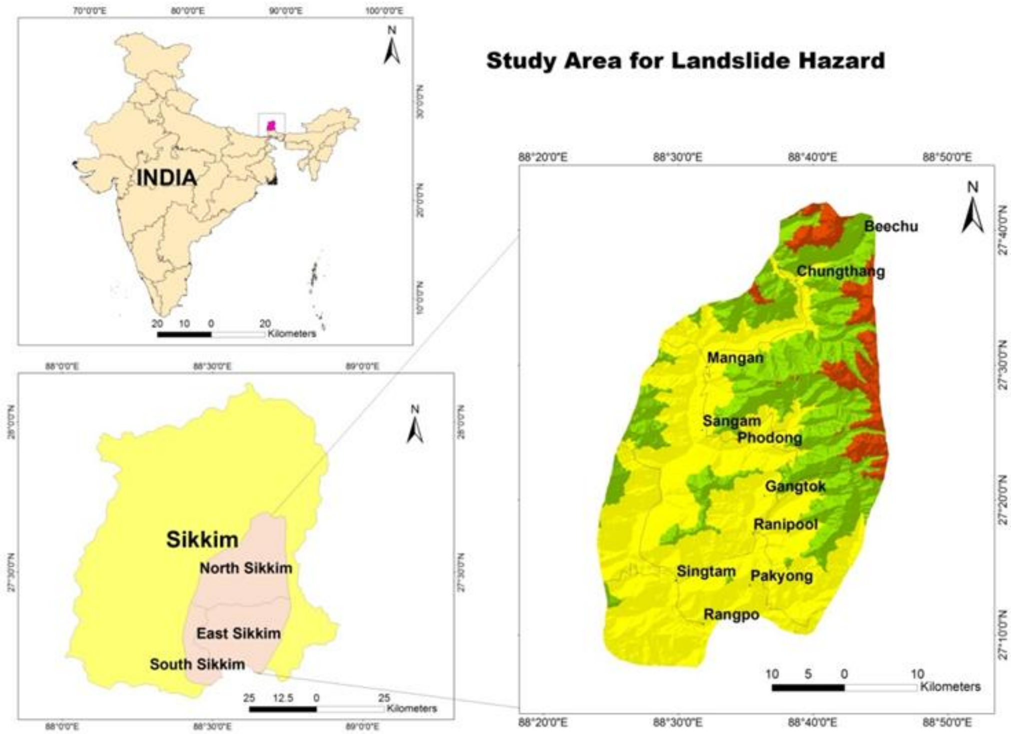


Fig 1 Study Area

Source: Created by Author

The magnitude, intensity and frequency of Himalayan landslides differ from north to south and east to west due to climatic dissimilarities and abnormalities, seismicity and neo-tectonism, where eastern Himalaya which includes Sikkim is prone to natural hazards, particularly landslides and earthquakes. In Daling Group of rocks, Gorubathan formation is most prone to landslides, due to its mineral composition and shear distortion as an outcome of repetitive loading and unloading during orogenesis, and subsequent high rate of weathering, than that of semi homogeneous quaternary deposits, gneisses and schists of the Higher Himalaya.

From field survey it was found that the major causes of landslides along NH 10 were high ground water table, severely jointed structure, similar geological bedding and geomorphological dip and the last but not the least is the continuous river toe cutting of the slopes. High groundwater table is traced due to presence of numerous springs due to which the surface area is always saturated and more especially in rainy reasons causing pore water pressure causing landslip. The presence of innumerable set of joints in three different directions, in the study area gives it a blocky appearance and the material easily slides and breaks under the impact of local and major faults and lineaments.

Sikkim faces mass wasting generally after continued exposure to monsoon rains, and also during or soon after cloudbursts or when precipitation intensity exceeds 135-145 mm in 24 hours.
The presence of high level of fluid may undermine the slope through other processes given as follows:

- Past events causing fluidization of debris leading to its flow.
- In heavy silted materials, shallow failures occur because of loss of pull forces after deforestation.
- Snowmelt in cold mountainous areas gives rise to very new landslides when rapid temperature acceleration leads to melt-water infiltration and sometimes into impermeable layers leading to excessive pore water pressure and finally landslides.
- Rapid alterations in groundwater level along a slope also triggers landslides and this is when the slope is near to a water body when groundwater cannot dissipate fast enough, resulting in a temporary high water table subjecting the slope to higher than normal shear stress.
- Seismicity triggers landslides as the earthquake waves passes through rock and soil generating a complex set of accelerations which changes the gravitational load on the slope due to which seismic landslides are more widespread and sudden.
- Increasing landslides in Sikkim since 1995 is attributed to anthropogenic activities which not only triggers, but also gives way to new slides. The prime human triggers are excavation of a slope at its toe, drawdown, road cut, and construction of hydroelectricity projects.

Objectives

- To analyse temporal change in size and extent of landslide.
- To make a landslide hazard zonation.
- To make risk map to analyse the socio-economic losses of the state.

Literature review

Immense importance have been given to landslide research in India from 1994 with the help of a report published by Ministry of Agriculture, India, in international conference on the IDNDR, Japan (Sekhar, 2006). Rao (1989) confirmed that there were five major areas in India which were hazard prone to landslides namely,

- Western Himalayas (Himachal Pradesh, Uttarakhand, Jammu Kashmir and Uttar Pradesh)
- **Eastern & North Eastern Himalayas (Sikkim,Arunachal Pradesh and West Bengal)**
- Naga – Arakkan Mountain Belt
- Meghalaya in the NE India and Plateau Margins in the Peninsular India
- Western Ghats Region.

Although there were considerable number of works that were done in the Himalayan region, but only after 1994 most of them concentrated in construction of landslide hazard zonation map and landslide inventory mapping by various geospatial techniques. But, until now there were only few researches which were carried out in India which used multivariate statistical approach for landslide susceptibility assessment (Mathew et al., 2007; Saha et al., 2013).

Landslide hazard zonation was questioned by many scholars in recent decades and as a result to construct a landslide hazard zonation map various methods such as Analytic Hierarchy Process (AHP), fuzzy logic and statistic methods was utilized. Ever since 1970s, many experts have attempted to evaluate landslide hazards and prepared hazard zonation maps representing the spatial distribution of landslides by applying many different Rs and GIS based approaches and thereafter, various disaster models were proposed to produce Landslide hazard zonation wherein, one of them was AHP by Saaty (Saaty, 1980), (Barredo et al., 2000), (Komac, 2006) and (Yalcin, 2008). Complete summaries of the use of GIS for landslide hazard zonation was found in Van Westen (1994), Carrara et al. (1995), Dai et al. (2001), Cevik and Topal (2003), Ayalew and Yamagishi (2005).

Landslide risk mapping not only takes into consideration the exposure and vulnerability but it also takes in susceptibility/ hazard of the area and is an important component for total hazard vulnerability (Cruden and Fell 1997; Guzzetti 2000; Dai et al.,Jelinek 2007).

2. Research Method

Data Source

Data was taken from Sentinel 2 MSS data of January 2017 with a spatial resolution of 10 m in visible spectrum, and was validated from google earth, for landslide inventory mapping, whereas, for the temporal change analysis two more year of data was taken namely, October 1990 Landsat 5 TM and October 2000 Landsat 7 with SLC on. ASTER DEM (30m resolution), 1974 toposheet, LISS III March 2014, Sentinel 2 MSS 2017, Geological Survey of India map, BHUVAN thematic maps and ENVIS database was used for Susceptibility mapping. Finally, for exposure and risk zonation map the population numerical, economic data and cost analysis data was taken from Census 2011 and DCH Sikkim, 2011, ENVIS database, Human Development Report 2014-2015 and ACC Cement house construction cost calculator respectively (table 1).

Table 1 Database

Layers	Sources
Landslide Inventory	
Landslide Inventory Map	LISS III (2005), Landsat 7 (SLC on)(2011), Sentinal 2 MSS (2017) and ancillary data
Susceptibility Mapping	
Slope	Aster DEM (30 m spatial resolution)
Aspect	
Curvature	
Drainage Network & Density	
Contour	
Main River Drainage Line	Toposheet (1974) and Aster DEM (30 m)
NDVI	LISS III image (2 March 2014) (23.5 m Spatial Resolution)
LULC	Sentinel 2 MSS Data (January 2017) (10 m Spatial Resolution)
Geology	Geological Survey of India (1:500000)
Geomorphology	LISS III and BHUVAN (23.5 m and 5.8 m Spatial Resolution)
Soil Map	ENVIS
Probabilistic Risk mapping for Socio-economic Impact	
Road	Toposheet (1974) and Ancillary data
Population Density	Census of India, 2011
Infrastructure Map	LULC, road map, Toposheet, Census of India
Economy Data	Census of India, 2011 and Ancillary data and ACC Agency, Human Resource Development of Sikkim (2014)

Source: Created by author

Methodology

Landslide susceptibility mapping was done using ten layers were used, which were ranked and their weighted maps were made with the heuristic method of AHP (Analytical Hierarchical Process) and were converted to raster before integrating them according to their AHP ranks. All the sub elements of the ten primary elements were classified into four ranks. The following steps were used in AHP method:

1. Pair-wise comparison matrix;

2. Synthesizing the pair-wise comparison matrix;
3. Calculating the priority vector;
4. Calculating the consistency ratio; CI = λmax - n / n-1.The consistency ratio (CR) is calculated as: CR=CI/RI
5. Calculating the λ max;
6. Calculating the consistency index, CI;
7. Selecting appropriate value of the random consistency ratio

Next, before the construction of risk map, an exposure map was created using ten layers of population elements (Shown in fig. 5) integrating quantitatively. The exposure map was then integrated multiplicatively with susceptibility map, giving the physical exposure map, which is the actual exposure in accordance to hazard zonation. Thereafter, the physical exposure map was integrated multiplicatively with the HDI and GDP maps, resulting in the risk map showing the rate and areas of economic loss in the area. The model used in the research was that adapted from Phillipines multihazard risk model.

3. Results and Analysis

Temporal Changes in Landslide

Landslide temporal change analysis has been done by monitoring landslides of 17 years (January 2005, November 2011, and January 2017). 2011 was noteworthy due to a major earthquake that activated many old and new landslides. Landslides significantly increased from 2005 to 2011 (epicentre Sikkim-Nepal border), this triggered not only active and dormant landslides but also there was development of many new slides owing to the tremendously dense faulted, jointed network of lineaments and frequently disturbed geology of the area due to fore and post shocks of seismic activity. Anthropogenic actions cannot be undervalued in the form of unscientific development which has started to take toll of the previously destabilized slopes. The landslide inventory map of 2017 shows a sudden intensification in the rate of landslide occurrence because of rapid unempirical development in the region, rapid population growth through migration. Development of hydroelectricity projects (HEP) (Teesta HEP Phase IV) is to be blamed the most (according to the Primary survey by author). North and South Sikkim districts have been affected the most.

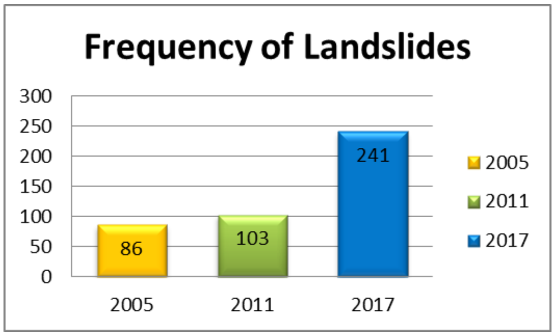
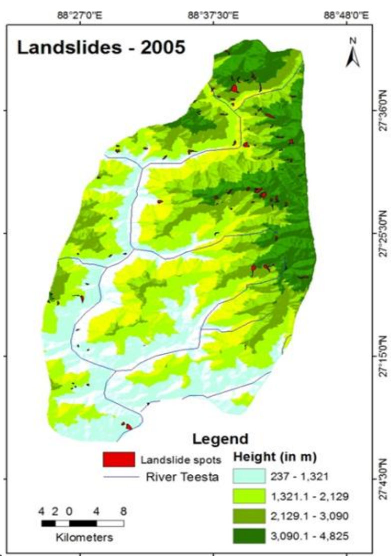
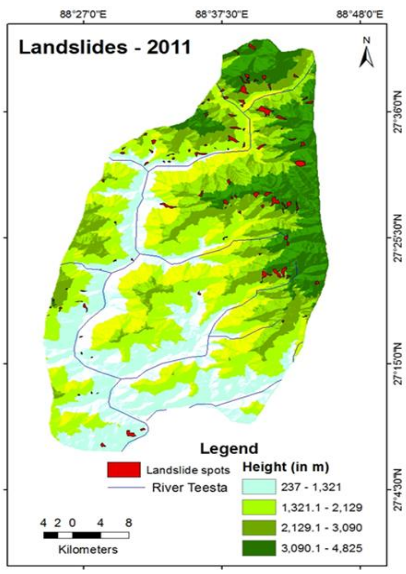


Fig 2 Rate of Increase in Landslides in Sikkim

Source: Same as fig.





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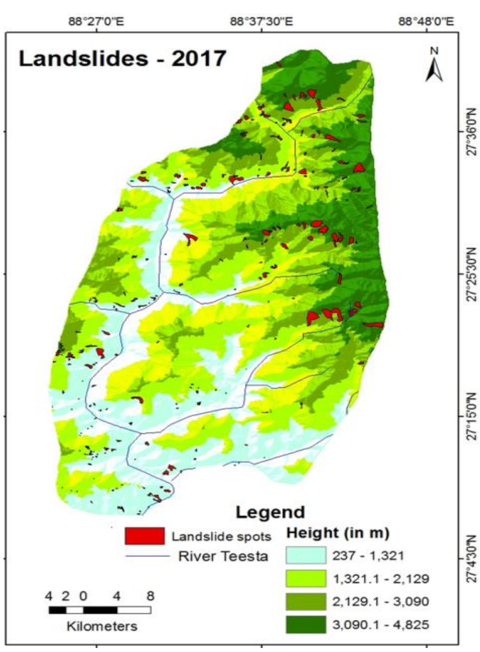


Fig 3 Temoral Change in landslides in region around NH 10

Source: Same as fig 1

Landslide Susceptibility Zones

To construct the hazard zonation map, ten layers were used and they were ranked and their weighted maps were made with the heuristic method (based on mathematics and psychology) of AHP by Satty (Analytical Hierarchical Process). The process of ranking the sub elements of the primary factors for influencing are done by the help of previous knowledge and literature. After classification of all the sub components of all the layers they are reclassified and are transformed to raster maps which were then integrated in the raster calculator. Each landslide spots were placed or overlaid on the landslide susceptibility map. It was found that the landslide locations fitted well in the high and very high susceptible regions. The region was sub-divided into five hazard zones - very high, high, moderate, low and very low. The western and south western regions of the area were most susceptible to landslides, followed by northern, southern reaches whereas, parts of central region and almost the entire eastern part is comparatively less hazardous. According to area calculation, 28.44 percent area fell under very high risk, moderate 31.61 percent and 26.25 percent low. The landslide hazard zonation map (fig.4) was then underlain with the existing landslide inventory map of 2017 (fig 3) which then had been validated with ROC curve (fig 6) and the results were almost accurate.

Table 2 AHP Table for Hazard Zonation

Class	Slope	Geology	Curvature	Aspect	Drainage	Soil	Lineament	Geomorphology	NDVI	LULC	P.V	Rank
slope	1	2	3	4	4	5	7	6	6	8	0.8000	1
geology	1/2	1	2	3	3	4	6	6	7	9	0.9000	2
curvature	1/3	1/2	1	2	3	6	5	6	7	9	0.9000	3
aspect	1/4	1/3	1/2	1	2	3	5	6	7	7	0.7000	4
drainage	1/4	1/3	1/3	1/2	1	3	2	3	4	5	0.5000	5
soil	1/5	1/4	1/6	1/3	1/3	1	4	3	2	4	0.4000	6
Lineamen	1/5	1/6	1/5	1/5	1/2	1/4	1	3	4	8	0.8000	7
geomorph	1/7	1/6	1/6	1/6	1/3	1/3	1/3	1	2	3	0.3000	8
NDVI	1/6	1/7	1/7	1/7	1/4	1/2	1/4	1/2	1	2	0.2000	9
LULC	1/8	1/9	1/9	1/7	1/5	1/4	1/8	1/3	1/2	1	0.1000	10
Total											1	

Source: Same as fig 1

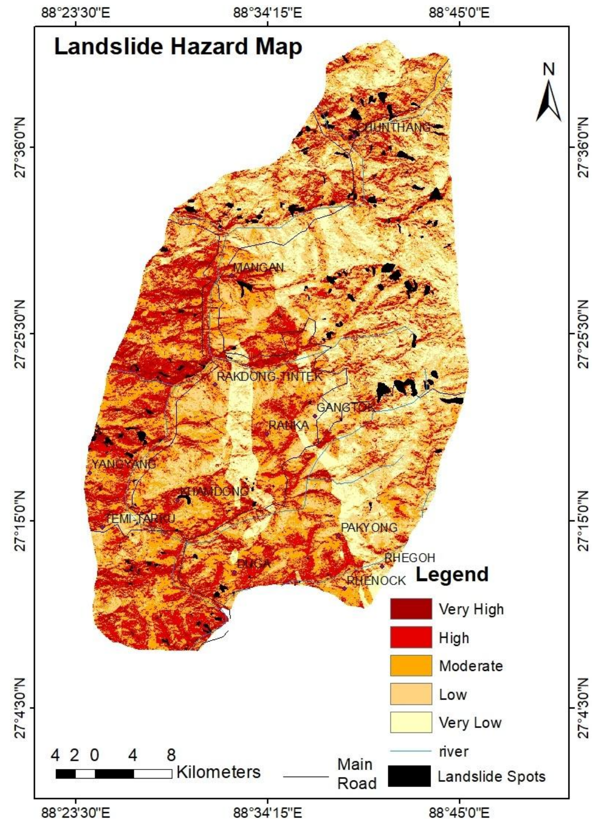
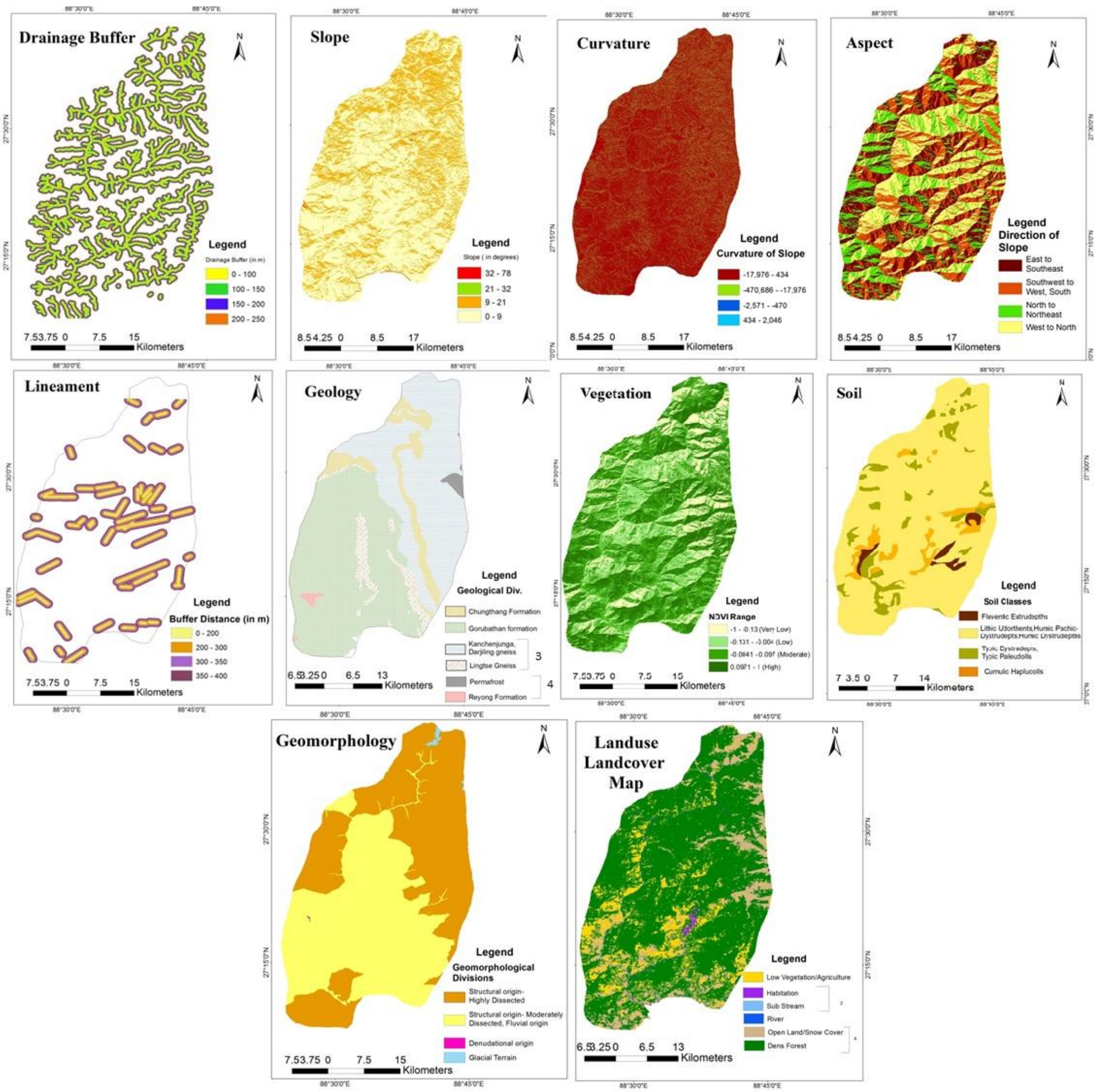

Landslide Hazard Map
88°23'30"E
88°34'15"E
88°45'0"E
27°36'0"N
27°25'30"N
27°15'0"N
27°4'30"N
N
CHUNTHANG
MANGAN
RAKDONG-TINTEK
GANGTOK
RANKA
YANGYANG
KHAMDONG
TEMI-TARKU
PAKYONG
RHEGOH
DUGA
RHENOCK
Legend
Very High
High
Moderate
Low
Very Low
river
Landslide Spots
Main Road
4 2 0 4 8
Kilometers

Fig 4 Landslide susceptibility



map

Fig 5 Landslide Factors taken for AHP

Table 2 Rank of stream distance (in m) according to AHP analysis

Cumulative Percentage of Landslide	Percent of Landslide Pixels	Percent of Class area	Cumulative percent of area of class
65.2	65.2	28.44	28.44
95.5	30.3	31.61	60.05
99.5	4.5	26.25	86.3
100	0	13.7	100

Source: Figure 3

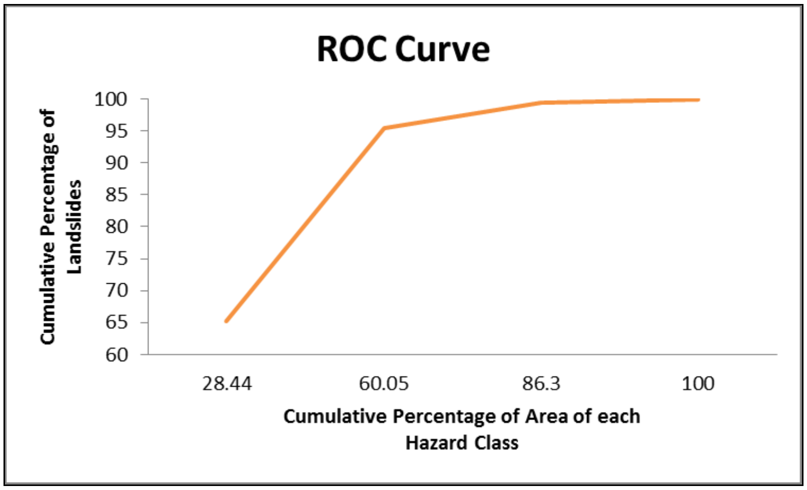


Fig.6 Landslide Susceptibility pixel count

Source: Table 2

Landslide exposure and physical exposure map

Landslide exposure map is the next step for making the landslide risk map according to the model used by author. Assessment of the number and location of hazard exposed people and property is a indispensible step in proper landslide risk management and emergency planning, as also confirmed by Promper and Glade (2016) in multilayer exposure map of Austria. In this study population and property exposed to landslide risk were analysed using 2011 census data. The exposure zones had been created using the thematic layers of population density, number of household, housing structure (permanent, semi-permanent, temporary), poverty and infrastructure,road network and agriculture,.

The physical exposure map was constructed by multiplicatively integrating the raster maps of landslide hazard zonation and exposure zones. The map shows the actually exposed population and property in accordance to the hazard map, and showed that the most vulnerable areas were that of central, eastern and south eastern regions of East District besides a large portion of North District and South District was the least (fig 7).

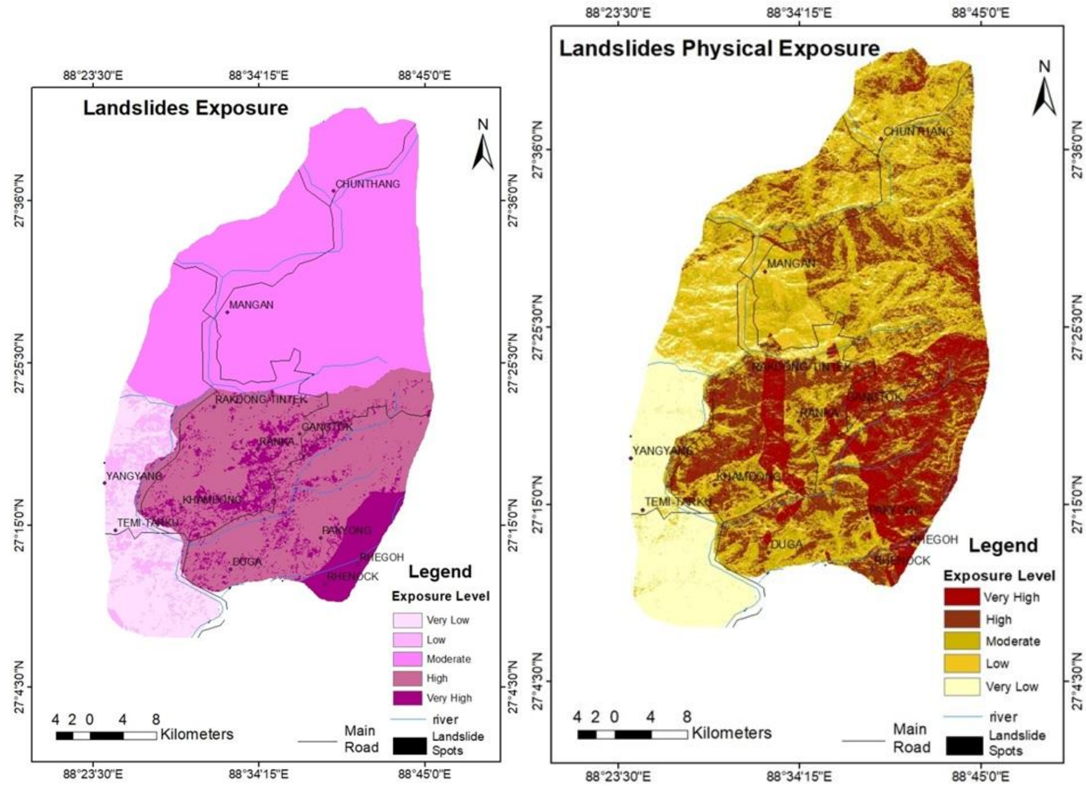


Fig 7 Exposure and physical exposure map

Landslide risk zonation

Risk map shows the impact of disasters on socio-economic condition of the people of the region as it calculates the actual areas of danger to human, economic, infrastructural and environmental sectors of a region. It resulted by multiplying the raster maps of HDI and MPI of each district with the physical exposure map. The HDI (human development index) is a compound index of longevity of human resource and economy and can be taken for loss calculation and MPI (multidisciplinary poverty index) was taken as it shows the coping capacity of people post disaster because poor are the most affected population after.

The highest risk zone is the South Sikkim areas followed by North and least in areas of East Sikkimt. East Sikkim, which had the highest population density (2011), has the lowest risk due to moderate hazard expectation and better coping capacity of the people due to higher HDI and lower MPI. South District has a greater risk because of high hazard, very low HDI and higher MPI leading to people's lower coping capacity (fig 8).

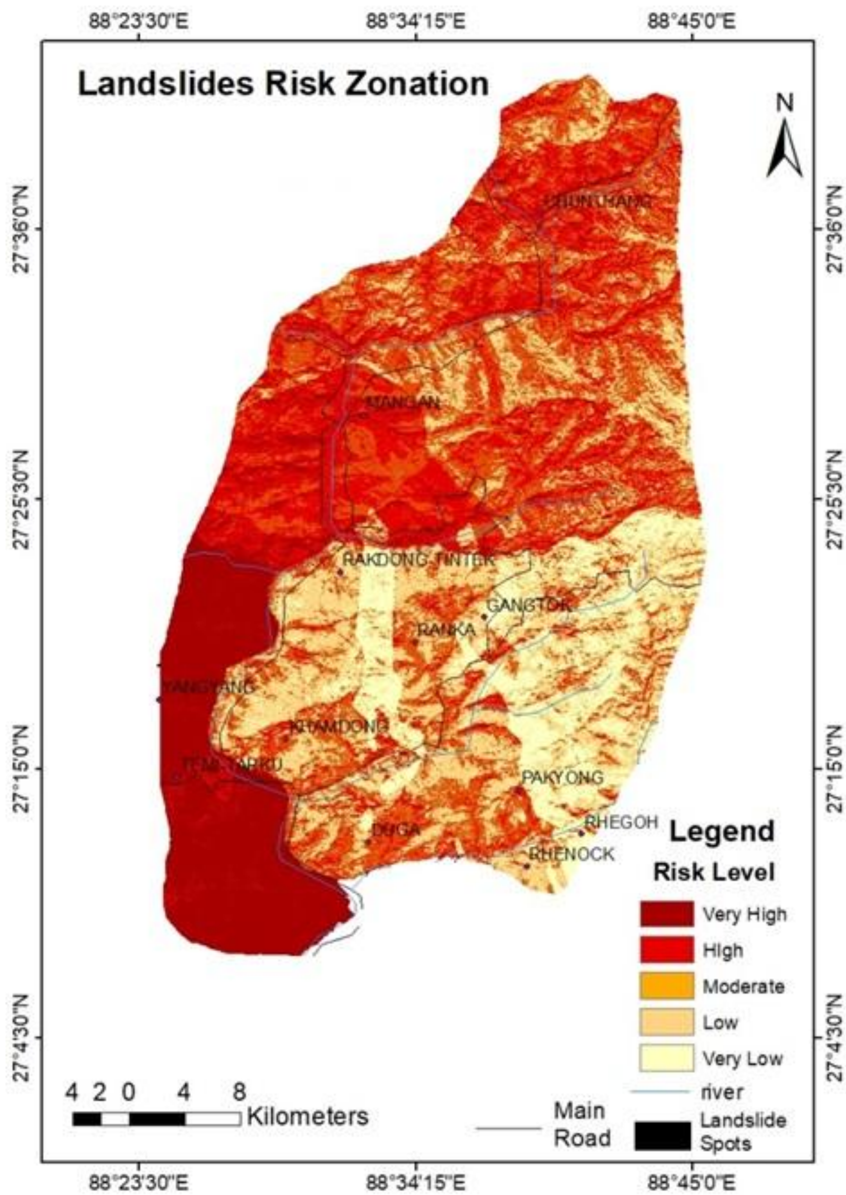


Fig 8 Risk Zoantion Map

4. Conclusion

North Sikkim is most affected by landslides with old, perennial and dangerous landslides recur annually followed by South Sikkim and East Sikkim with increasing human interference. Landslides increased from 2005 (86) to 2011(103) as an outcome of the massive 2011 earthquake and 2017 (241) shows a steep rise in the number of landslides because of rapid unscientific development in the region, rapid population growth through migration. The western, but has less landslides because of dense vegetation, and south western regions of the area are the most susceptible to landslide, followed by northern, southern and parts of central region and almost the entire eastern part is comparatively less hazardous. It was found that 28.44 percent area fell under very high risk, moderate 31.61 percent and 26.25 percent low. The most exposed areas are of central, eastern and south eastern regions of East District besides a large portion of North District and South District is the least in accordance to the landslide exposure and physical exposure zones. The highest risk zone in Sikkim is the South District followed by North and lowest in East District. Tourism revenue from the monsoon months (June to September) was lowest because of increasing landslides and rising river water level. Increasing human interventions in the form of HEP trigger many old and give birth to new landslides has been proven scientifically and substantiated by field survey as the construction of HEPs needs deforestation, slope cutting, river blocking, etc. The government has initiated various programs to deter the landslides from creating further havoc, but as of now only a few could be controlled. The total average loss of the state due to landslide is approximately 100 crores.

Apart from the activities the state government has done to improve the situation of the landslides in Sikkim and clearing its mess aftermath a slide, but there are few more suggestive measures namely, not permitting the building of new houses in the vicinity of a big landlide or may be building it 500 m away from the area, construction of an alternative route rather than depending on the single highway connecting all of Sikkim and lastly before a construction project be sanctioned the landslide hazard zonation should be considered.

Acknowledgements

This article is a part of my Ph.D research in Department of Geography, Jamia Millia Islamia, New Delhi. I am grateful to Prof. Mary Tahir and Department of Geography, Jamia Millia Islamia for providing me means and facilities for carrying out my investigation work.

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