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Dissertation Report On

Inventory of Landslides and Susceptibility Mapping Using Analytical Hierarchy Process (AHP), Sikkim, India.

Carried out at

NORTH EASTERN SPACE APPLICATION CENTRE

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Shillong,
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ABSTRACT

The aim the study is to generate temporal inventory map for entire Sikkim using visual interpretation method from 1063 to 2018, the landslide inventory used to identify and map landslide susceptible areas using AHP method.

Around 1895 landslides have occurred from last 58 years, most of the landslides are repeating or continuing every year, and out of 1898 landslides 19 landslides are still active from 1963 to 2018 which are mainly concentrated in the southern and Western part of Sikkim. Most of the landslides are present in the South and central part of the state where the human developments or involvements are more. In northern part of study area landslides are mainly affected by melting snow and erosion. Most of landslides are occur mainly in monsoon season, due to topographical and geological condition.

For overlay analysis Weighted overlay analysis tool was used to combine all causative parameters. The study explains that susceptible areas are spread unevenly where the 14% (101 sq.km) of the total geographical area is under highly susceptible areas. This very high susceptible areas are mostly covered the areas of south and central parts of south Sikkim, next 39% (284sq.km) area is under highly susceptible areas mainly concentrated in north and southern parts, 33% (239sq.km) under moderate susceptible areas.

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1. Introduction:

1.1 Landslide:

Landslides is one of the natural hazard which can be take place on both land and water, it is common in all over the world and mainly concentrated on the hilly areas. Landslide caused by various phenomena that depends on earthquake, intensity of rainfall, rate of melting snow and human involvements.

Himalayas are shelter for millions of population which spread over different nations. In India, around 12.6% of its domain is inclined to different degrees of landslide risk (**GSI, 2009**). Out of total area, 0.18 million square kilometres come within the North East part of Himalayas region of seven sister's states. Landslide are common natural phenomena in India mostly in the monsoon seasons, Landslides are delicate to rock quality, slope geometry, and topographical and natural conditions and to their disturbances.

Economic loss due to landslides in this particular region is about 1 billion US dollar per year and it constitute 30% of world's landslides-related damages, it also cause to human lives.

Heavy rainfall, weak geology and earthquakes makes the Sikkim prone to natural hazards. Actually Sikkim is a landslides prone region due its land and climatic conditions. It primarily influenced Vegetation cover since most of the consider region is beneath hilly region with exceedingly covered vegetation, Apart from human lives it moreover devastate road and building infrastructure.

Remote sensing and GIS are the major instruments and methods which gives precise information as well as results for Inventory of Landslides mapping.

The landslide inventory map depicts the spatial distribution of a single landslide event a single trigger or numerous landslide events over time authentic.

1.2 Classification of Landslides:

The common sorts of landslides are portrayed underneath. These definitions are based primarily on the work of **Cruden and Varnes** (2016).

Fall:

The separation of soil or shake, or both, from a steep slope along a surface on which small or no shear uprooting has happened example falling, bouncing, or rolling.

Flow:

Water-saturated with fine-grained fabric that liquefies and after that runs out taking off a basin-shaped depression on the sloping land surface are called soil flows.

Creep:

Moderate, consistent down slope movement of soil fabric, frequently indicated by bended tree trunks, bowed wall or holding dividers, tilted shafts or fences.

Debris flow:

It is Quick development of free soils, rocks, and natural matter combine with entrained air and water to make slurry that stream down slope, more often than not associated with soak gullies. “Debris landslide” An assortment of exceptionally rapid to greatly fast debris stream.

Lahar:

Debris stream or mudflow that start on the slope of a volcano, usually triggered by heavy precipitation disintegrating volcanic stores, sudden dissolving of snow and ice due to heat from volcanic vents, or the breakout of water from ice sheets, crater lakes, or lakes dammed by volcanic eruptions.

Mudflow:

Mass of stream damp fabric that contains at slightest 50 percent of sand, silt and clay particles.

Slides:

Sorts of mass development are included within the common term **landslide.**

The two major sorts of landslides are rotational slides and translational landslides.

Rotational Landslide:

Squares of fizzled fabric can turn as they fall flat and can at times be seen to tilt in reverse towards the incline illustration: slump.

Translational Landslide:

It is down-slope development of fabric that happens along a distinctive surface of weakness such as a blame, joint or bedding plane.

Topple Landslide:

It is a forward revolution and development of a mass of shake, soil or debris out of a slope.

This kind of incline disappointment for the most part happens

1.3 Inventory of Landslide:

A “landslide” is the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity (Cruden and Varnes, 1996).

According to (Guzzetti et al., 2000, 2012) Landslide inventory Map Mainly Shows the Location of movement that have left a discernible signs in a landslide occurred region. No particular preference for Inventory of landslides, it can be done by using various techniques and tools that is depends on purpose of inventory, quality of satellite image and cartographer.

A Landslide inventory Map recognizes positive and likely regions of existing landslides, and is the foremost fundamental necessity for a landslide risk assessment. The term landslide inventory incorporates all those exercises aimed at recognizing past landslide occasions that happened in a particular region, it is all about a classification of existing landslide.

These maps produced using different methods like historic data, field survey, interviews, and visual interpretation from aerial photographs. Inventory maps can be generated by utilizing both new techniques and traditional methods **(Guzzatti et al 2012).**

Landslide inventory mapping is the primary data or tool in any landslide susceptibility mapping analysis **(Guzzetti, et al., 2006)**. It provide high predictive power for landslide susceptibility and vulnerability analysis. These maps can be used to impressively diminished harm potential and cost-effects of future landslides.

Subsequently, it was essential to create a scientific examination technology to anticipate landslides to reduce death of human life and damage to properties. Be that as it may, it needs time and human assets to collect individual spatial data and field information to analyse landslides. Luckily, we will overcome the challenges in a field examination by utilizing farther detecting .

Landslide maps are generate in every nation from large scale **(village level inventory)** maps to small scale maps **(country level inventory)**, selection of landslide inventory scale depends on the area of interest.

2. Review of literature:

Fausto Guzzetti et al. (2012) in this paper, he explain about new techniques and tools for landslide inventory mapping using different methods and satellite data and the main aim of this study is to facilitate new technology In remote sensing to reduce time and make resource intensive.in this study inventory was done by using **conventional method**. Finally he conclude these new techniques and tools in remote sensing are providing better quality for landslide inventory mapping and also improving the quality of susceptibility and hazard type of mapping.

Michele Santangelo et al. (2014) in the present study inventory of landslide mapping done for earthquake induced landslide. **Visual interpretation** method used to identify and map landslides at 1:30000 scale from aerial photographs, field survey and high resolution satellite images, Also identified the characteristics (Size, Shape, Height, Volume etc.) of an each landslides. Analysis of this study finalized that most of the landslides are reactivated and rainfall induced landslides are more comparatively.

Himan Shahabi et al. (2017) have developed the landslide inventory mapping done by using **aerial photographs** and **AIRSAR,** data root mean square error (RMSE) method has been used to detect automatically using remote sensing data. AIRSAR data is very useful for detecting or mapping a small size landslides. Root Mean Square Error (**RMSE**) method is used to get more accurate and preciseness for inventory.

Kimaro et al. (2003) have discussed the influence of causative factor for occurrence of landslides, in this study inventory of landslide mapping generated using aerial photographs and field survey using Geographical Information System (**GIS**) during rainfall season. In this study, result showing that geomorphic factors are affected more comparatively after that soil influencing more due to more porosity.

Ghosh et al. (2011), this study highlighted about the generation of landslide inventory maps for distinctive activating events, based on the accessible data within the forms of landslide maps, pictures and files. These maps ought to depict the avalanche designs and sorts of activating events with a run of return periods, which can be utilized to examination the worldly and greatness probabilities.

M. Santangelo el al (2015) in this work they mainly present inventory of landslides with new remote sensing techniques and tools, this is all about identifying landslides or producing landslide inventory map by semi-automatic method using aerial photographs and **GIS**. Main aim of this study is to transfer information from the aerial photographs to digital imagery.

A.C. Mondini et al (2014): This study describes the preparation event-based inventory for two selected events which are affected by high rainfall intensity by **visual interpretation** method using remote sensing (high resolution satellite images) and aerial photographs. Comparative analysis was done for both event-based landslides to examine differences.

David J. Sauchyn (1978): Have prepared landslide inventory map using Landsat imageries and Landsat imageries are more useful to identify rotational type of landslides. Identification of landslides using multi-spectral images from Landsat gives less accuracy compared to band-based identification. **Band 7** (0.8-1.1μm) is very suitable to generate landslides from Landsat image. Finally the results shows that Landsat imageries are not useful for identification of small landslides.

Franny G Murillo Garcia (2014): have analysed the use of very high resolution satellite stereo**-** images (**GeoEye 1**) to recognize landslides. This study analysed that Very high resolution images are enough for detection of landslides which consume less time but the cost little for buying images from organization. According to the study 385 landslides are occurred, from that 171 landslides are old and 21 landslides are new and the density of landslides is 10.5 landslides/square kilometre.

Bushra Praveen et al (2017): This present study mainly concentrated on landslide inventory for two event pre- post landslides generated by visual interpretation using **LISS-IV** satellite image. This study shows comparative analysis for kedarnath flood pre and post landslides. According to analysis most of the landslides are detected along river course.in this study susceptibility and vulnerability mapping also done by using eight causative factors for predicting future landslides and damage to human lives.

Tolga Alkevli (2011): This study stated that preparation of landslide inventory using stereoscopic images by visual interpretation is the best approach. The stereoscopic satellite image advanced space borne thermal emission and reflection and radiometer (**ASTER**) for landslide inventory. These ASTER satellite images are very useful for small and medium scale inventory provide accurate information.

Biswajeet Pradhan et al 2015: In this study very high resolution images were used which are used robust data fusion techniques to combine high resolution lesser data of (**LIDAR**) and high resolution **Quick Bird** satellite images for landslides inventory, in study Object-based oriented method was used to identify landslides location from various land use covers. Aspect and slope factors derived from LIDAR which played major role in identifying direction and movement of landslides. The results saying that method which is used in this study is easy to implement but only applicable for tropical countries.

M.S. Rawat et al. (2012): In this study landslide susceptibility mapping done by using analytical hierarchy process (**AHP**), using high resolution remote sensing data with various causative factors like geology, geomorphology, rainfall, slope, aspect, soil. **AHP** method mainly used to acquire weightage for each factor and to identify their influence with weighted sum technique. Validation for susceptibility done by performing cumulative percentage technique.

Michalis Papadakos et al (2017): In this present study landslide susceptibility mapping was done for Finikas watershed, it is more susceptible area for landslides because of high erosion from Finikas river makes slope more instable. Analytical hierarchy process **(AHP**) used to generate susceptible map for selected watershed. Geographical information system (**GIS**) producing more accurate mapping comparatively.

J.D Jimenez-Peralvarez et al (2007): This study explains the use of model builder from Arc GIS (ESRI) to generate landslide susceptibility mapping with **GIS** matrix method. Causative factors were reclassified and ranked according to their influence on landslides. Validation for landslide mapping done by cross tabulation.

Ankit Sharma et al (2014): In this paper landslide susceptibility mapping done by integrating geo-spatial technology. Here weighted overlay analysis were used to produce susceptible areas using selected causative factors. Weightage given to each reclassified factor and ranked. Finally identified the spatial distribution of susceptibility of a selected area and classified into low, moderate, high using **GIS** spatial analyst tools.

T.Y Duman et al (2006): In this Study a unique method called regression method has been used to find out susceptible area using aerial photographs and field survey. For this analysis landslide inventory was used to find out the characteristics of landslides. For regression analysis 37 variables were used and out of 37 variables 25 are influencing more those are slope, aspect, geology, soil, geomorphology and curvature etc. After validation study shows susceptible area are correct 83.5% accurate.

Mehdi Moradi et al (2012): this study demonstrated the susceptible mapping employing Analytical Hierarchy Process (**AHP**) using ArcGIS as a tool, a selected causative factors have been taken for susceptible mapping. Each factor was reclassified and separated into a smaller factors based on their influence and weightage. **ArcGIS** mainly used to produce layer maps and final susceptible.

He Chun Quan et al (2012): In this papers two methods were used for identifying susceptible areas in South Korea, those are Analytical Hierarchy Process (**AHP**) and Artificial Neural Network (**ANN**). The causative factors are slope, geomorphology, geology, slope, rainfall intensity, drainage, land use land cover, these seven factors influencing more, layers reclassified and assigned a weightage using both AHP and ANN. Finally comparative analysis were done and the results shows that Artificial Neural Network is better for analysis compared to AHP.

Jinyi Huang et al (2014): Here the attempt have been made to identify susceptible landslide areas using **frequency** analysis and **logistic regression** model, these are statistical methods. In this study nine causative parameters has been selected for susceptibility mapping with spatial relationship of landslides within that area. Finally landslide susceptibility map generated by integration of all parameters according to their weightage. Landslide susceptibility mapping validated using old landslide inventory. According to the results **logistic regression generated** (84.6%) better prediction of landslides than **frequency (67.5%)** analysis.

methods that make it easy to obtain morphological and physical information about a broad zone. In expansion, we will proceed to gather, oversee and analyse enormous spatial data databases about landslides by using the GIS **(Lee, 2003).**

3. Study Area:

Introduction:

Sikkim is located in the eastern part of Himalayas, mainly situated in lesser and greater Himalayas. Sikkim is located in younger mountain system which is high in rock folds and rock faults. Study area is about entire **Sikkim** covers an area about **7069** sq.km which covers 0.22% of India's total territory, Which is lies between 27°46' to 28°7'48" North and 88°0'5" to 88°55'25" East, the state is bounded by Bhutan country in the east, Tibetan Autonomous Region in the north, Nepal country in the west, West Bengal state in the south.

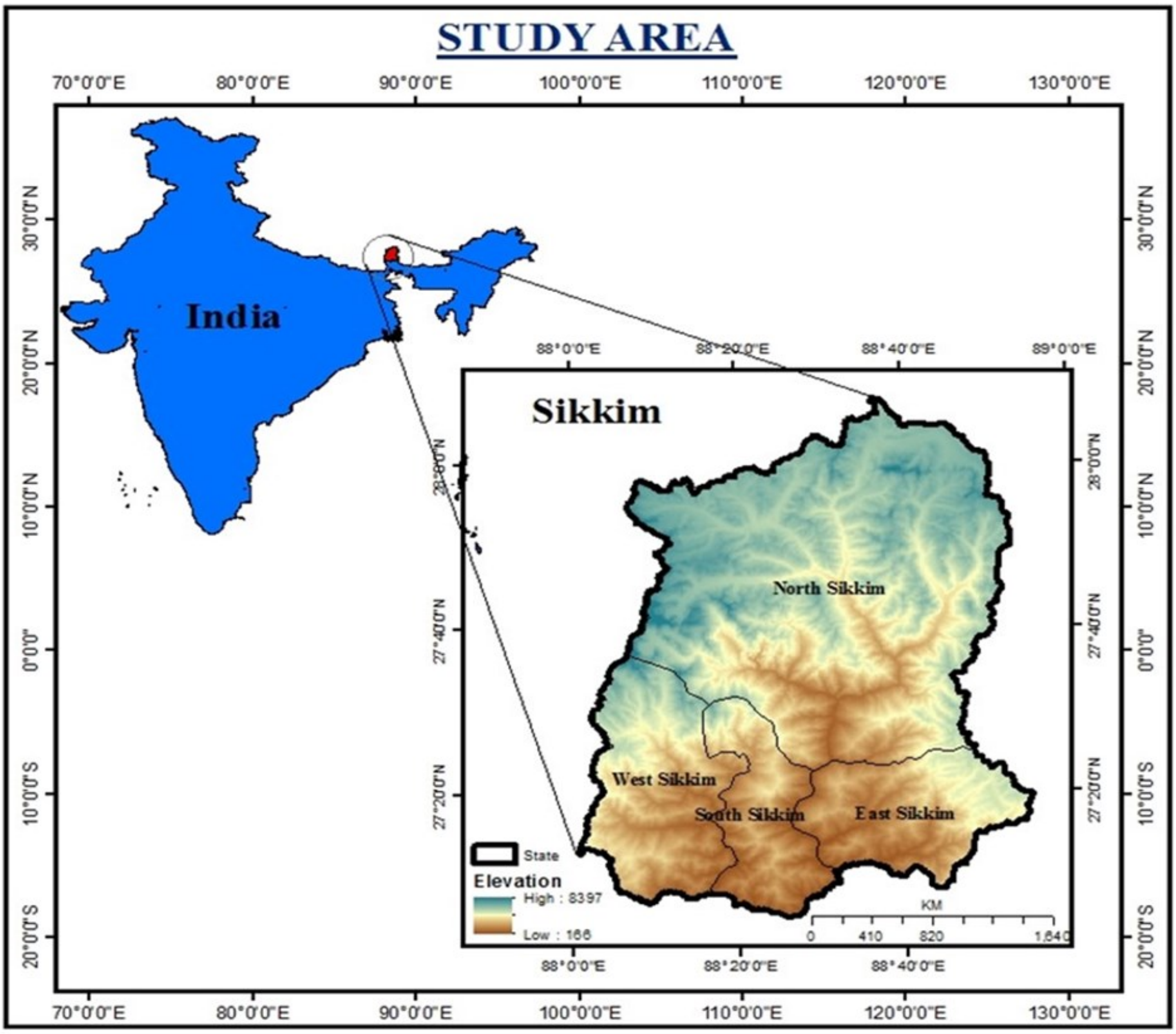


Fig 1: Study area map of Sikkim.

The state stretches its boundary approximately 64km from east to west and 114 km from north to south. The elevation between 300 meters to 8583 from mean sea level. Entire Sikkim falls under the Himalayas with the undulated surface.

3.1 Climate:

Topography and altitude are the major factors controlling climatic and weather conditions in Sikkim, the state itself has three climatic zones respectively:

Tropical,

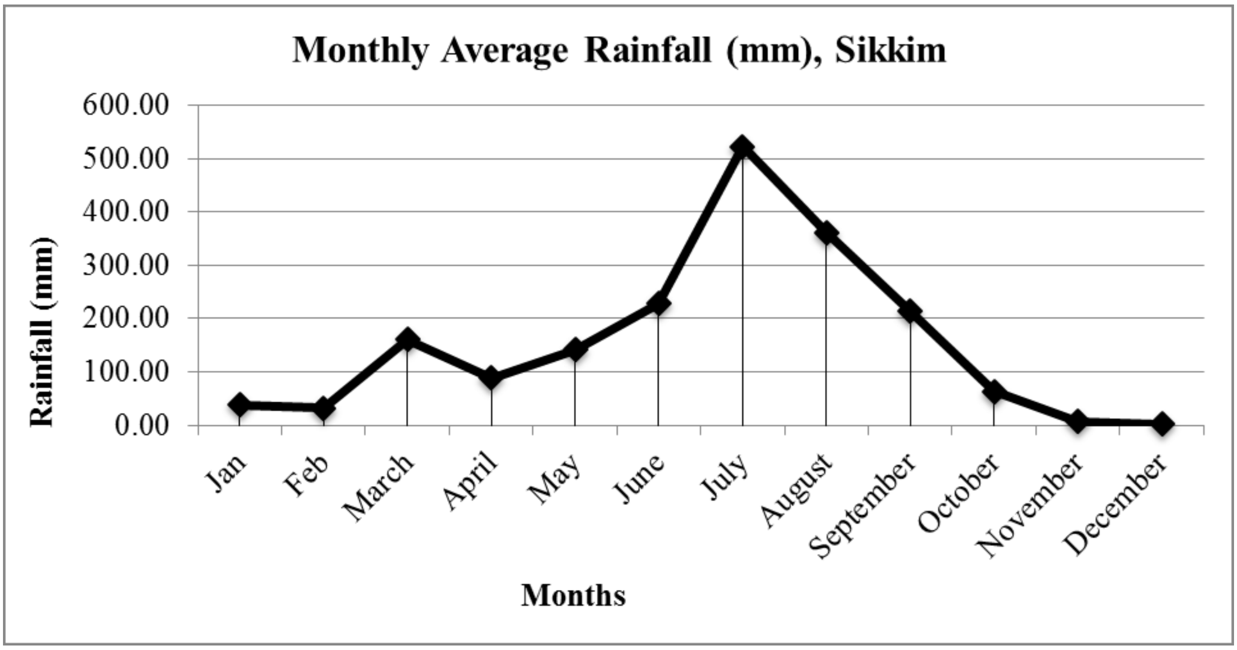
Temperate,

Alpine.

Respectively from south to north. Distribution of precipitation varies from north to south where the northern part of Sikkim gets high snowfall and southern part get high rainfall. Altitude and Winds from central Asia are resulting snowfall in north and western part of Sikkim where the altitude are very high from 6000 to 7000 meters from mean sea level. Approximately 84 Glaciers are located in Sikkim in the higher altitudes, Zemu and Rathong are the major Glaciers in Sikkim.

3.2 Rainfall:

The average rainfall of the state is between 2000 mm to 400 mm, rainfall in Sikkim is occurring in every month, south-east and south-west regions gets more rainfall and very little in the northern part in monsoon season from May to September, most of the places experience rainfall mainly in the month June and July. It also experiences Orographic type of rainfall in the Southern part of the state. Landslides are also occurring mainly in monsoon season.



Graph 1: Monthly Average rainfall of Sikkim.

3.4 Drainage:

Sikkim has two major rivers respectively Rangeet and the Tista which flows from north to south direction across mountains. These are the major sources of water for Sikkim state which provides water for entire year because Rivers in Sikkim are perennial, Tista River originates in Tista change glacier in the north-eastern part of North Sikkim and Ranjeet river originates from Rathong glacier from western part of Sikkim, both the rivers are flowing from north to south direction.

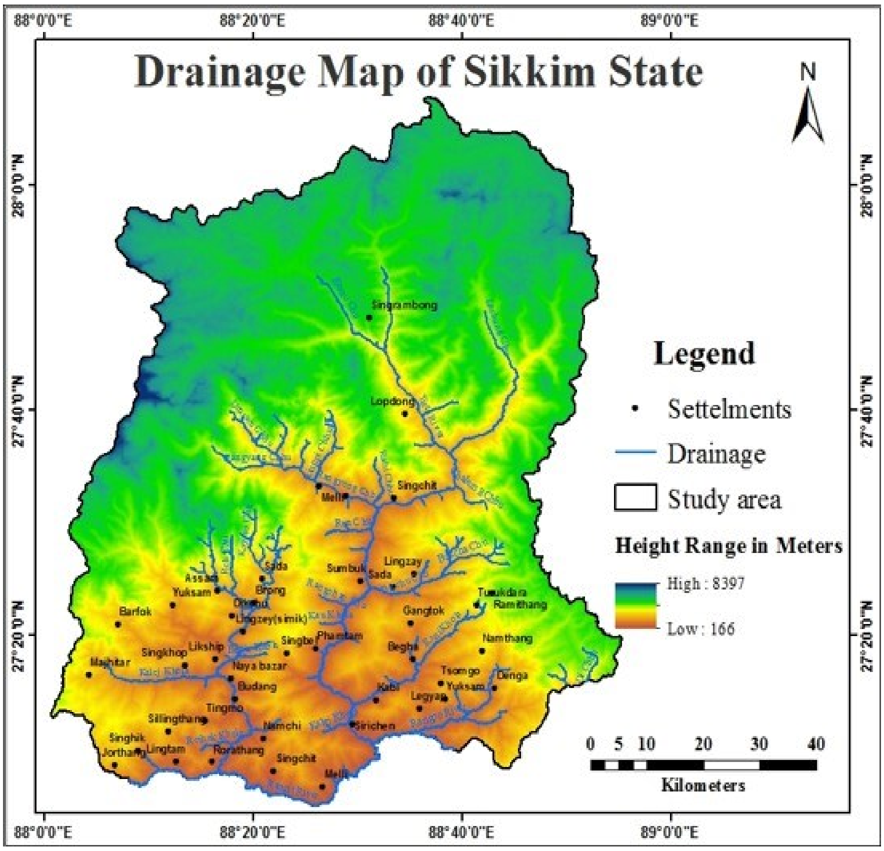


Fig 2: Drainage Map of Sikkim state.

3.5 Geology:

Sikkim is a part of a young Himalayan mountain system. The state mainly consists of gneiss and schist rock, around 45.5% of the total area is under hard massive gneiss rock which is most resistant rock mainly spread over the north, east, south-east and south-western part of Sikkim. 19.3% of the total land is covered by schist which is very soft in its nature, it is covered the south and central part. Alpine-Himalayan mountain system, it is a major earthquake belt in Sikkim.

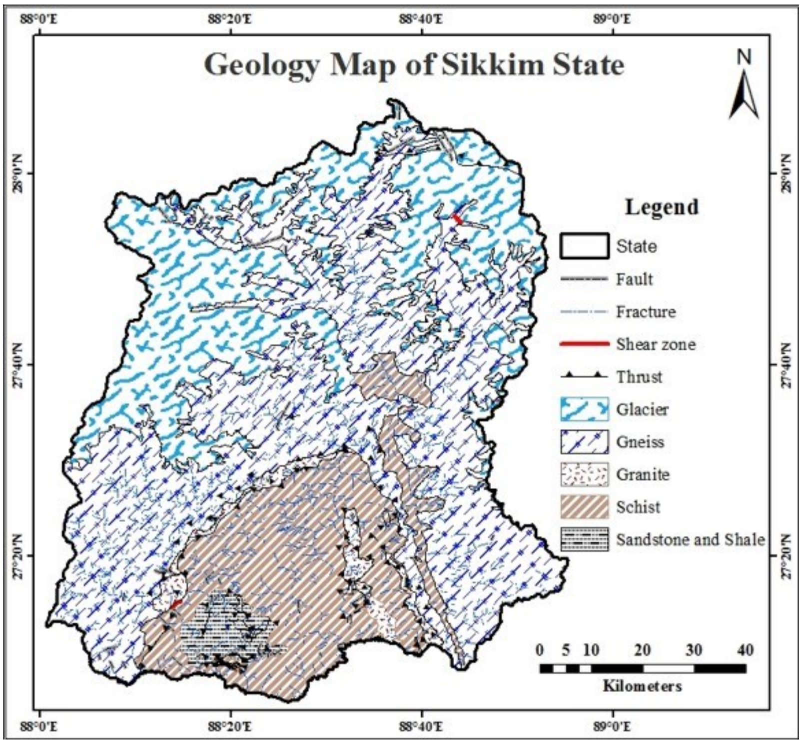


Fig 3: Geological map of Sikkim State.

3.6 Temperature:

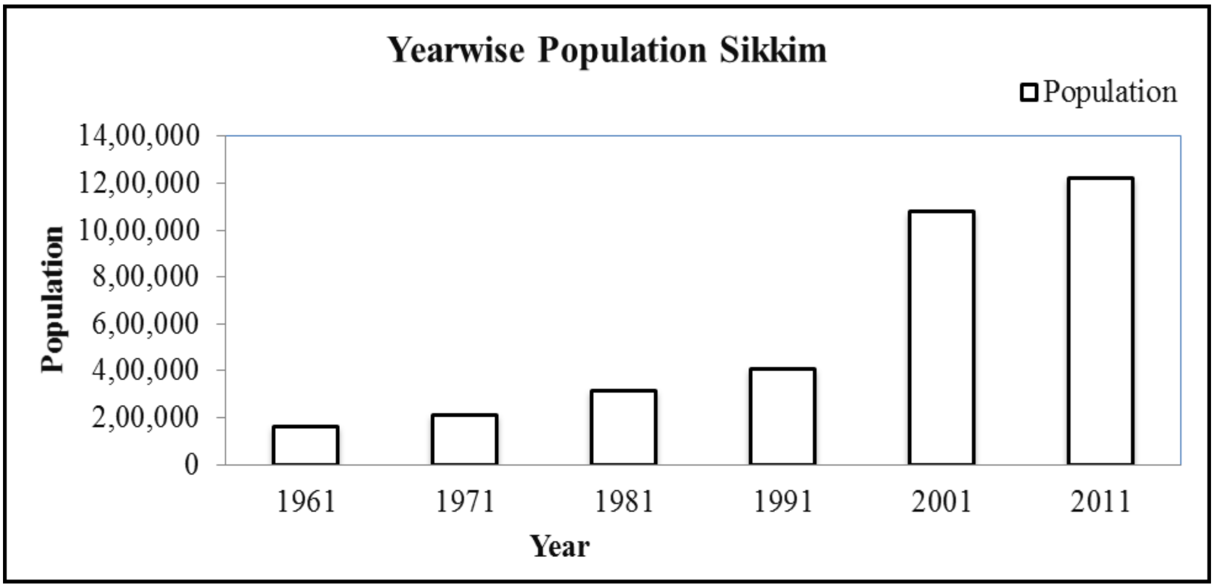
The maximum temperature occurs mainly in the months of July and August and minimum temperature from December to January, Temperature varies with altitude from south to north with respective values -6C0 to 21C 0.

3.7 Vegetation:

Agriculture is a backbone of state and it is a primary activity in Sikkim, Agriculture pattern and practices are different due to climatic and altitude variations. The major part of the Sikkim is under forest. More than 82% of the total geographical area is covered by forest.

3.8 Social Profile:

The state's population is 354643 with a population density of 635/sq.km, around 75% of the state Population resides in rural areas and 25% from urban areas.



Graph 2: Year wise population Data for Sikkim State.

The sex ratio of Sikkim state is 1000 females for 889 males with literacy rate of 82%, density of population is 86 persons per square kilometre.

Gangtok is a capital of Sikkim state which is located in West Sikkim district, it is most populated district and north Sikkim district being less populated district due to its topography and inaccessibility.

4. Aim of the Study:

The aim the study is to generate temporal inventory map for entire Sikkim using visual interpretation method from 1063 to 2018, the landslide inventory used to identify and map landslide susceptible areas using AHP method.

5. Objectives:

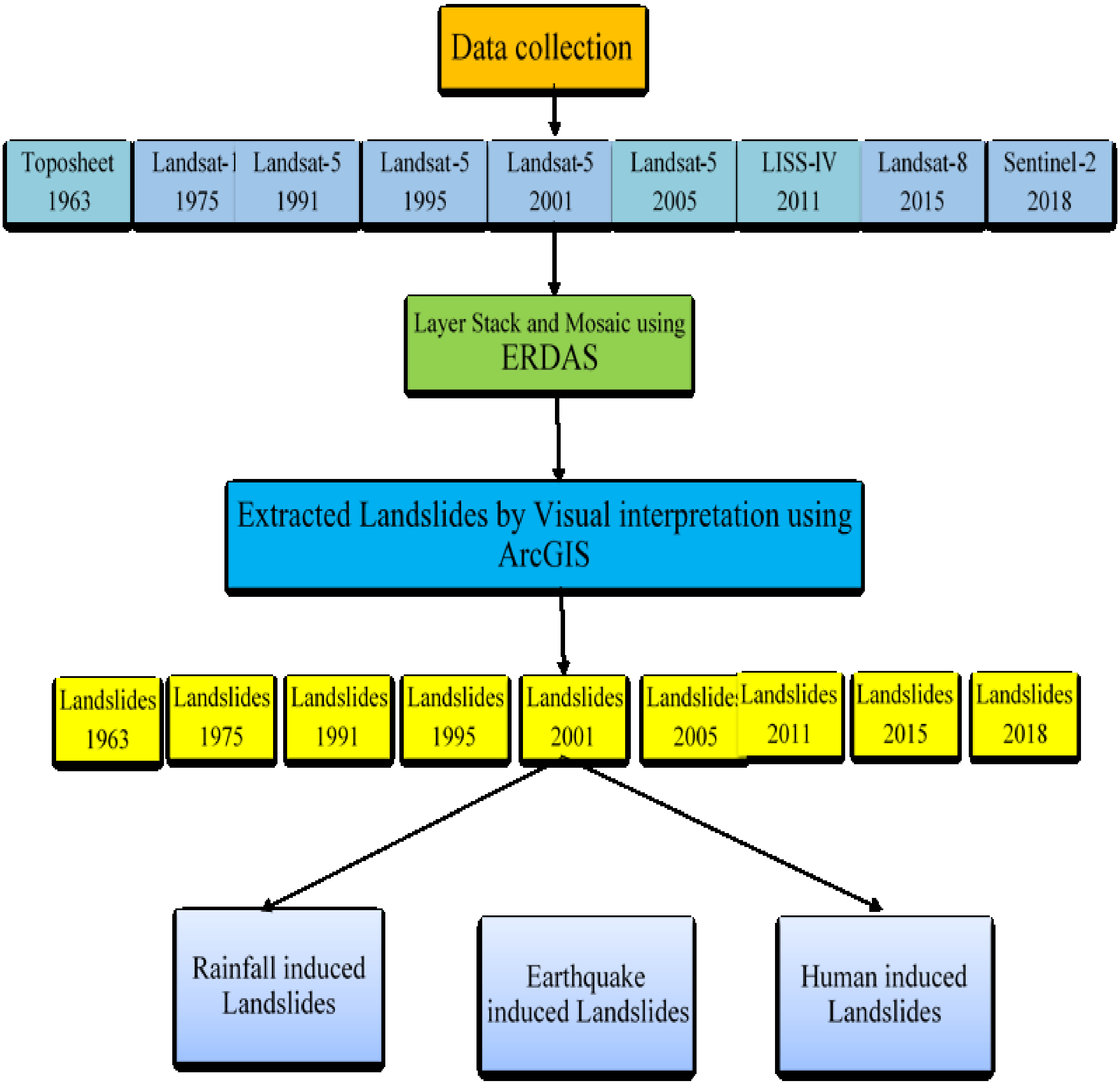
To identify area of landslide through visual image interpretation.

To assess the influence of geological, geomorphological and slope on landslides.

To assess impact of anthropogenic activities on landslides.

To identify landslide susceptible area using AHP method.

Methodology Chart:



Flow Chart 1: Methodology Chart for Inventory of Landslides.

6. Data and Method:

Methodology for landslide inventory studies is based on **visual interpretation** method using **Satellite images** and **Toposheet**. The information has been generated for each and every landslide, the database for landslide inventory data collected at three levels (**Roberta Pellican 2014**):

- Location, Type of landslide, movement, material, volume of landslide are collected at first level inventory data.
- Geomorphology, Geology, causes, structure of landslide are collected at level two inventory data.
- Third level collected data sets are like damage, risk reduction, early warning measures.

6.1 Data Sets Table:

Sl.No	Data	Source
1	Toposheet, (tiff)	Provided by NESAC, Survey of India
2	Landsat-1, (MSS,)	Earth Explorer
3	Landsat-5,(TM, 30M)	Earth Explorer
4	LISS-lV (MS, 5.8M)	Provided by NESAC.
5	Landsat-8, Multispectral Image(OLI and TIRS, 30M, 15M pan)	Earth Explorer
6	Sentinel-2, (MS, 10)	Copernicus
7	Roads (Shape file)	Provided by NESAC, RGDWMP.
8	Geology (Shape file)	Provided by NESAC, RGDWMP.
9	Lithology(Shape file)	Provided by NESAC, RGDWMP.
10	Geomorphology (Shape file)	Provided by NESAC, RGDWMP.
11	Rainfall (net.CDF)	TRMM.
12	Digital Elevation Model, Alos DEM (12.5M)	Alos DEM, http://ift.tt/2fl30Yx
13	NDVI (tiff)	Extracted from Landsat-8 image
14	River (Shape file)	Provided by NESAC
15	Census data	census of India

Table 1: Data sets for Landslide Inventory.

7. Analysis:

7.1. Preparation of Landslide inventory:

Visual interpretation method has been used for **Landslide inventory mapping** from 1963 to 2018 with 5 years interval using remote sensing and **GIS**. Different data sets have been collected from various websites and organizations, most of the data sets were collected from open sources and rest are collected from **North Eastern Space Application Centre** (NESAC).

This project explains conventional methods, tools and techniques to generate landslides inventory maps at different spatial resolution**. Hill-shaded** visualizations created from Alos **DEM** with 12.5 meter resolution used to delineate morphological highlights of landslides.

SL. N	Study Area	Year	Type	imagery	Type (IMG)	Scale of production	Spatial Resolution	Investigators	Time
1	Sikkim	1963	MTI	Toposheet	TS	1:25000	-	2	6
2	Sikkim	1975	MTI	Landsat-1	SI	1:30000	80*80M (MSS)	1	1
3	Sikkim	1991	MTI	Landsat-5	SI	1:20000	30*30 M (TM)	1	2
4	Sikkim	1995	MTI	Landsat-5	SI	1:20000	30*30 M (TM)	1	2
5	Sikkim	2001	MTI	Landsat-7	SI	1:15000	30*30 M (ETM)	1	5
6	Sikkim	2005	MTI	Landsat-7	SI	1:15000	30*30 M (ETM)	1	7
7	Sikkim	2011	MTI	LISS-IV	SI	1:5000	5.8*5.8M (MSS)	2	10
8	Sikkim	2015	MTI	Landsat-8	SI	1:10000	30*30 M (OLI & TIRS)	1	10
9	Sikkim	2018	MTI	Sentinel-2	SI	1:7000	10*10 M (OI)	1	12

Table 2: Structure of Landslide Inventory.

The Multi-Temporal landslides inventory done at various scales from 1.30000 to 1:3000 at different spatial resolution and visual interpretation method applied in this study to identify multi-temporal landslides using referenced satellite image.

Software's used for analysis:

ERDAS 2015
ArcGIS 10.3
QGIS 2.18

All obtained satellite images were layer stacked for selected bands and done mosaic to extract area of interest by using ERDAS 2015 and Landslides were digitized manually on Georeferenced satellite images using **Arc GIS 10.3** (ESRI). Landslides are identified and mapped by examining the variations like changes in texture and tone.

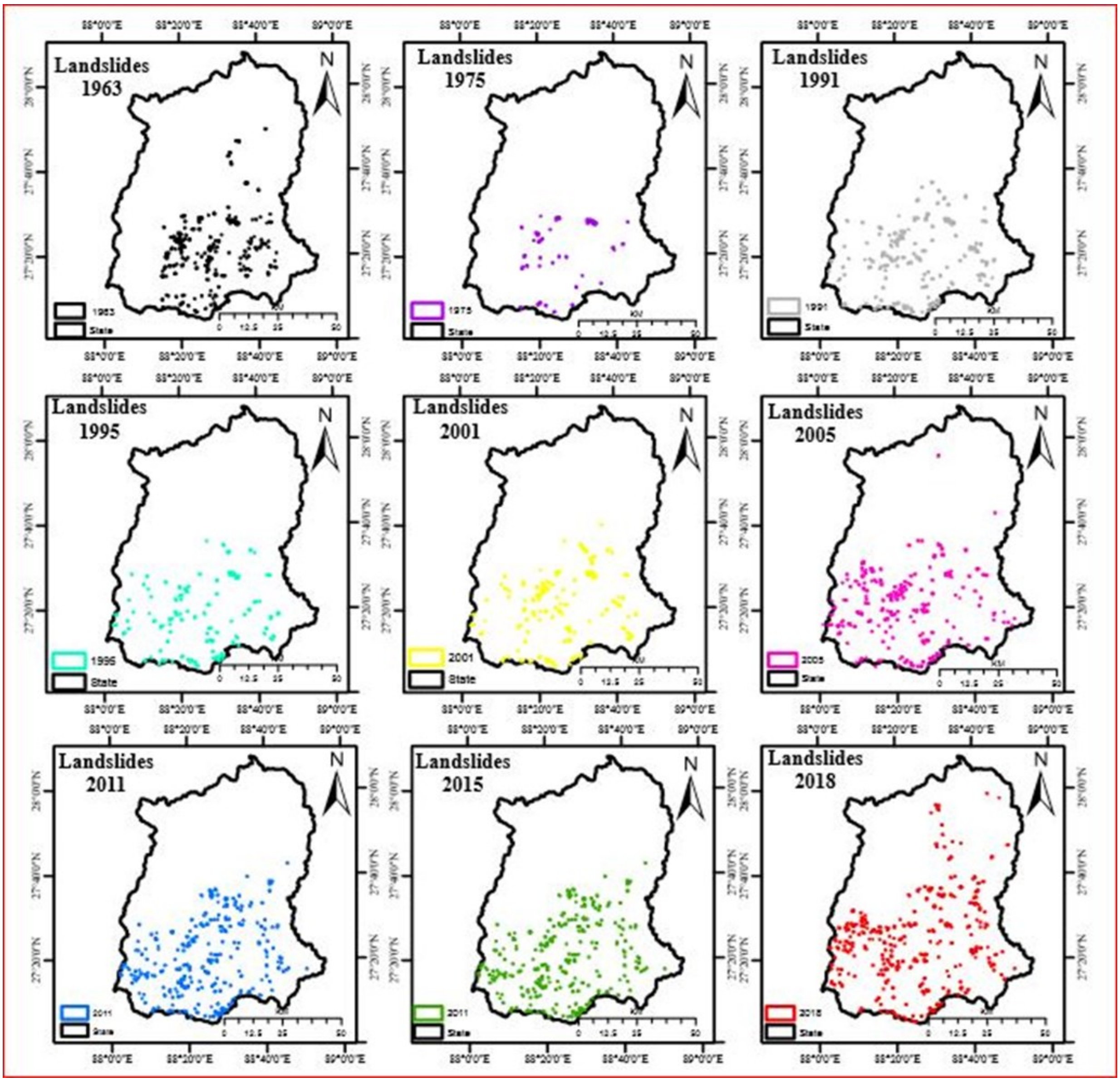
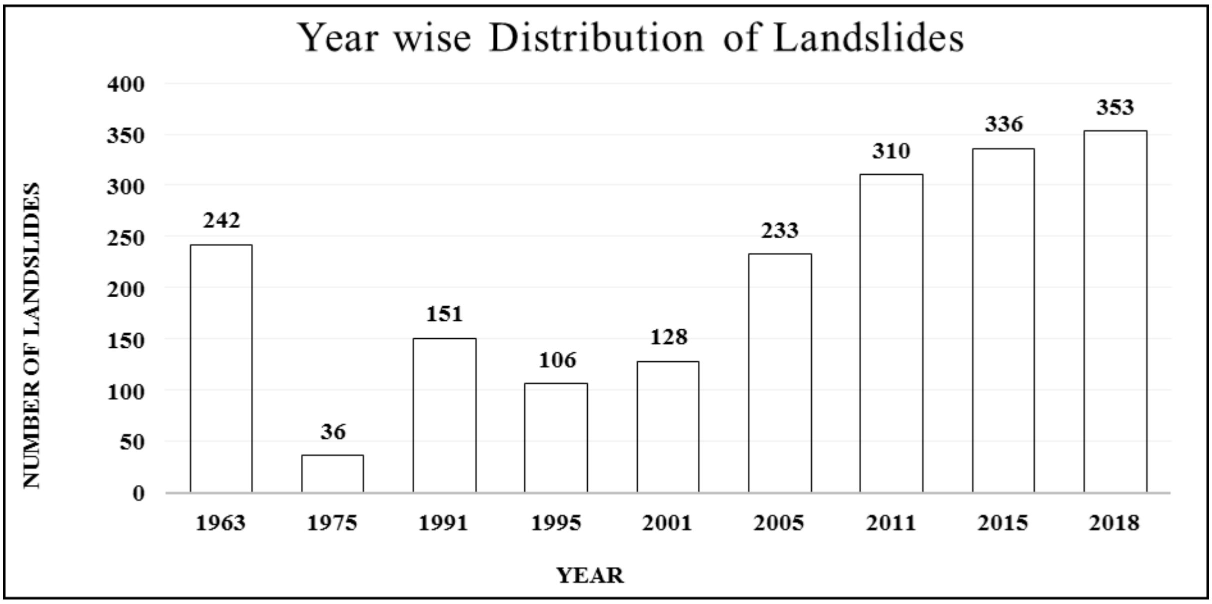


Fig 4: Temporal landslides data from 1963– 2018.

Analysis:

7.2. Year wise Distribution of Landslides:



Graph 3: Year wise Distribution of Landslides:

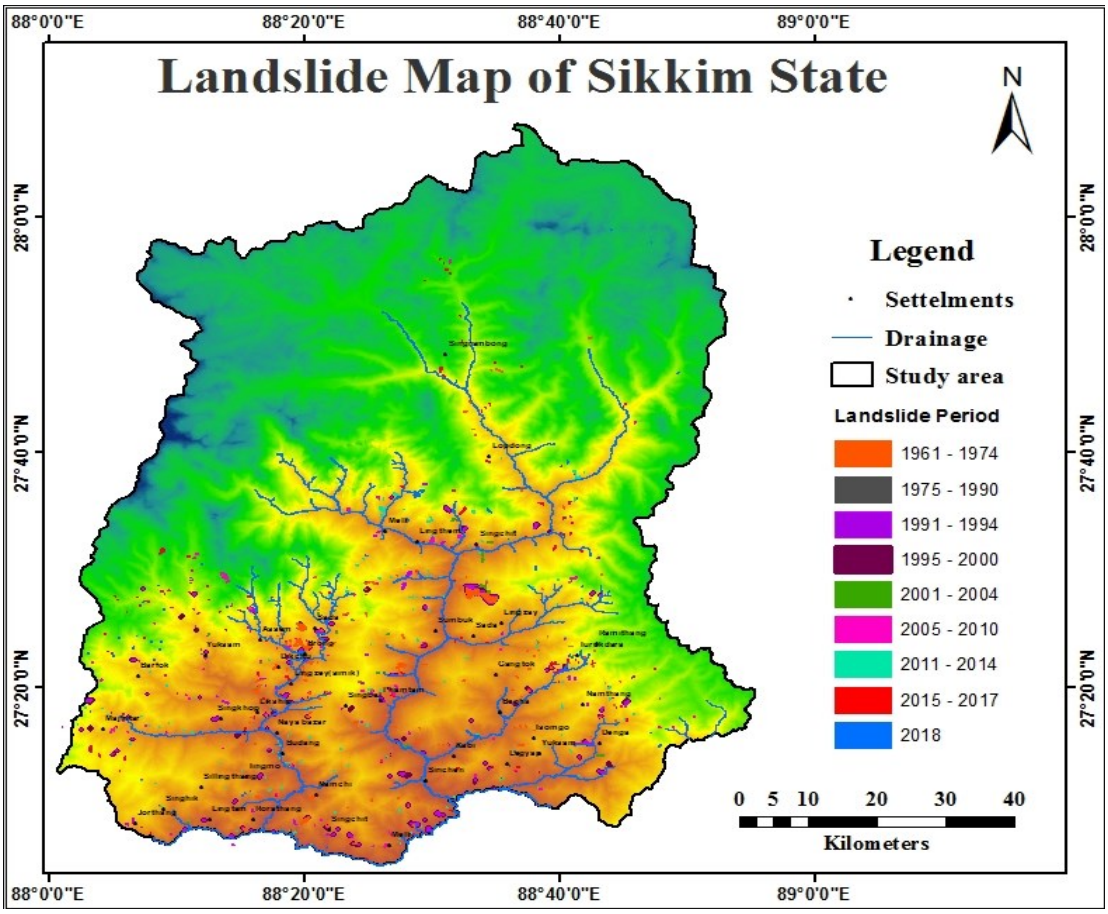


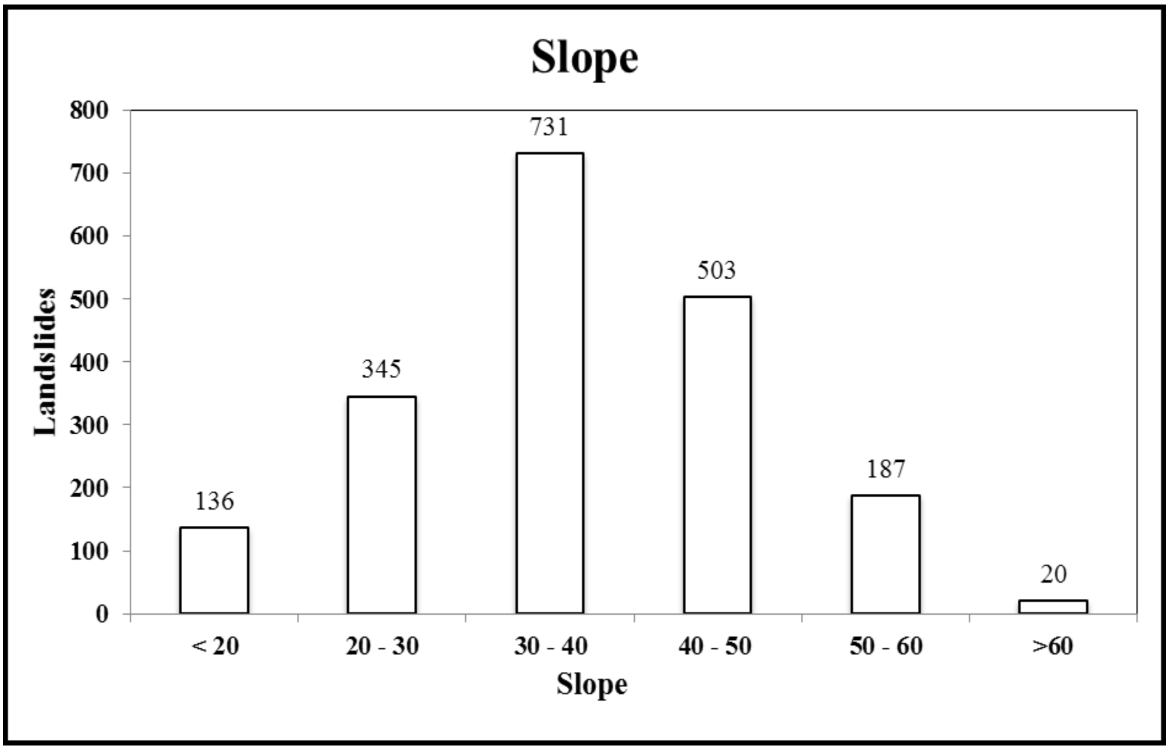
Fig 5: Multi-temporal map of landslides in Sikkim state.

Out of 100% of landslides, 31 %(577) of landslides have occurred in south Sikkim, 30 % (583) of landslides have occurred in west Sikkim, 21 %(396) in North Sikkim, 16 % (308) in East Sikkim.

Year	Number of Landslides
1963	242
1975	36
1991	151
1995	106
2001	128
2005	233
2011	310
2015	336
2018	353

Table 3: Year wise distribution of multi-temporal landslide.

7.3. Influence of slopes on landslides:



Graph 4: Distribution of landslides at different slope classes.

Slope	**Number of Landslides**	**Number of Landslides %**
< 20	155	8
20 - 30	345	18
30 - 40	736	38
40 - 50	503	26
50 - 60	187	10
> 60	20	1
Total	**1946**	**100**

Table 4: Number of Landslides for each respective Slope classes.

Slope:

Landslides are less abundant at heights higher than 1,000 m, where hard rock's (Mesozoic lime stones, and rocks relating to the metamorphic basement) trim out. (M. Santangelo et al.), it is also one of the reasons why the density of landslides in north and west of the study is comparatively less.

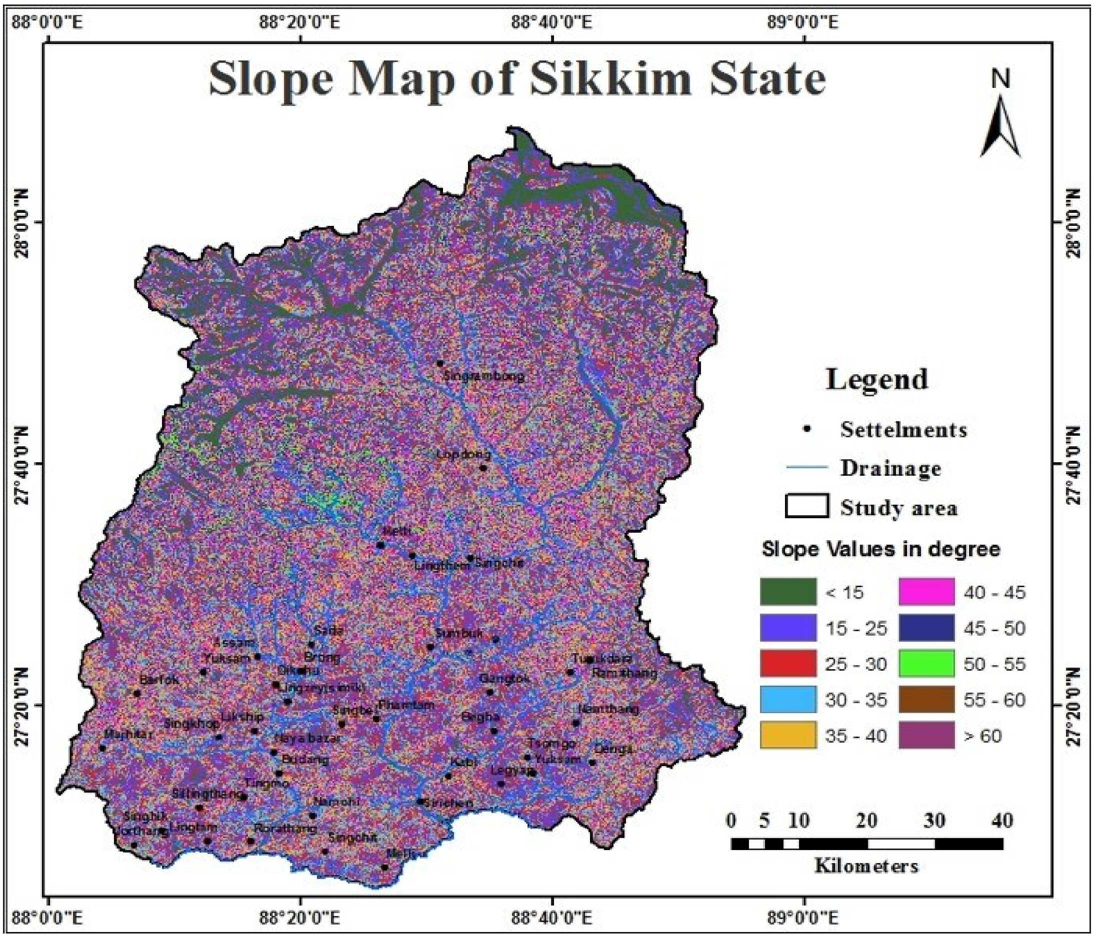
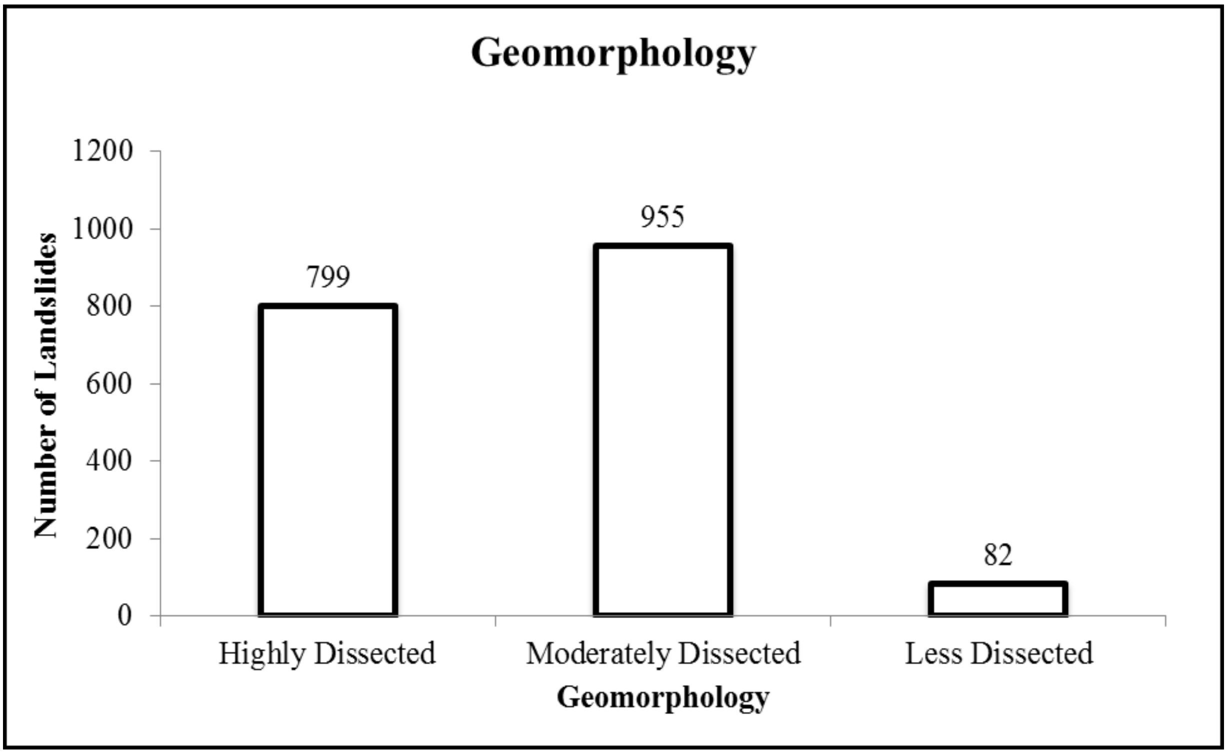


Fig 6: Slope map of Sikkim in Degrees.

Slopes are a significant factor which is very susceptible to landslides, Most of the landslides occurred along river side's because riversides are Steeper than others with 300- 400.

7.4 Influence of Geomorphology on landslides:



Graph 5: Number of landslides in each Geomorphological Class.

Geomorphology is also one of the factors for landslides occurrence in Sikkim but it has a less influence as compared to other factors because most of the landslides are fall in structural hills and moderately dissected with 52%.

Geomorphology classes	**Number of Landslides**	**Number of Landslides %**
Highly Dissected	799	43.52
Moderately Dissected	955	52.02
Less Dissected	82	4.47
Total	**1836**	**100.00**

Table5: Distribution of Landslides at different Geomorphological classes.

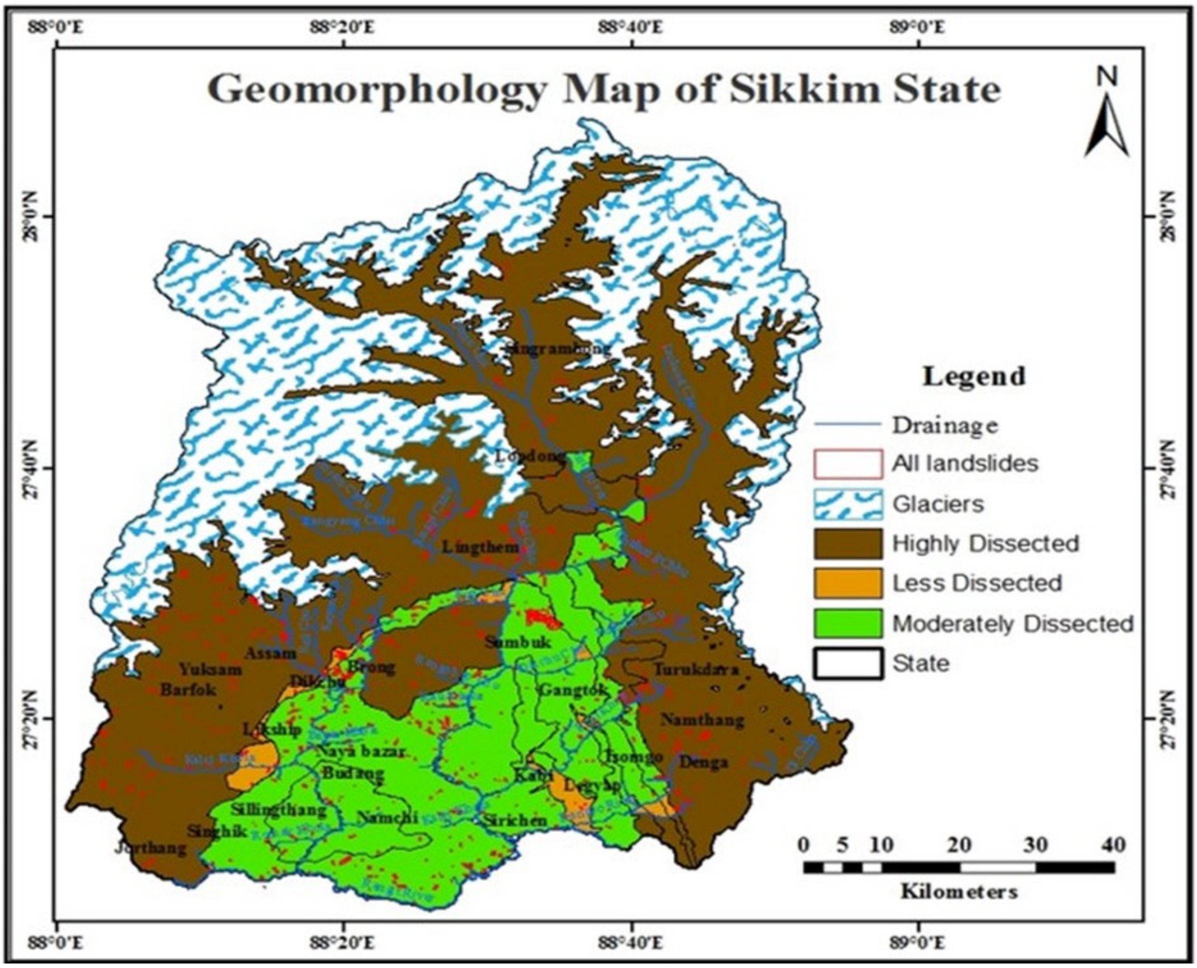


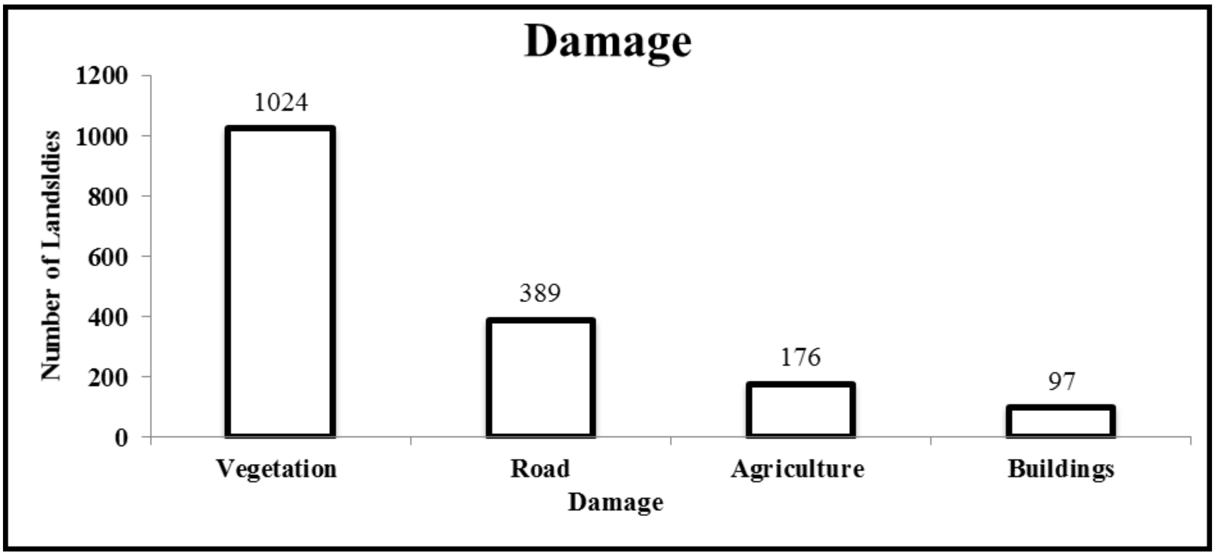
Fig 7: Geomorphological Map of Sikkim.

Geomorphology classes Number of Landslides Number of Landslides %Highly Dissected 799 43.52Moderately Dissected 955 52.02Less Dissected 82 4.47Total 1836 100.00Terrain of whole Sikkim is undulate surface with zero percent of plains, Out of 100% of land-slides52.0 %(955) are fall under Structural hills and Moderately Dissected Geomorphology, 43.5 %(799) of landslides are Structural hills and Highly Dissected, remaining 4.4 %(82) of landslides have occurred in Structural hills and Less Dissected

7.5 Damage:

Out of 100% of damages by landslides, vegetation was affected highly with 60.7 %(1024), Road damage with 23.1 %(389), Agriculture damage 10.4 %(176), Buildings 5.8 %(97). Naturally, Sikkim is a landslide-prone area due to its topographical and climatic conditions. It mainly affected Vegetation cover because most of the study area is under mountainous region with highly Covered vegetation.

Comparatively, Sikkim is less populated and less in density, around 80% of the total geographical Area is under forest cover.



Graph 6: Class wise distribution of damage caused by landslides.

7.5 Influence of Geology on landslides:

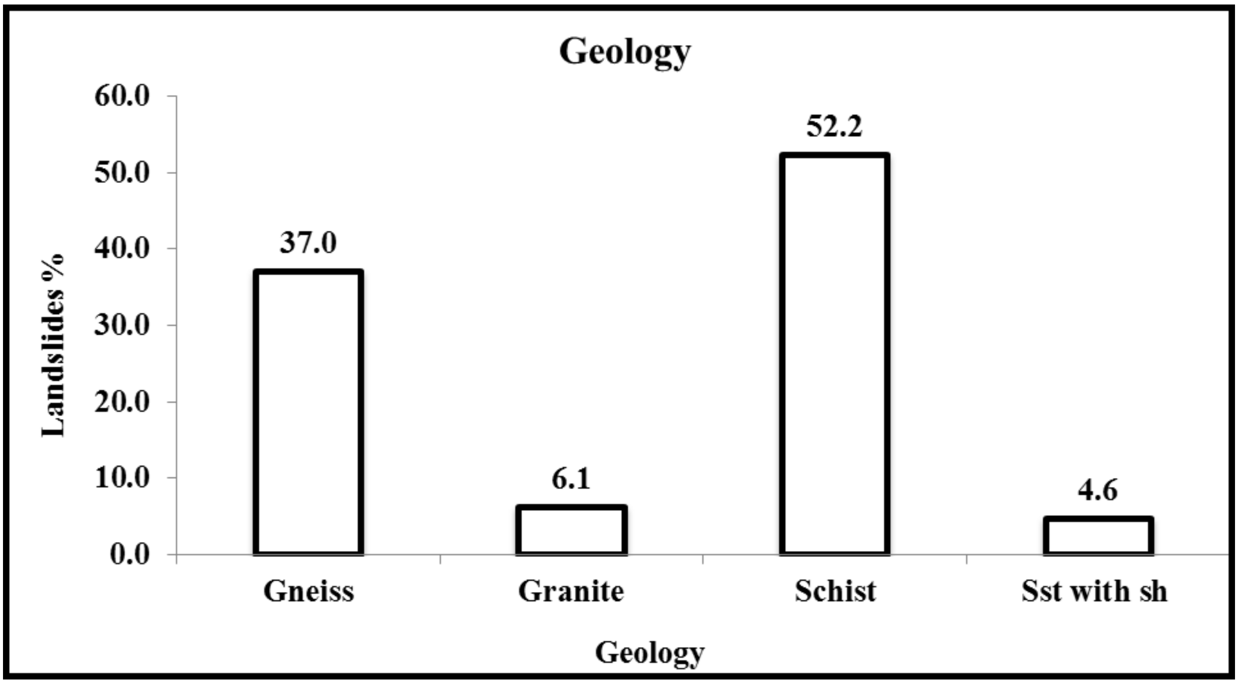
It is broadly recognized that geology significantly impacts the event of landslides, since lithological and structural changes frequently lead to a variation in quality and penetrability of rocks and soils (Pradhan and Lee, 2010).

- **SST**, **SH** and coal bands are more susceptible to landslides, percentage of landslides is comparatively less because it is very less in area.
- Gneiss rocks are hard which is capable of resistance denudation. Even though more landslides are present in this group because this region is very affected by steep slopes and other factors.

More landslides are present in Schist group region because it is very soft rock, highly weathered and denudes very easily.

Geological Classes	Area	Area in %
Gneiss	676	37.0
Granite	112	6.1
Schist	955	52.2
Sandstone with shell	85	4.6

Table 6: Distribution of Geological area in sq.km and percentage.



Graph 7: Distribution of landslides over geological classes.

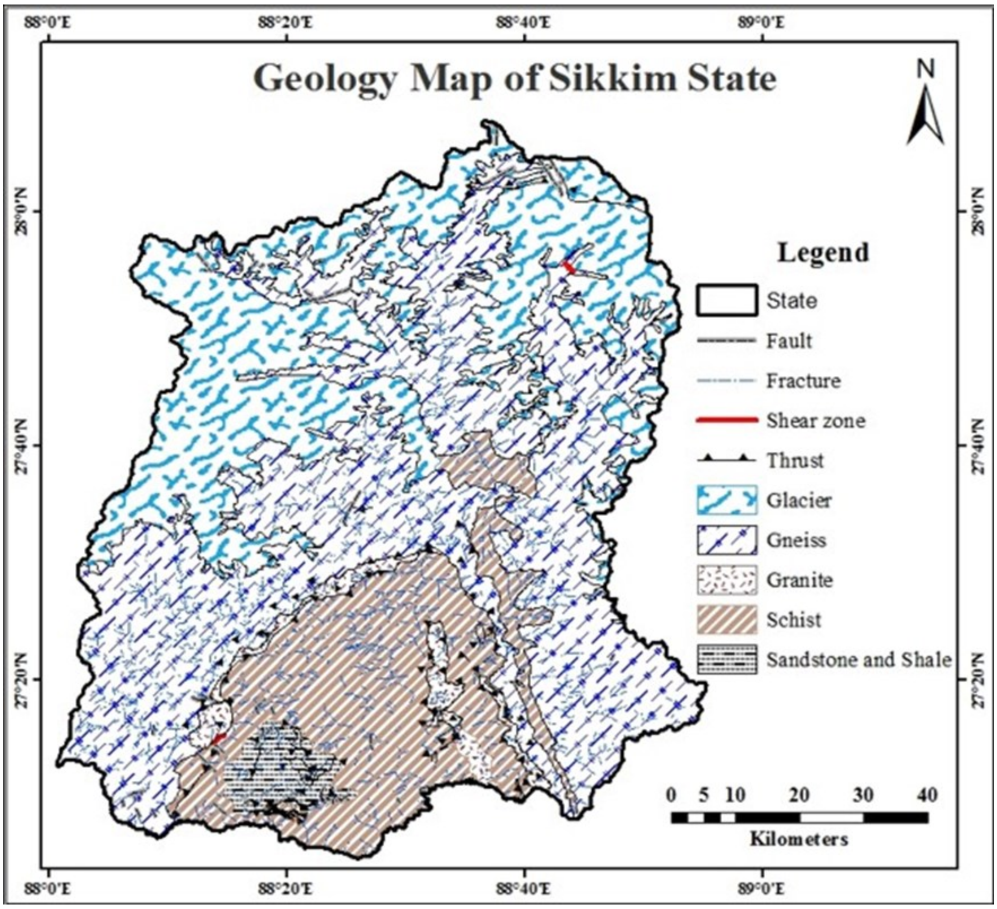


Fig 8: Geological Map of Sikkim State.

Geological structures also play a major role in landslides occurrence in Sikkim, 52.2 %(955) of landslides have occurred in Schist, 37.0 %(676) of landslides are under Gneiss, 6.1% (112) of landslides within Granite, landslides are less in SST with SH and coal band with 4.6% (85).

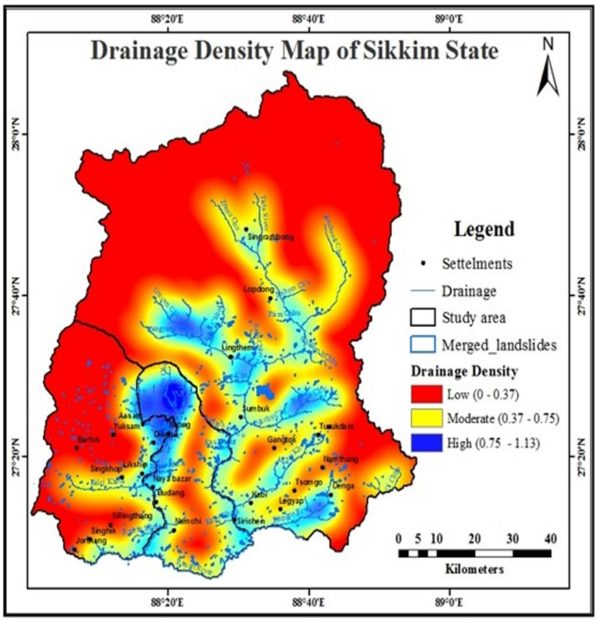


Fig 9: Drainage density map of landslides

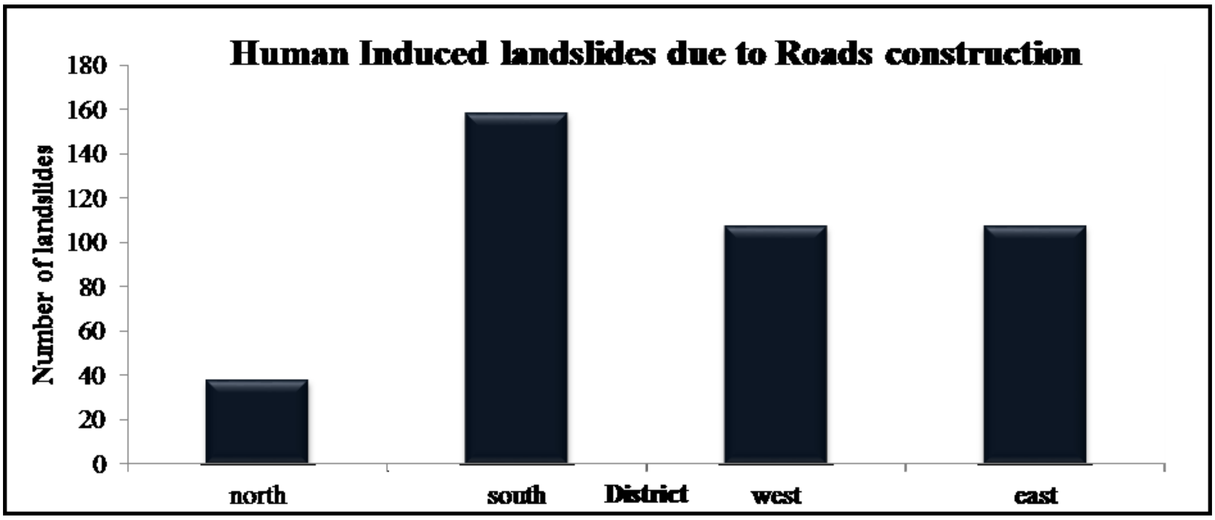
8. Human Induced landslides:

Most of the population in Sikkim resides along steep slopes which are very susceptible to landslides (Jane njoki ng'ang' a, 2014). Development and technology in Sikkim are also playing an important role in landslides, mainly due to road construction. Out of 1898 landslides, 413 landslides are fallen beside roads within 100-meter buffer.

Number of landslides are increasing year by year at the same time population is also increasing rapidly, anthropogenic activities are also

Fig 10: Before and after landslide event due to road construction.

Most of the landslides in Sikkim are also mainly affected by road constructions (Jawaharlal Nehru Marg) and infrastructure development because it is also a well-developed district with high population, development of tourism has been changing the landscape of mountains which causing material unstable.



Graph 8: Human Induced landslides due to road construction.

Entire Sikkim is an undulated area with very less percentage of plains which force them to make changes in the landscapes. Landslides in Sikkim are increasing day by day due to human activities. Due to construction of roads along steep slopes makes landscape unstable and cause to landslides.

9. Event Based inventory map:

This information is imperative to archive the total extent and size of landslide occasions, and is imperative to ponder the development (**Guzzetti et al., 2009**). It moreover demonstrates profitable for crisis and recovery from post-event endeavours. Event inventory maps give crucial data to decide dependable measurements of landslide size, mainly landslide zone have utilized robotic models to propose that the factual distributions of avalanche region and volume depend on the geo-mechanical properties of the soils and rocks where the landslides occur (**Katz and Aharonov2006 and Guzzetti 2009**).

Very High resolution optical satellite imagery can moreover be utilized to assist classify the distinctive areas of a landslide. In fact, VHR Digital elevation model information can helps to identify the differentiation between landslides and barren land and map event-based landslides, especially in Agriculture regions, landslides have cleared out unpretentious land use land cover changes (**Ardizzone et al** 2007).

9.1 Event Based Rainfall induced Landslide:

Precipitation is recognized as one of the components capable for the activating of landslides, especially in regions characterized by overwhelming regular precipitation. Greatly high occurrence of landslides is ascribed to the geology of the area and strong precipitation.

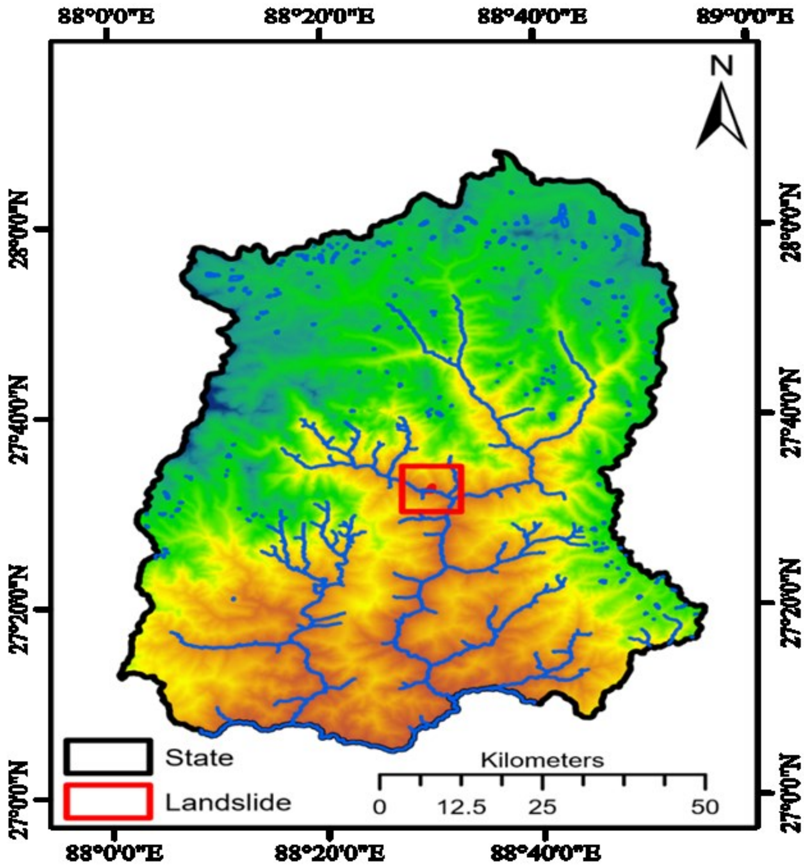


Fig 11: Location Map of So Bhir Landslide.

9.2 So Bhir Landslide:

In the month of August-3-2016 a massive landslide hit the hill state of Sikkim, this landslide occurred in **So Bhir** Hills at Dzongu near mantam village due to heavy rainfall this and landslide called as a "So Bhir Landslide" , The locational extent of landslide is 27°32′22.92²N and 88°30′ 2.47²E.

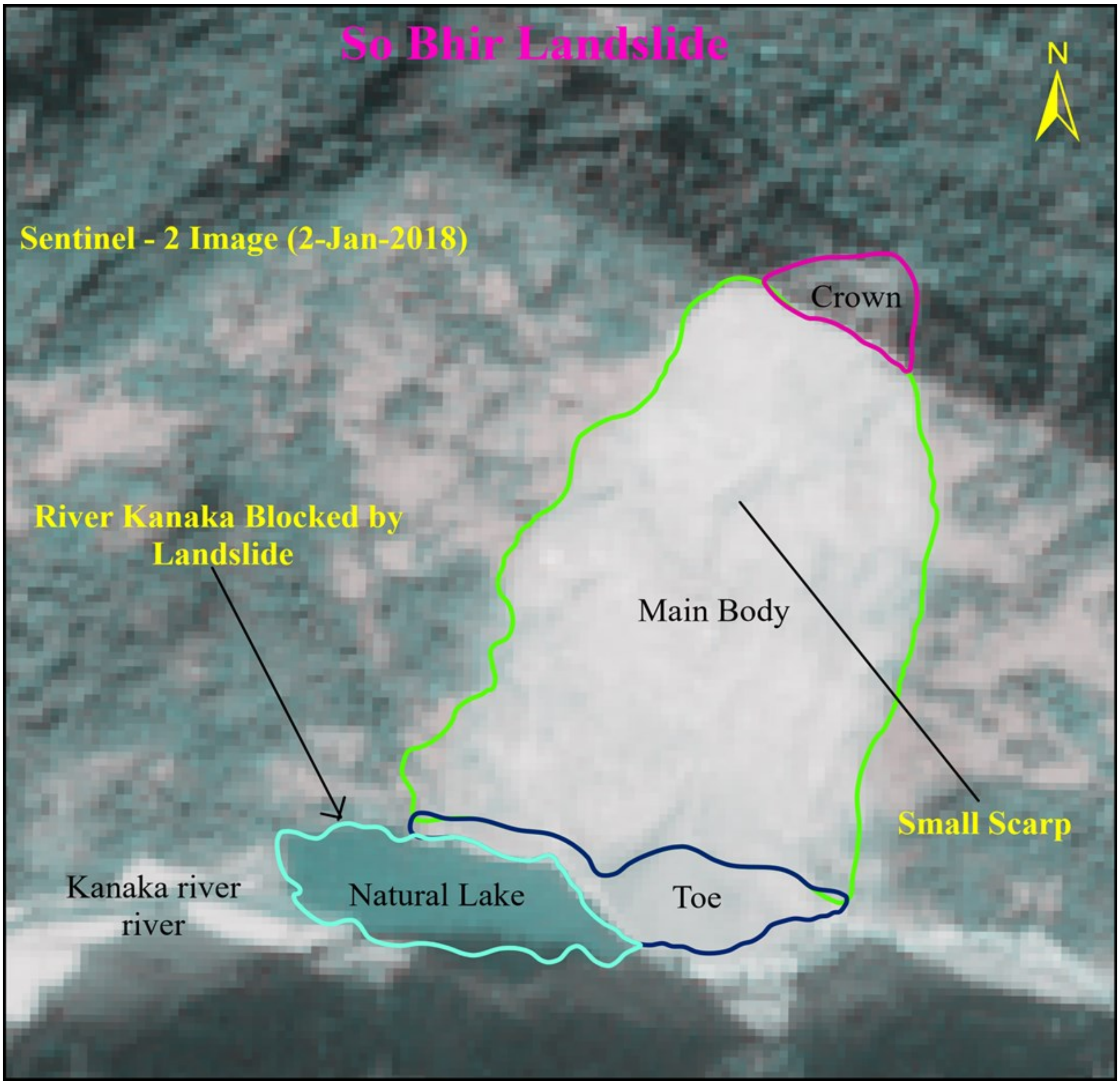
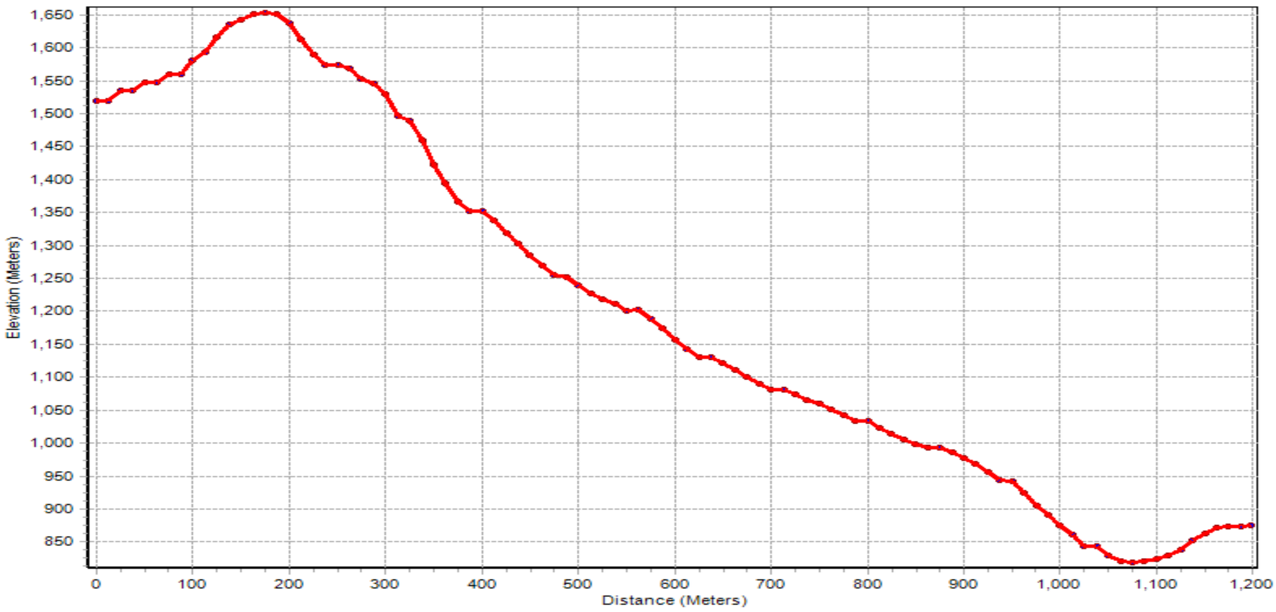


Fig 12: Morphometric analysis of So Bhir Landslide.

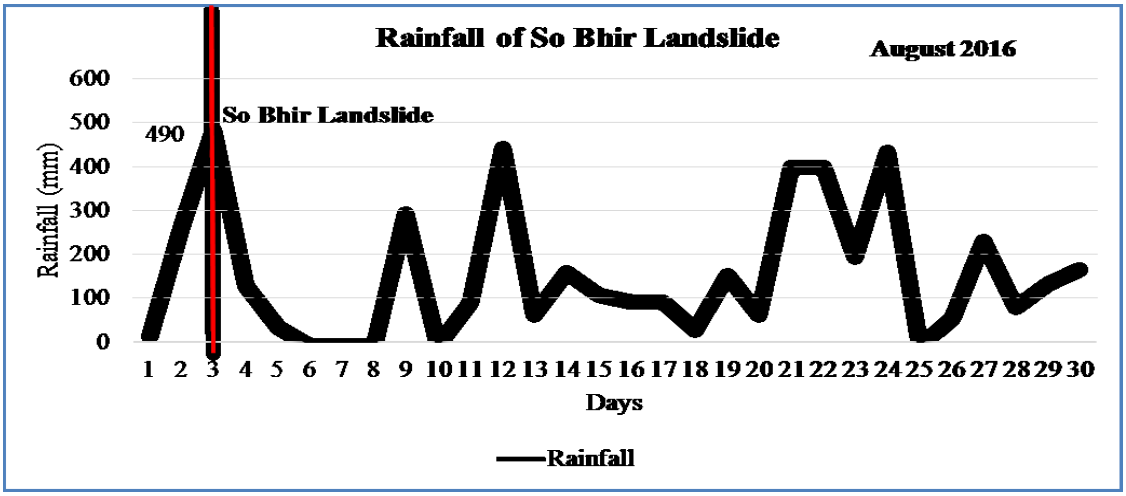
So Bhir is a huge Landslide in the Sikkim history from past 60 years. The elevation of landslides is 750 meters to 1680 meters from mean sea level, Slopes covers from 30^0 to 50^0, and Direction of Slope is in south. As shown in fig (), Debris material from So Bhir Blocked the River Kanaka which created a natural Dam and bridge located over Kanaka river was submerged, road washed away approximately 300 meter. It mainly caused to infrastructure and agriculture. Natural dam which was constructed due to avalanche was caused to rise in the water level, around 10 houses are submerged nearer to landslide.

Profile Graph of So Bhir Landslide:



Graph: Elevation profile graph of So Bhir Landslide.

Length of the landslide is 790 meters from crown to toe (North to South) and the width is 530 meters from east to west with 8321 meter elevation.



Graph 9: Daily rainfall of august 2016 for Sikkim.

So Bhir landslide occur due to heavy rainfall intensity in the month of august along the steep slopes of Kanaka River, it is a tributary of Tista River. The above graph showing that the intensity of rainfall is very high (490 mm) on the day of So Bhir Landslide occurs. Comparatively it is highest rainfall in the month of august.

SL.No	Field	Description
1	Name Of the Landslide	So Bhir Landslide
2	Village	Dzongu village, near mantam
3	District	North Sikkim
4	State	Sikkim
5	Latitude	27°32′22.92″N
6	Longitude	88°30′2.47″E
7	Width (M)	540
8	Length (M)	920
9	Height (M)	8231
10	Area (Sq.M)	402
11	Type of material	Debris
12	Type of movement	Translational
13	Perimeter (M)	4327
14	Geology	Gneiss
15	Geomorphology	Structural Hill and Highly Dissected
16	Land use land cover	Vegetation and Agriculture
17	Damage	Houses
18	Human Loss	No
19	Communication	Road Damaged
20	Date of Occurrence	3 – August - 2016
21	Reactive	No

Table 7: showing the detailed information of So Bhir Landslide.

9.3 Earthquake-induced landslides:

Earthquakes are also been playing an effective role in the occurrence of landslides in Sikkim, State Sikkim occurred in the seismic zone located in the Himalayan belt.

Sikkim comes under seismic zone lV which is considered as a more vulnerable zone for earthquake induced landslides.

Alpine-Himalayan mountain system is a major earthquake belt, it is actively tectonic zone and the likelihood of occurrence of Earthquake-induced landslides are also more in Sikkim.

The river Tista itself a lineament from NW – SE direction which is highly susceptible to earthquakes, most of the past major earthquakes are triggered mainly along the Tista river with

According to the Indian Meteorological Department (IMD), a major earthquake occurred in 2011 with a strong magnitude of 6.8 which cause to so many earthquake-induced landslides in Sikkim in a single day. Most of the landslides materials are rock fall..

10. Results and Discussions for inventory:

Around 1895 landslides have occurred from last 58 years, most of the landslides are repeating or continuing every year, and out of 1898 landslides 19 landslides are still active from 1963 to 2018 which are mainly concentrated in the southern and Western part of Sikkim. A number of events and frequency less in the northern part of the state due variation in geological and climatic condition.

Most of the landslides are present in the South and central part of the state where the human developments or involvements are more. In northern part of study area landslides are mainly affected by melting snow and erosion. Most of landslides are occur mainly in monsoon season, due to topographical and geological condition.

Accuracy and quality of landslides are gradually changed from 1963 to 2018.

New inventions and technology in remote sensing that providing very high-resolution satellite images from last 20 years, but before the satellite images with very less resolution. It is one of the major negative drawbacks to cartographers for visual interpretation which mainly affected the frequency of landslides till the 20th century. Availability of images and resolution plays a key role in the accuracy and quality of landslides.

Remote Sensing methods embraced for landslide inventory mapping related writing contributions are recorded. Visual interpretation and geomorphic highlight extraction from airborne photogrammetry, DEMs created information sets appear to be the foremost reasonable strategies for landslide inventory and mapping.

Educational and research organizations are not instructing adequately this essential ability, and satisfactory preparing in landslide discovery and mapping through the visual interpretation of satellite or aerial photography is troublesome to obtain.

Number and quality of landslides increases due to enhanced accuracy increased in thematic images. For the most part, more consideration should be paid to pre-processing organize, particularly when using analytical hierarchy strategies coordinate more data sources.

Inventory of landslides

Validation was done for landslides inventory by using old Archive inventory.

11. Landslide Susceptibility:

Landslide Susceptibility Analysis (LSA) endeavours to set up a relationship between landslides and the factors related to them, in arrange to decide the spatial likelihood of event of future landslides in a given region (**Swamp 2000; Remondo et al. 2003**); This can be done by recognizing past landslides, their dispersion and fundamental characteristics and applying statistical and geographic data instruments to set up which components are more related to landslides.

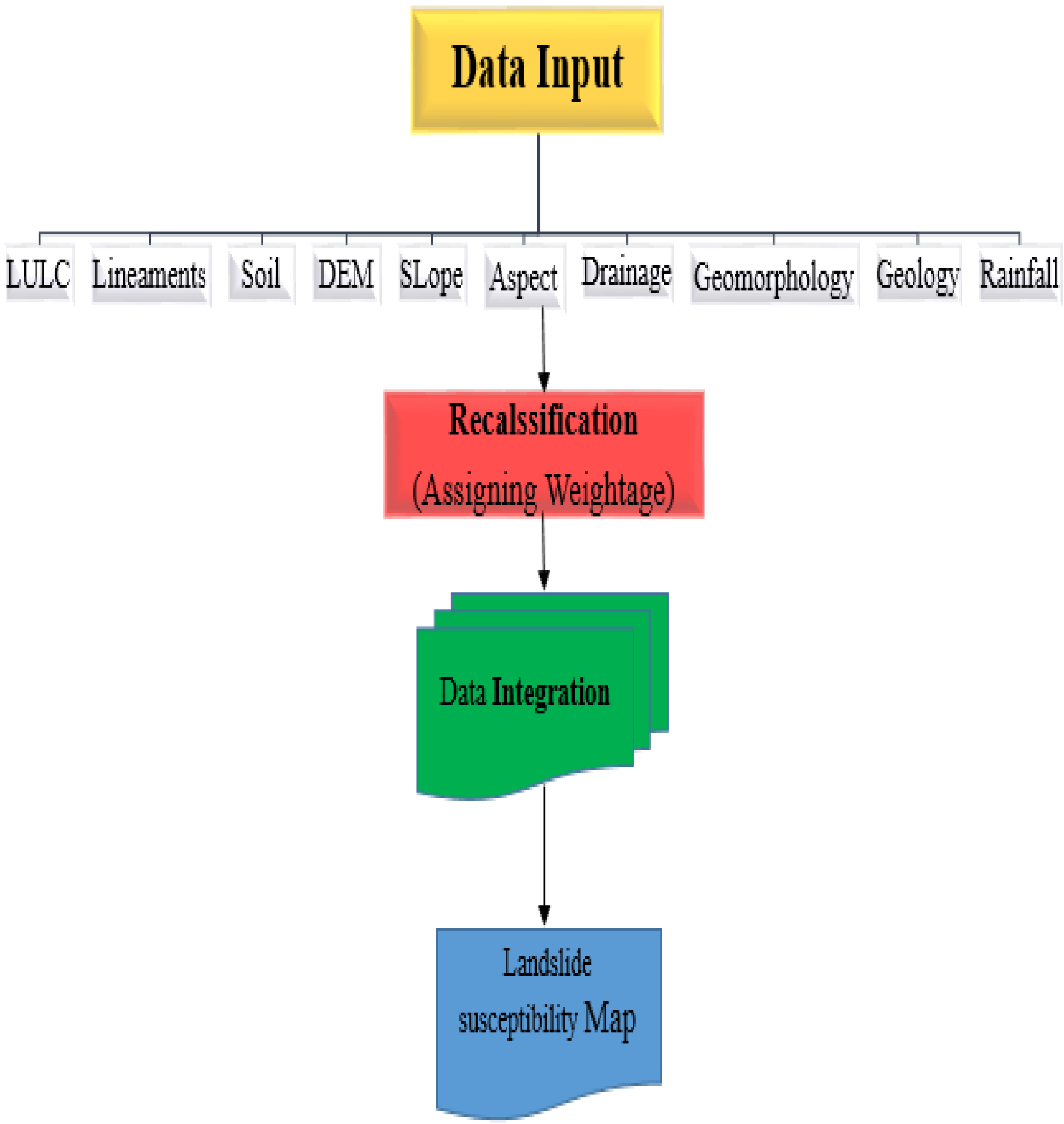
This landslides susceptibility mapping useful to identify landslide prone areas for future prediction. It doesn't give any information related to time and frequency of avalanches. In mathematical form, landslide susceptibility is the likelihood of spatial event of known slope failures, given a set of geoenvironmental conditions (**Guzzetti, et al., 2006**).

12. Data and Methods:

Landslide susceptibility mapping methods are differing and various and regularly vary dependent on the location, landscape, and budget.

In this study AHP (Analytic Hierarchy Process) used to assess landslide susceptibility mapping, which predict the occurrence of future landslides. The methodology adopted for this research work has been involving integration of remote sensing based inputs from the satellites and field data. Based on the numerous numbers of existing landslides, the South Sikkim district has been selected as the study area for this research work. An intensive study has been made for the South Sikkim to identify the susceptible zones using Analytical hierarchy Model.

Methodology Chart:



Flow chart: Flow chart of methodology

For landslide susceptibility mapping, the determination of preliminary components for landslides depend on the scale of investigation, the characteristics of the consider region, the landslide type, the failure components and the valuable information of the most causes of avalanches (**Guzzatti and Crozier, 2005**).

12.1 Data sets for Susceptibility mapping:

Data sets were collected from different websites and organizations to generate thematic layers for landslide susceptibility mapping.

SL.No	Data	Source
1	Roads (Shape file)	Provided by NESAC, RGDWMP.
2	Geology (Shape file)	Provided by NESAC, RGDWMP.
3	Lithology(Shape file)	Provided by NESAC, RGDWMP.
4	Geomorphology (Shape file)	Provided by NESAC, RGDWMP.
5	Rainfall (net.CDF)	TRMM.
6	Digital Elevation Model, Alos DEM(12.5M)	Alos DEM, http://ift.tt/2fl30Yx
7	NDVI (tiff)	Extracted from Landsat-8 image
8	River (Shape file)	Provided by NESAC
9	Soil (Shape file)	Food And Agriculture Organization Of The United Nations
10	Aspect (TM)	Generated using Alos DEM
11	Land use Land Cover (TM, 100 M)	Earth Data, Nasa.

Table 8: data sets used for thematic layers.

12.3 Analytic Hierarchy Process (AHP):

The **Analytic Hierarchy Process** (AHP), Thomas is a founder, the AHP is maybe, the foremost widely used choice making approach in the world, nowadays it is a successful method for dealing with complex choice making, and may help the choice maker to set needs and make the best decision. The AHP considers a set of assessment criteria, and a set of elective alternatives among which the best choice is to be made.

Utilizing this method each layer is broken into smaller factors, at that point these components are weighted based on their significance, and at last the final arranged layers are assembled and the ultimate outline is created.

Landslide susceptibility Index (LSI) computed from the combined weighed raster thematic maps of components based on the given weights and appraisals.

Intensity of Value	Interpretation
1	A and B values are Equal
3	A has slightly higher value than B
5	A has strongly lightly higher value than B
7	A has very strongly lightly higher value than B
9	A has absolutely higher value than B
2, 4, 6, 8	These values are indicates the scales between two adjacent judgements
Reciprocals	If A has lesser value than B

Table 9: interpretation of intensity values for landslides occurrence.

12.4 Preparation of Susceptibility mapping using AHP:

In this present study both natural and artificial causative factors have been taken for Landslide susceptibility analysis. DEM (Digital elevation model), slope, Aspect, Land Use Land Cover, Soil, Lineaments, Roads, Drainage, Vegetation, Rainfall, Geomorphology, lithology are casual factors were generated for landslide susceptibility mapping, rainfall and earthquake factors analysed as triggering factor.

Below table showing the weightage and rank for each and every class on the basis of their influence on occurrence of landslides. Weightage and ranks allotted to causative factors using statistical calculations using Analytical hierarchy process. This is all about distribution of weightage percentage according to theirs contribution in occurrence of landslides.

Pairwise Comparison:

	Pair wise comparison									
	NDVI	Distance from Linean	Land Use Land	Distance from Dr	Distance from R	Soil	Geomorphology	Rainfall	Slope	Geology
Geology	1.00	2.00	3.00	4.00	7.00	6.00	7.00	6.00	8.00	9.00
Slope	0.50	1.00	2.00	3.00	6.00	5.00	6.00	5.00	7.00	8.00
Rainfall	0.33	0.50	1.00	2.00	5.00	4.00	5.00	6.00	6.00	7.00
Geomorphology	0.25	0.33	0.50	1.00	4.00	3.00	4.00	5.00	5.00	6.00
Soil	0.14	0.17	0.20	0.25	3.00	2.00	3.00	4.00	4.00	5.00
Distance from Road	0.17	0.20	0.25	0.33	2.00	1.00	2.00	3.00	3.00	4.00
Distance from Drainage	0.14	0.17	0.20	0.25	1.00	0.50	1.00	2.00	2.00	3.00
Land Use Land Cover	0.13	0.14	0.17	0.20	0.50	0.33	0.50	1.00	1.00	2.00
Distance from Lineament	0.11	0.13	0.14	0.17	0.30	0.33	0.50	0.50	1.00	1.00
NDVI	0.10	0.11	0.13	0.14	0.10	0.25	0.33	0.33	0.50	1.00
Total	2.9	4.7	7.6	11.3	28.9	22.4	29.3	32.8	37.5	46.0

Table 10: Calculation of Pair wise Comparison.

Standardized Matrix:

	Stanardized Matrix										
	NDVI	Distance from Line	Land Use Lan	Distance from I	Distance from	Soil	Geomorphology	Rainfall	Slope	Geology	Influence %
Geology	0.35	0.42	0.40	0.35	0.24	0.27	0.24	0.18	0.21	0.20	28.58
Slope	0.17	0.21	0.26	0.26	0.21	0.22	0.20	0.15	0.19	0.17	20.61
Rainfall	0.12	0.11	0.13	0.18	0.17	0.18	0.17	0.18	0.16	0.15	15.46
Geomorphology	0.09	0.07	0.07	0.09	0.14	0.13	0.14	0.15	0.13	0.13	11.36
Soil	0.05	0.04	0.03	0.02	0.10	0.09	0.10	0.12	0.11	0.11	7.66
Distance from Road	0.06	0.04	0.03	0.03	0.07	0.04	0.07	0.09	0.08	0.09	6.03
Distance from Drainage	0.05	0.04	0.03	0.02	0.03	0.02	0.03	0.06	0.05	0.07	4.04
Land Use Land Cover	0.04	0.03	0.02	0.02	0.02	0.01	0.02	0.03	0.03	0.04	2.63
Distance from Lineament	0.04	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.02	2.04
NDVI	0.03	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.02	1.58

Table 11: Calculation of Standardized Matrix.

All causative parameters were reclassified in **ArcGIS using Reclassify tool.** As we observe the above table that intensity values are from 1 to 9 which distributing scale of landslides, 1 indicates less contribution for landslides as well as 9 represents high contribution. The weights are very for each class because the variation in the influence.

Finally overlay analysis have done for all causative landslides parameters using weighted overlay tool in spatial analyst tool in ArcGIS 10.3.

SL.No	Thematic Layer	Classes	Weight
1	Geology	Gneiss	6
		Granite	5
		Schist	9
		Glaciers	2
		Semi-consolidated	2
2	Slope	0 - 17	2
		17 - 35	6
		35 - 50	8
		50 - 70	7
		70 - 80	6
3	Rainfall	0 - 60	1
		60 - 120	3
		120 - 180	4
		180 - 240	6
		240 - 300	8
4	Geomorphology	Hilly and Low Dissected	2
		Hilly and Moderately Dissected	5
		Hilly and Highly Dissected	8
5	Soil	Lithosols	2
		Gleysol/Humic Acrisols	3
		Dystric Cambisols	5
		Dystric Regosols	8
6	Distance from Road	0 - 300	1
		300 - 600	2
		600 - 900	3
		900 -1200	4
		1200 - 1500	5

6	Distance from Road	0 - 300	1	6
		300 - 600	2	
		600 - 900	3	
		900 -1200	4	
		1200 - 1500	5	
		1500 - 1800	6	
		1800 - 2300	7	
		2300 - 2600	8	
		2600 - 2900	9	
7	Distance from Linea-ment	0 - 400	1	7
		400 - 800	2	
		800 - 1200	3	
		1200 - 1600	4	
		1600 - 2000	5	
		2000 - 2400	6	
		2400 - 2800	7	
		2800 - 3200	8	
		3200 - 3600	9	
8	Land Use Land Cover	Barren Land	0	8
		Snow & Ice	1	
		Grassland	2	
		Evergreen Forest	3	
		Water Bodies	5	
		Built-up Land	7	
		Cropland	8	
9	Distance from Road	0 - 200	1	9
		200 - 400	2	
		400 - 600	3	
		600 - 800	4	
		800 - 1000	5	
		1000 1200	6	
		1200 - 1400	7	
		1400 - 1600	8	
		1600 - 1800	9	
10	NDVI	Very Less	5	10
		Less	4	
		Moderate	3	
		High	2	
		Very High	1	

Table 12: Weightage and ranks for all parameters.

13. Analysis:

Landslide causative factors:

As we already discussed regarding causative factors for occurrence of landslides. The selected parameters have been taken according to their influence, those are:

- Slope.
- Aspect.
- Distance to Drainage.
- Distance to Lineaments.
- Distance to Road.
- Normalized Difference Vegetation Index NDVI.
- Soil.
- Land Use Land Cover.
- Geomorphology.
- Geology.
- Rainfall.

Selected causative landslides factors are containing both:

Continues (Rainfall, Aspect, Slope, Distance to Drainage, Distance to Lineaments, Distance to Road and NDVI).

Discrete factors are (Soil, LULC, Geology and Geomorphology).

Both Natural and artificial (Human Causative) factors are also selected to identify susceptible landslide areas.

DEM: Digital elevation model was collected from Alos DEM, it is an open source with 12.5 meter spatial resolution from Alos DEM website which is used for creating Slope and Aspect layers for further susceptibility analysis.

13.1 Geology:

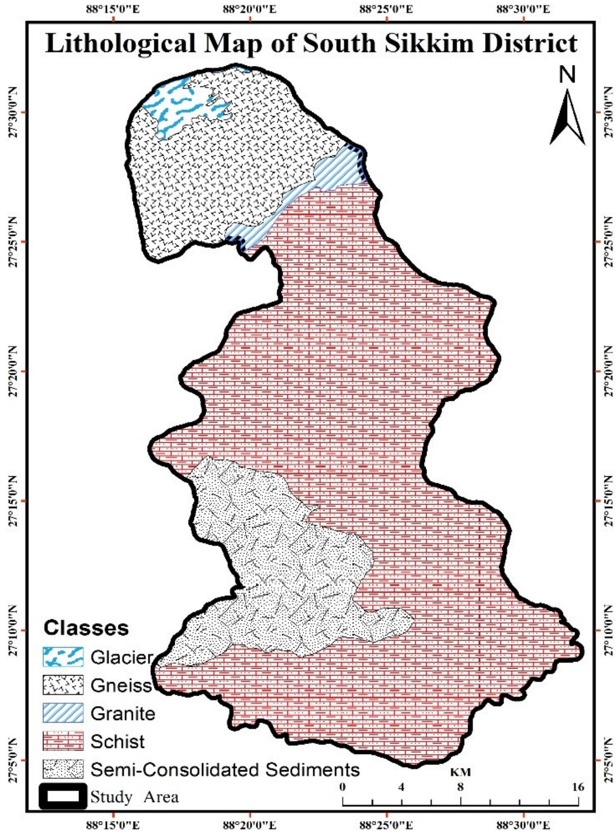


Fig 14: Geological Map of South Sikkim.

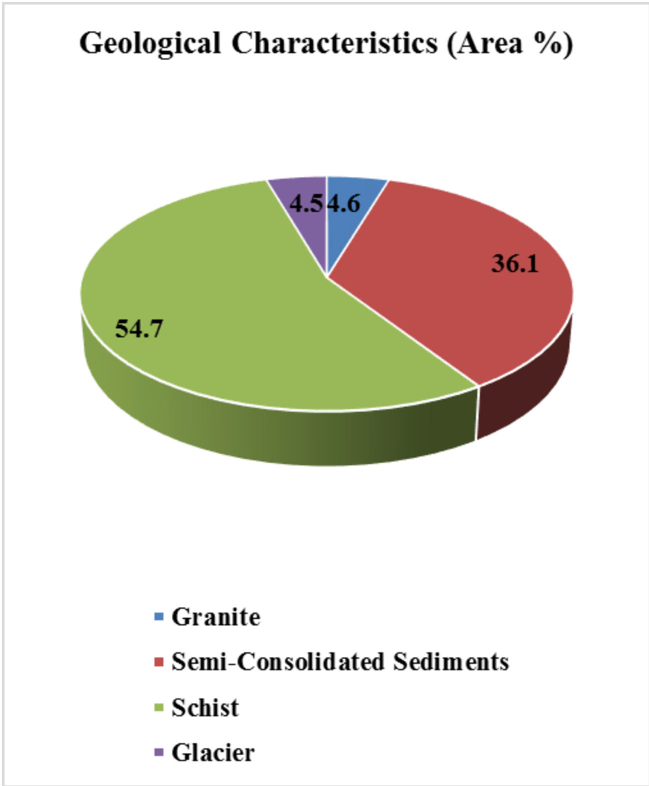


Chart: Percentage of area for geological characteristics.

Geology map was collected from North Eastern space Application centre, geological factor is one of the most causative factor which makes slopes instable and cause landslides where the degree of slopes are high. Calculated area of different groups to identify the dominance and influence. South Sikkim is mainly dominant by schist which covers 54.7% of its total Geographical area and mainly concentrated in central and southern parts of south Sikkim. It is highly weathered and denudes very easily and according to the landslide inventory data, more landslides are occurred under the schist zone. South western parts of Sikkim is dominated by semi-consolidated sediments which is more permeable and more causative for landslides occurrence

13.2 Slope:

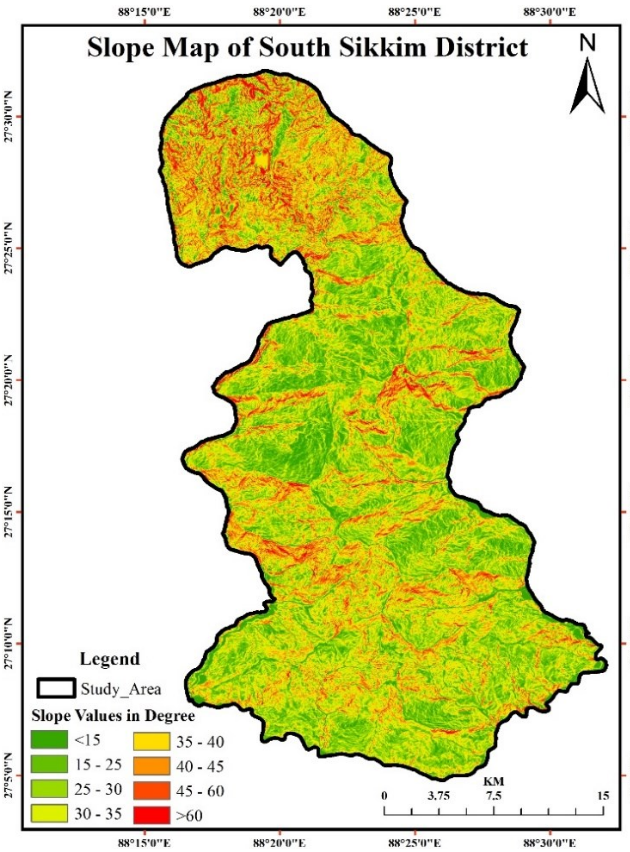


Fig: Slope map f Sikkim.

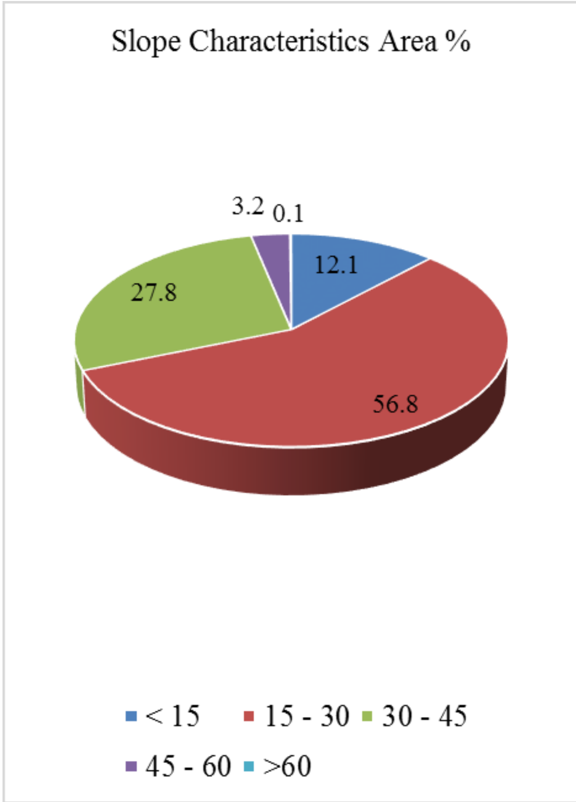


Chart : Slope classes in area in percentage

Slope refers to the horizontal height divided by the vertical height. By using Pythagoras theorem we can find slope and tan inverse function will give us the slope of the area. the rainfall intensity, soil moisture and exposure to sunlight/wind of slopedeposit are strongly controlled by terrain aspect

The main parameter of the Landslide analysis is the slope degree. Because the slope degree is directly related to the landslides Slopes are prominent factor for occurrence of landslides which makes . Steeper the slope more are the chances of the occurrence of landslides.

Slope map is generated from Alos DEM which is 12.5 meter resolution, collected from Alos DEM. Slopes are classified into 8 class (>15, 15-30, 30-45, 45-60, >60).

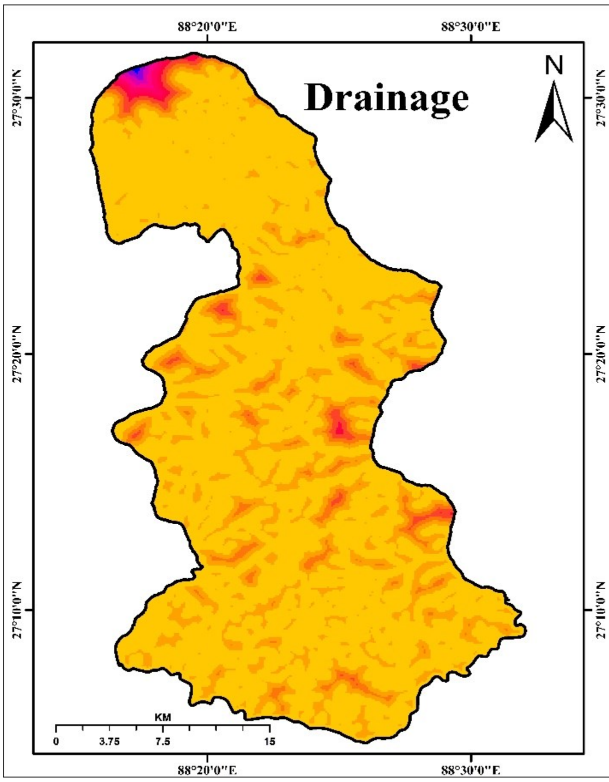


Fig: Drainage density map of Sikkim

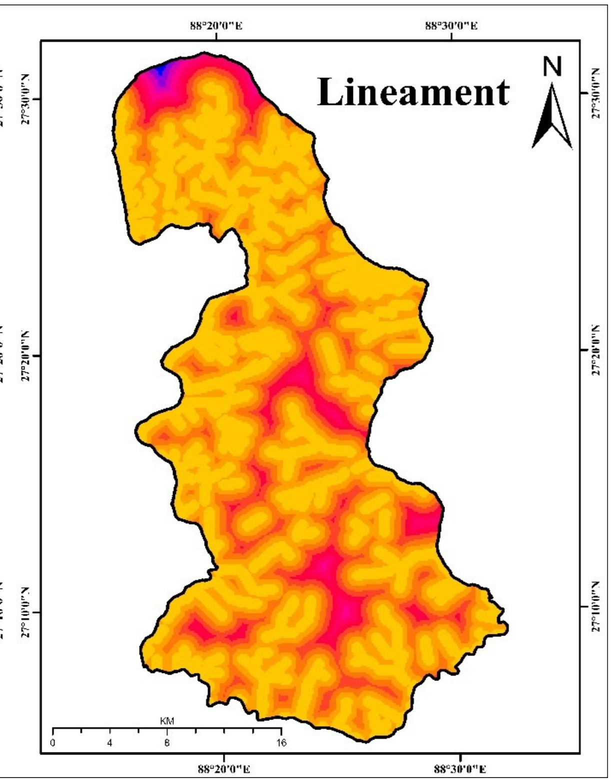


Fig: Lineament density map of Sikkim.

13.3 Drainage Density:

Drainage density map generated from Drainage map which is collated from **North Eastern Application Centre,** using Euclidean distance tool in Arc GIS 10.3.it is refers to that more streams indicate more density and also explain degree of susceptibility according to distance. Drainage density more at rugged terrain areas as compared to other. It is also a one of the major factor for occurrence of landslides. (0 -200, 200-400,400 -600, 600-800, 800- 1000, 1000-1200, 1200- 1400, 1400-1600, 1600-1800).

13.4 Lineaments:

Many landslides happen for the most part in and around this weaker plane. The lineaments are parallel to the (buffers) to these structures increments the likely-hood of event of avalanches as specific disintegration, and movement of water along basic planes advances such phenomena Lineaments layer provided by **North Eastern Application Centre**, Proximity have created for lineaments to show the distance variation in meters using Euclidean distance in spatial analyst. the river it self a lineament and most of the faults are present along the river sides.

tool using ArcGIS. The interval have given as a default, intervals are (0 -200, 200-400,400 - 600, 600-800, 800- 1000, 1000-1200, 1200- 1400, 1400-1600, 1600-1800).

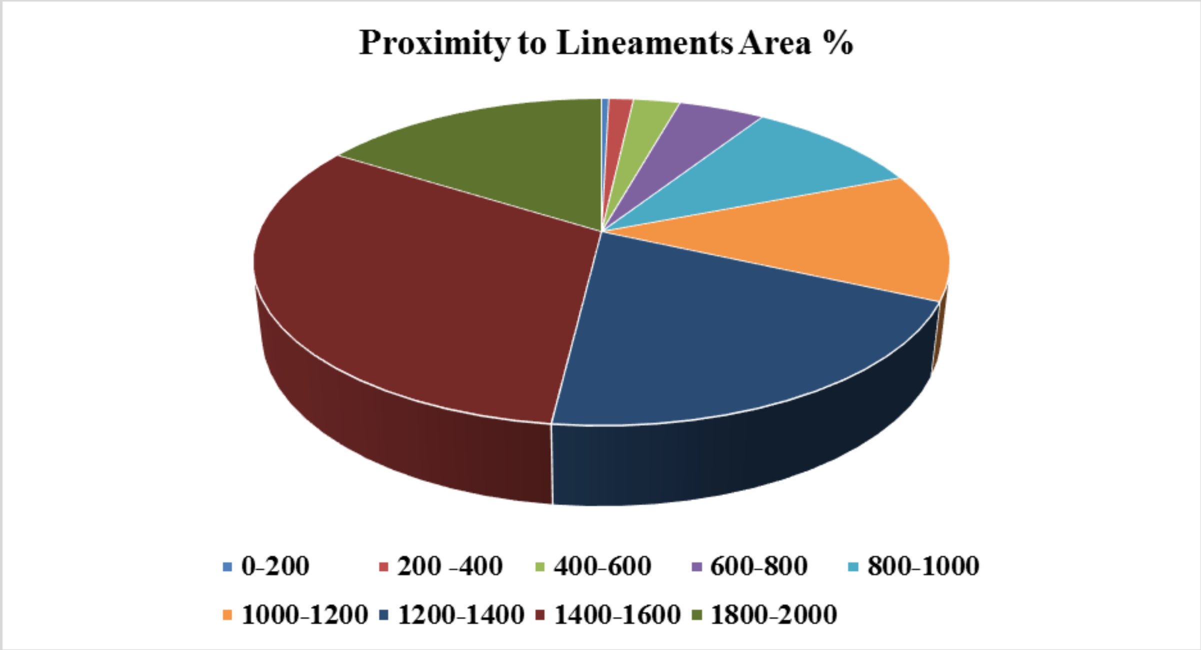


Chart :

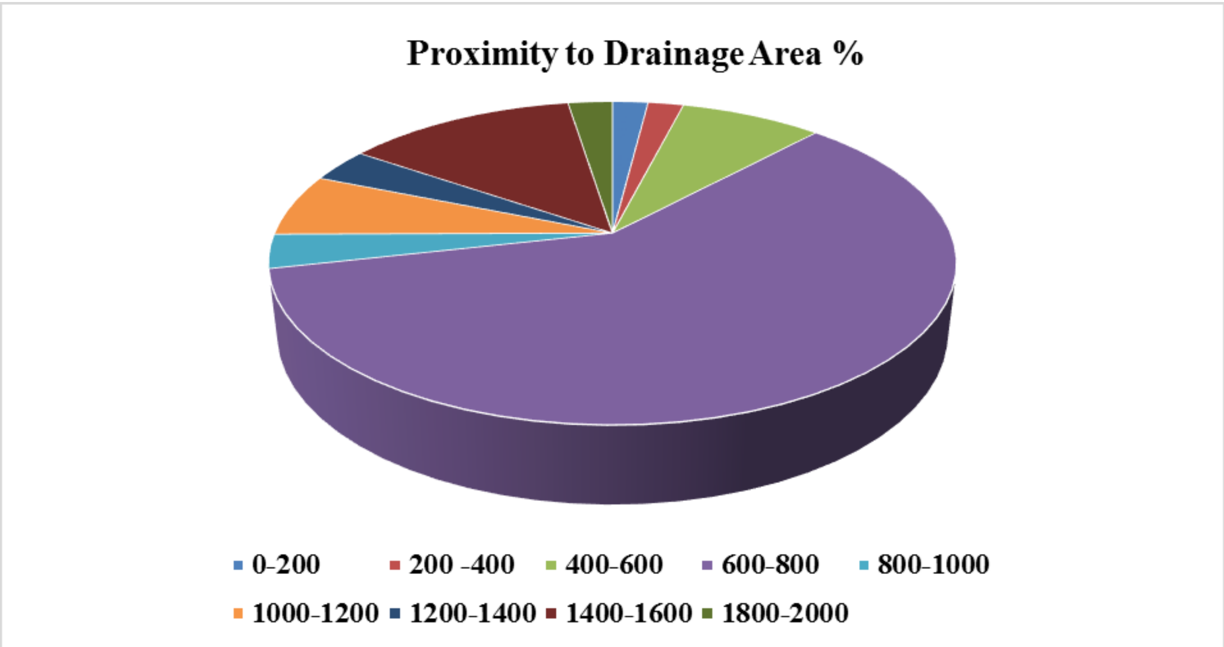


Chart:

13.5 Normalized Difference Vegetation Index:

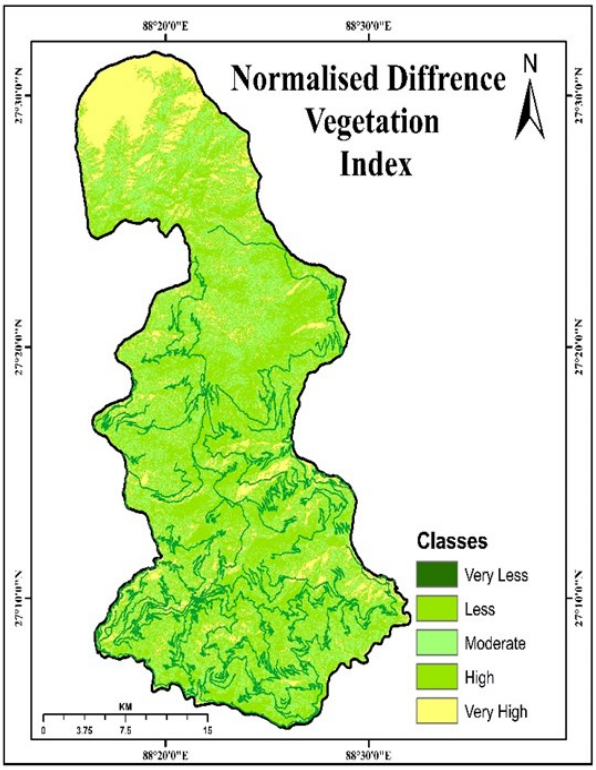


Fig: NDVI map of South Sikkim

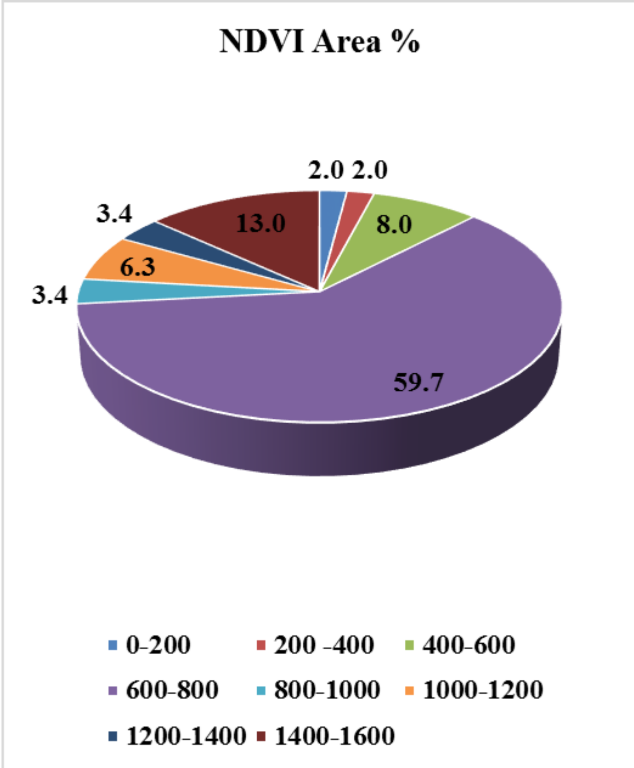


Chart: NDVI Classes area in %

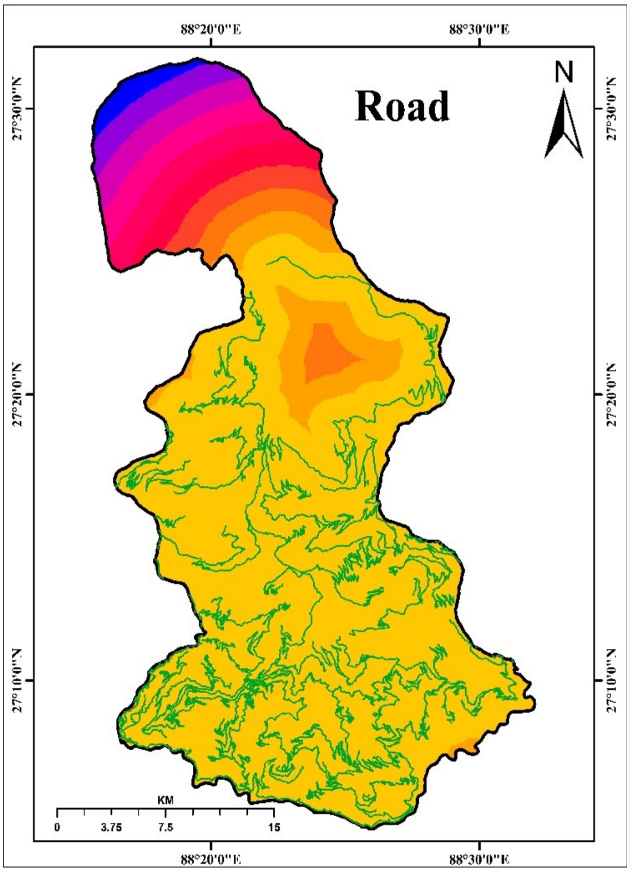
Normalized Difference Vegetation Index prepared from sentinel-2 image with 10 meter resolution,

$$NDVI = \frac{(NIR-R)}{(NIR+R)}$$

NDVI map generated using Raster Calculator in Arc GIS 10.3 software.

Development of rainfall-triggered avalanches, and changes to vegetation cover regularly result in adjusted avalanche conduct. Pioneers moved into the back nation and changed over broad slope ranges from local timberland and bush to field. This diminished the quality of the Regolith and rendered the inclines more vulnerable for landslides.

13.6 Distance to Road:



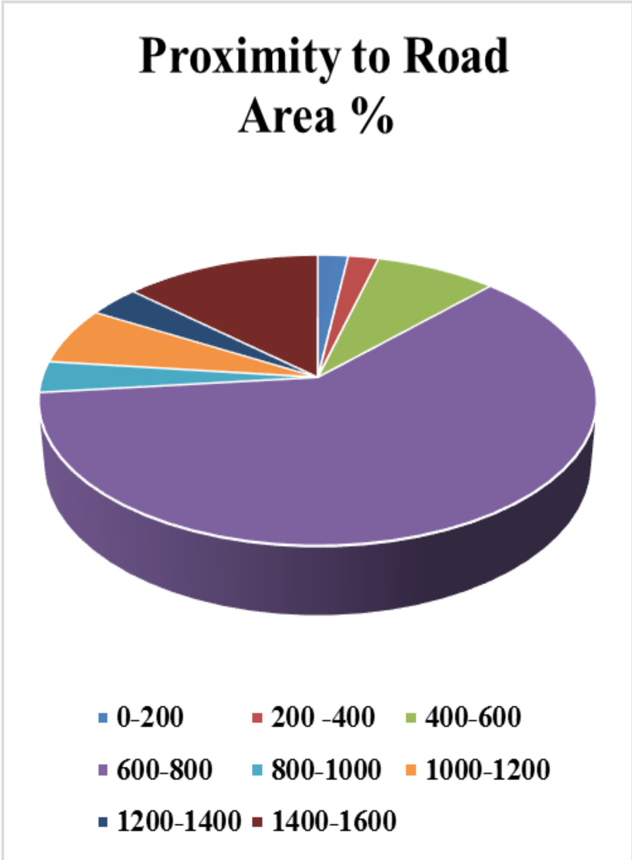


Fig: Road map of south Sikkim **Chart:**

Road map collected from north eastern space application centre Road sides are more susceptible for landslides due to make changes in the landscape .

One of the controlling factors for the stability of slopes is road construction activity. However, in the present study area, road access was prime factor of forest degradation. As a result, many landslides are prominent in the degraded forest area. Thus, density of road map was generated as per the hypothesis that slope failure may be more frequent along roads and trails, owing to excessive forest declination along the roads and trails. Using the road network map of South Sikkim. The region has better road accessibility than Munguthang.

13.7 Land Use Land Cover:

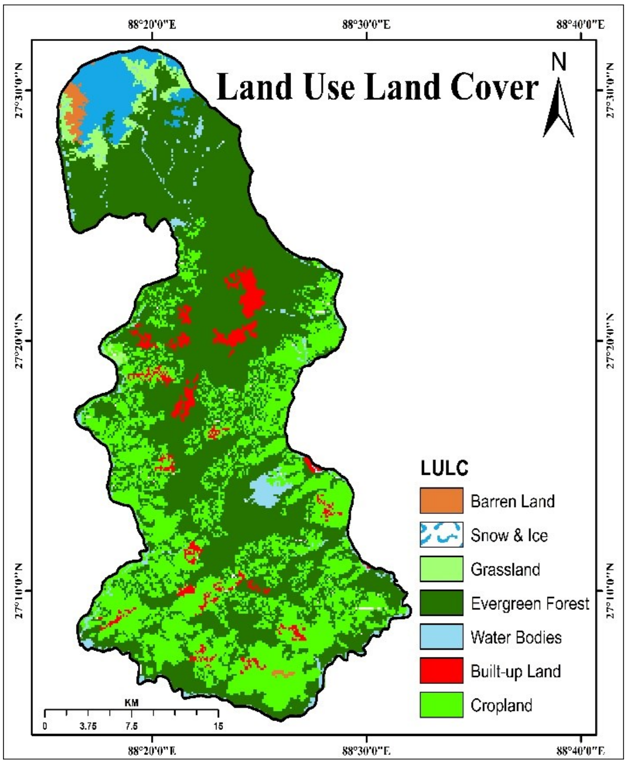


Fig: LULC map of Sikkim.

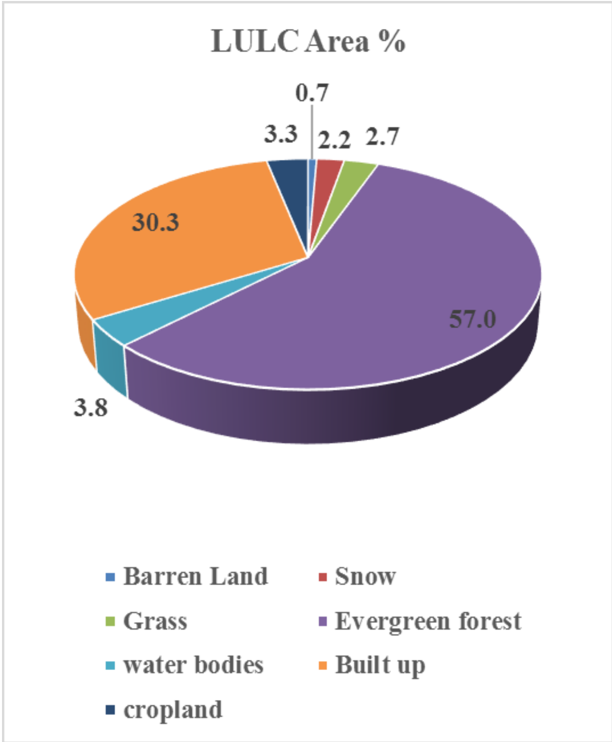


Chart: lulc area in %

Land use land cover map have collected from Earth data, NASA. After the area of interest was clipped from area of interest.

Land cover indicates the physical land type such as forest or open water whereas land use documents how people are using the land. Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types.

According to various classical as well as neo-classical theories of land use, the land use practices are influenced by the socio-economic factors like locational factors of land use and social customs and traditions of landholders, tenancy status and the consumption patterns of the farming communities, at micro-aerial scale, but at macro level the land operations and land use intensifications accelerated by physical factors of land, namely, the relief features, geological structure, soil characteristics and climatic conditions.

13.8 Soil:

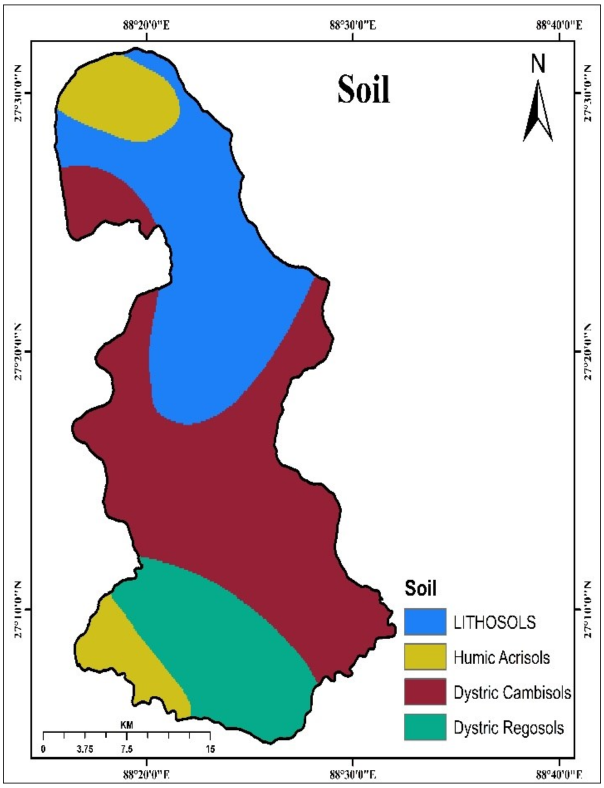


Fig: Soil map south Sikkim.

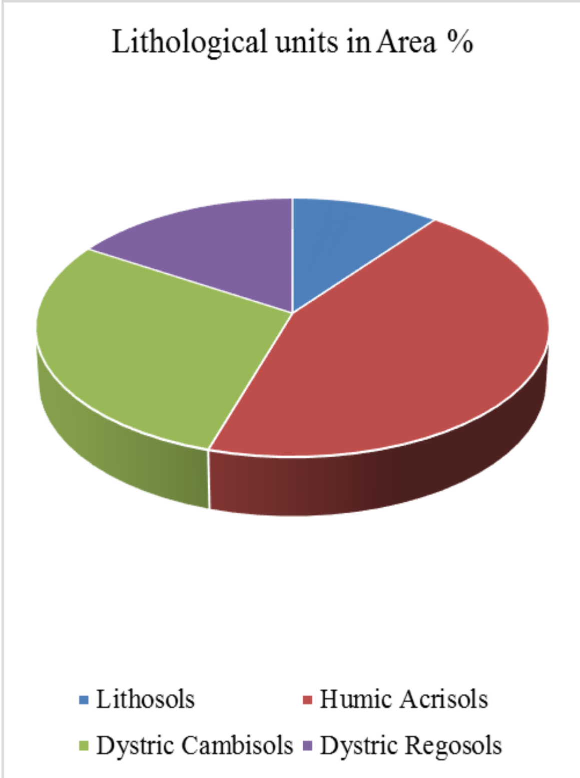


Chart: Soil units in area %

Soil map was collected from Food and Agriculture Organization of the United Nations and re-classified using reclassify tool in Arc GIS. The soil types are Lithosols, Humic Acssols, Dystric Cambisols, Dystric Regosols.

The soil of Sikkim contains medium nutrient and moisture. Soil moisture has an overt impact on forest type and coverage in area. The state primarily consists of gneissose rocks and half-schistose rocks. The first type of rock is brown clay and generally shallow and poor. These groups of rocks are typically crude with high ferric concentration and neutral to acidic and poor organic/mineral nutrients. Most of the evergreen and deciduous forests are carried by this rock.

13.9 Geomorphology:

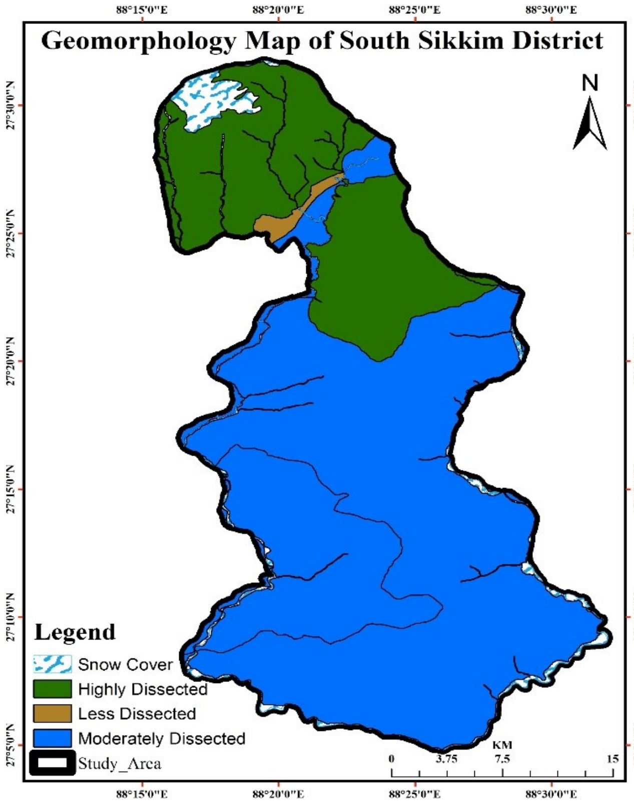


Fig: Geomorphological map of south Sikkim.

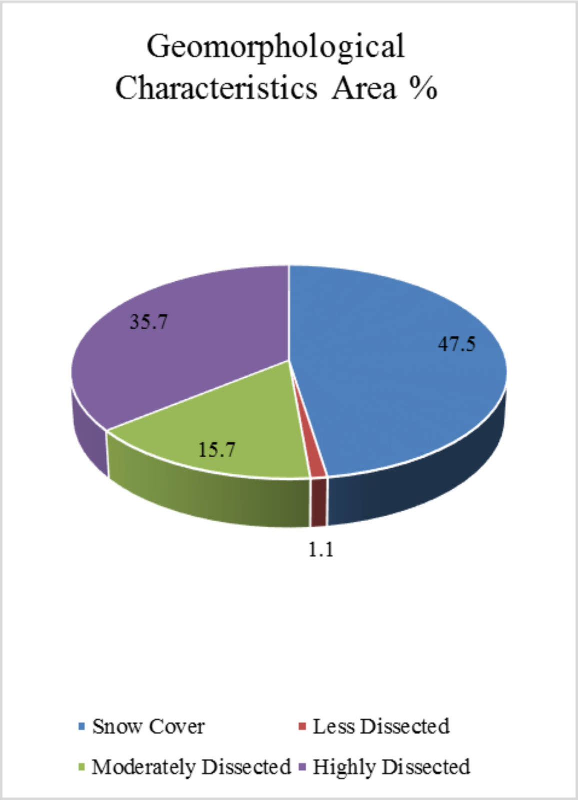


Chart: geomorphological units area %

Geomorphology depicts the present morphological set-up. This is very important since some of the important geomorphic elements give us a clue for the future landslide in that area. The dissection pattern of hills likes the highly dissected hill, moderately and low dissected hills helps in understanding the denudation chronology of the area.

Geomorphology map was provided by North Eastern Space Application Centre, in the study area 3 features are identified:

- Hilly and less dissected area.
- Hilly and moderately dissected areas.
- Hilly and highly dissected areas.

13.10 Rainfall:

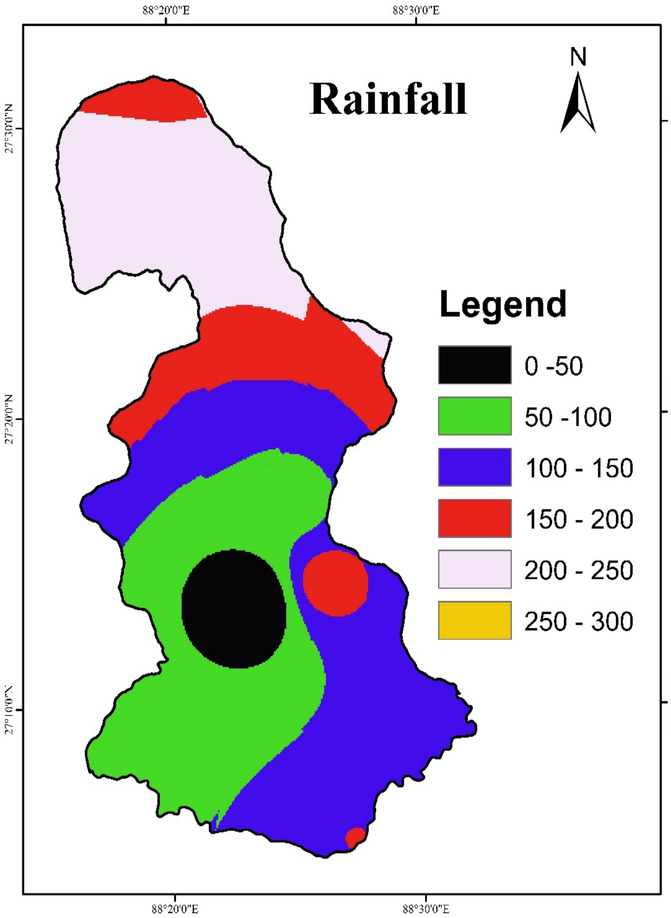


Fig: rainfall of south Sikkim

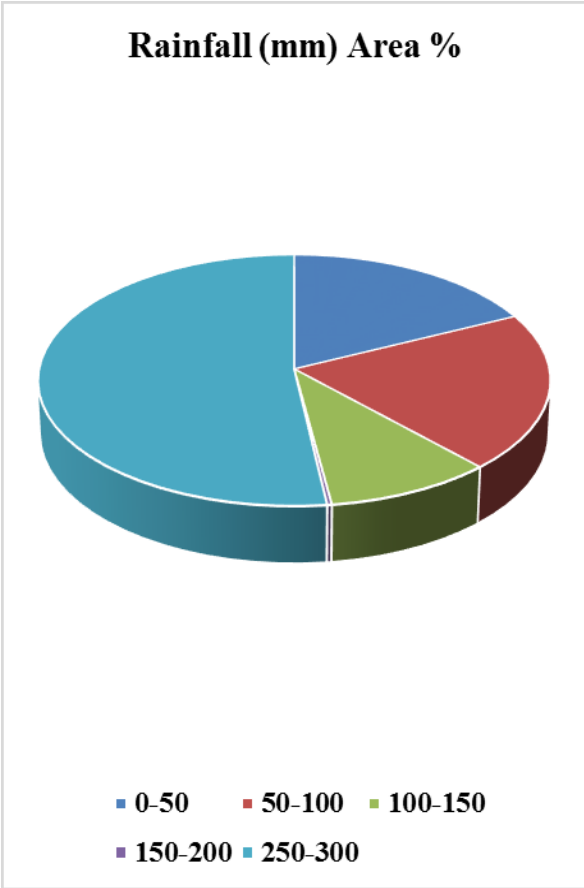


Chart : Rainfall area in %

Rainfall plays a key role in occurrence of landslides and it considered as a one of the major triggering factor. On the other hand heavy precipitation energizes the surface run-off as well as the discharge and erosive capacity of little stream segments. The fast disintegration caused by little rills, ravines and lower order streams specifically influence the incline steadiness by decreasing the cohesiveness of soil.

Rainfall has been collected from Tropical Rainfall measuring mission (**TRMM**), the data has been converted from pixel format to point then interpolated using IDW technique in Spatial Analyst Tool, Arc GIS. The Rainfall values are in mm which are classified in to 6 classes (0-50, 50-100, 100-150, 150-200, 200-250, and 250-300).

14. Results:

Landslide Susceptibility Map of Sikkim:

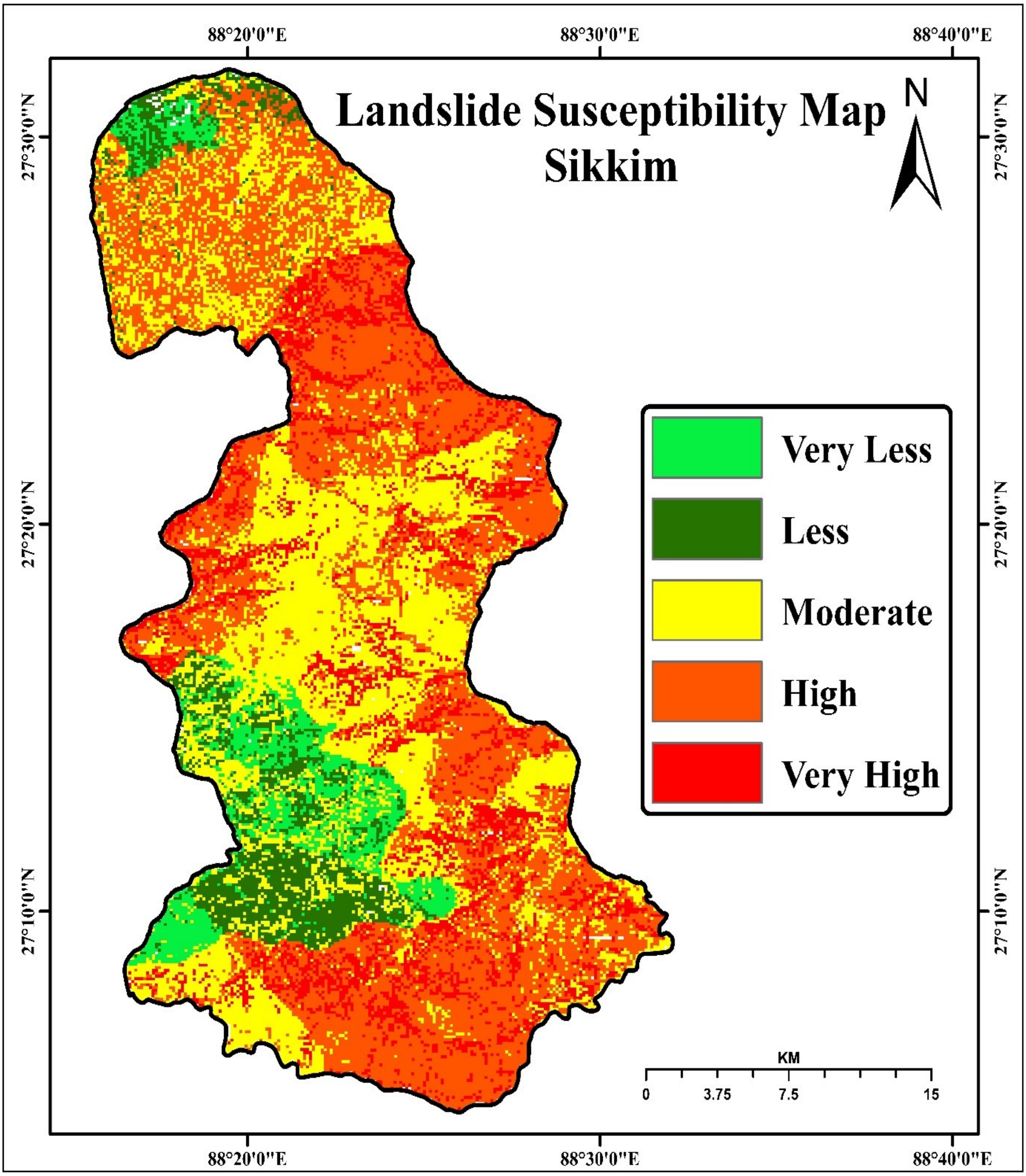


Table: Susceptible area in Area Square kilometres and Area in percentage.

Susceptibility classes	Area Square kilometres	Area in percentage
Very Low	45	6.2%
Low	55	7.6%
Moderate	239	33.0%
High	284	39.2%
Very High	101	14.0%
Total	**724**	**100%**

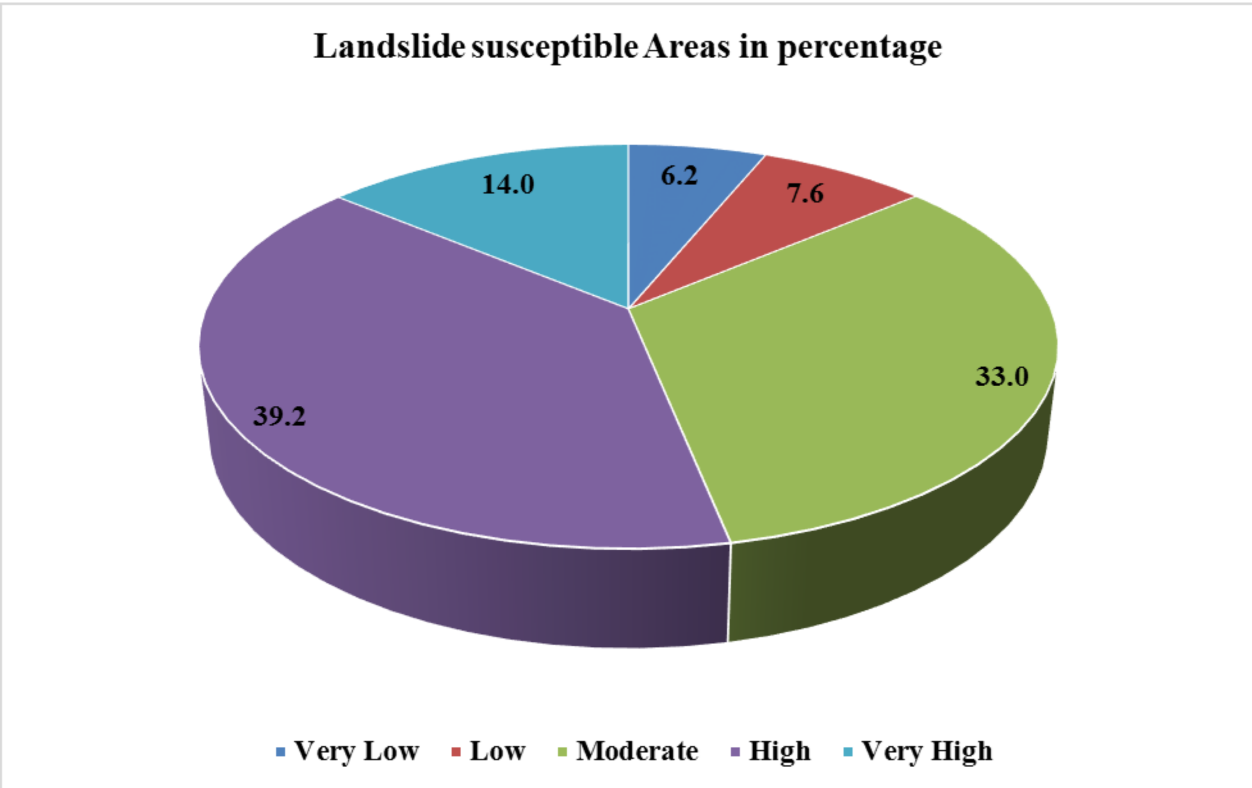


Chart: Landslide susceptible areas in percentage.

15. Discussion:

In this present study AHP model has been used to identify and map landslide susceptibility map by overlay all the causative factors using Arc GIS. The results which shows the spatial distribution of susceptible areas.

The landslide susceptibility map was classified into five Very low, Low, Moderate, High, Very high. The ranks were assigned from very high to very low with the numerical value of 1 – 5 respectively with natural break method.

The results showing that that Overlay Analysis divided study area into five classes which indicates the different levels of susceptibility. After that Raster Pixel values are converted in to shape file to area in sq.km using Arc GIS.

The study explains that susceptible areas are spread unevenly where the 14% (101 sq.km) of the total geographical area is under highly susceptible areas.
This very high susceptible areas are mostly covered the areas of south and central parts of south Sikkim, next 39% (284sq.km) area is under highly susceptible areas mainly concentrated in north and southern parts, 33% (239sq.km) under moderate susceptible areas.
As well as northern tip and south western parts are located under less 6.2% (55sq.km) and very less 7.6% (45 sq.km).

REFERENCES

Ayele, S., Raghuvanshi, T. K., & Kala, P. M. (2014). Application of Remote Sensing and GIS for Landslide Disaster Management: A Case from Abay Gorge, Gohatsion–Dejen Section, Ethiopia. In Landscape Ecology and Water Management (pp. 15-32). Springer Japan.

LM Bilwa et al (2015), Identification of Potential Landslide Hazard Zonation Mapping using Geoinformatics for Kohima region, Nagaland, India.

Sarkar, S., Roy, A.K. and Martha, T.R., 2013. Landslide susceptibility assessment using Information Value method in parts of the Darjeeling Himalayas. Journal society of India. 82, pp. 351-362.

Van Westen C.J., Rengers, N. And Soeters, R., 2003. Use of Geomorphological Information in Indirect Landslide Susceptibility Assessment. Natural Hazards,30, pp.399-419.

Lallianthanga, R. K., & Lalbiakmawia, F. (2013). Micro-Level Landslide Hazard Zonation of Saitual Town, Mizoram, India Using Remote Sensing and GIS Techniques. International Journal of Engineering Sciences & Research Technology, 2(9), 2631-2546.

Huang, J. (2014). Investigation on landslide susceptibility using remote sensing and GIS methods.

Ayalew L., Yamagishi H. and Ugawa N. (2004), 'Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River', Niigata Prefecture, Japan. Landslides 1, pp.73-81

Clerici A., Perego S., Tellini C. and Vescovi P. (2002), 'A Procedure for landslide susceptibility zonation by the conditional analysis method', International Journal of Geomorphology, Vol. 48, pp. 349-364.

Gokceoglu C. and Aksoy H. (1996), 'Landslide susceptibility mapping of the slopes in the residual soils of the Mengen region (Turkey) by deterministic stability analyses and image processing techniques', Engineering Geology, Vol. 44, pp. 147-161.

Komac M. (2006), 'A landslide susceptibility model using the analytical hierarchy process method and multivariate statistics in perialpine Slovenia', Geomorphology, Vol. 74, pp. 17-28.

Megotsohe Chasie and P.K.Theophilus, GSI (2016), "Preparation of Landslide Susceptible Maps(1:50,000 scale) for Mountainous/ Hilly Terrain in Toposheet nos. 83K/2, K/6 & G/14 (Parts of Kohima, Phek, Peren & Dimapur Districts, Nagaland and Senapati District, Manipur)"

Van Westen, C. J., Castellanos, E., & Kuriakose, S. L. (2008). Spatial data for landslide susceptibility, hazard, and vulnerability assessment: an overview. Engineering geology, 102(3-4), 112-131.

Pradhan, B., & Lee, S. (2010). Landslide susceptibility assessment and factor effect analysis: backpropagation artificial neural networks and their comparison with frequency ratio and bivariate logistic regression modelling. Environmental Modelling & Software, 25(6), 747-759.

Kilburn, C. R., & Pasuto, A. (2003). Major risk from rapid, large-volume landslides in Europe (EU Project RUNOUT). Geomorphology, 54(1-2), 3-9.

Dai F.C. and Lee C.F. (2002a), 'Landslide characteristics and slope instability modelling using GIS, Lantau Island, Hongkong', Int. Journal of Geomorphology, Vol. 42, pp. 213-218.

Dai F.C., Lee C.F. and Ngai Y.Y. (2002b), 'Landslide risk assessment and management: an overview', Int. J. Engineering Geology, Vol. 64, pp. 65-87.

6. Wilcke W., Valladarez H., Stoyan R., Yasin S., Valarezo C. and Zech W. (2003), 'Soil properties and a chronosequence of landslides in mountain rain forest, Educator', International Journal of CATENA, Vol. 53, pp. 79-95.