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PART ONE

Abstract

Natural Hazard events such as earthquakes, landslides, flash floods, urban / forest fire, hailstorm, thunder lightening etc. in the Sikkim are reality. Man and man-made structure stand no chance against the awesome power and furry of such disaster when they strike. Therefore, a mechanism is needed to safeguard against massive and unwarranted loss of life and property in the event of such calamity. Solution to counter these trends exists and the knowledge and technology necessary to apply them are widely available. Disaster reduction is the sum of all the action which can be undertaken to reduce the vulnerability of a society to natural hazards. The solution includes proper land-use planning, aided by vulnerability mapping, to relocate people in safe areas, the adaptation of proper building codes in support of disaster resilient engineering, based on local multi hazard risk assessment/maps. The proposal of this assignment is to identify and map composite risk for the State of Sikkim and prepare a Composite Risk Atlas for the State. As part of the hazard risk and vulnerability assessment, in-depth analysis in relation to identified/ selected hazard risks along with relative vulnerability were undertaken. The Land Revenue and Disaster Management Department and State Disaster Management Authority databases are a part of an integrated control system designed to administrate and control Disaster. Therefore the Hazard Risk and Vulnerability assessment was conducted by SSDMA (Sikkim State Disaster Management Authority) based on the technical data made available by Department of Mines, Minerals and Geology, Government of Sikkim along with other Governmental and Non-governmental central and state government organizations were GIS mapping was prepared by Disha Services.

1. Justification/rational of the study

At the State level Multi Hazard databases information can be geo referenced to address coordinates or to a large scale field Atlas map and managed as Multi Hazards atlas of Sikkim. Data from the Central Multi Hazard databases should include information about the thirty one disaster identified by the Govt. of India, primarily hazard risks for earthquakes, landslides, floods, wind and cyclone & associated vulnerability across physical, social and economic elements specific to Sikkim. Forest fire and climate change induced hazard risks should be analysed. For the purpose of analysis, the assignment seeks to examine the hazard risk and vulnerability at the District, Sub-District and Gram Panchayat Level. It will be pragmatic to focus the first level of assessment at the District Level. The detailed geographical analysis will depend after examining the datasets. This information is made available and visualized through the established connection. Data collection and analysis are clearly necessary for the initial production of this Atlas and its later updating.

2. Objectives of the MHRVA

The objective of Multi Hazard Risk and Vulnerability Assessment (HRVA) is to help a community and make risk-based choices to address vulnerabilities, mitigate hazards and prepare for response and recovery from hazard events. Risk-based means based on informed choices of alternate unwanted outcomes. In other words, communities make risk reduction choices based on the acceptability of consequences and the frequency of hazards. The intent of this Hazard Risk and Vulnerability Assessment is to provide a basis from which local planners, politicians, and responders can create or update the Regional emergency plan, allocate resources for risk mitigation, enhance community preparedness, and prepare budgets for cost-effective, on-going emergency planning. This assessment is based on both primary and secondary sources. Both quantitative and qualitative methods are used to determine hazard ratings for the area of interest.

Considering **hazards** alone may lead to a skewed set of priorities for action. It is equally important to consider the **severity** of possible impacts from the hazard as well as the frequency or **likelihood** of a hazard event occurring. The combination of severity and likelihood is termed the **level of risk**. In determining the severity of a hazard event, a community's vulnerability must be examined. **Vulnerability** is defined as people, property, infrastructure, industry and resources, or environments that are particularly exposed to adverse impact from a hazard event. Hazards reflects the frequency of occurrence for a particular hazard event and can range from rare events occurring every 50 years to more frequent events, which usually have a high number of recorded incidents or anecdotal evidence.

This MHRVA is designed to provide an assessment of the hazards that may present District wise risks to the Sikkim. The objective of the MHRVA is to:

- 1. Investigate prominent natural and human-caused events.
- 2. Identify the various hazards affected by that area and hazards likely to occur in Sikkim.
- 3. Identify any threats that may require a timely and coordinated response to protect lives, property, and to reduce economic losses.
- 4. Evaluation of the effectiveness of the mitigation and emergency plans and implementation of training activities such as simulation, seminars and workshops.

3. Methodology

Hazard risk, vulnerability and composite risk are specific technical terms with analytical implications. The study was focus on composite risk. In order to prioritize mitigation investments the study was focus on the development of composite risk maps at the District, Sub-District and Gram Panchayat level. The main objective is to undertake multi-hazard risk and vulnerability and risk assessment. The study objective identified hazard risks of geological and hydro-meteorological origin. Probabilistic models will be used in almost all the

cases, and for events of low probability and high intensity events deterministic models shall be used. It is assumed in this offering that the primary outcome will be a risk assessment within which hazard risk and vulnerability assessments are sub-components. This study is much wider than a conventional hazard assessment as it assesses the vulnerability of elements at risk and further aggregate to composite risk. This offering has scoped out collateral hazards associated with the state specific hazard risks. A Hazard risk and composite risk database was developed containing themes of both administrative and topographic origin, including high resolution digital maps. The digital map was then connected to the Multi Hazard Risk and Vulnerability Atlas (MHRVA) enabling data such earthquakes, Landslides, flash floods, wind and cyclone & associated vulnerability across physical, social and economic elements specific to Sikkim. Forest fire and climate change induced hazard risks were also analyzed at the ground level. The objective was to enable analysis at higher chorological level by aggregating the high resolution data from lower levels. Ouestionnaires were filled at spot. The interviews are used to check the land use information in the database. Field investigations were conducted to verify the digital maps. By use of linear transects of different size and resolution knowledge on errors generalization level is derived regarding the digital maps. The aerial photos, imagery provided by the Land Revenue and Disaster Management, Sikkim State Disaster Management Authority were used to select the best-suited maps for analysis at specific chorological levels. The maps were then used in the process of up scaling. This up scaling was only possible by using of the computer software databases that was verified by the Integrated transect method at micro and meso chore level.

HRVA risk rating interpretation

These risks are *low*. Implementation of mitigation measures will enhance emergency preparedness but it is of less urgency and highly unlikely to occur in that area than the following hazards.

These risks are **medium low**. Implementation of mitigation measures will enhance emergency preparedness. Hazards are highly unlikely to occur in that area, but are of more urgency than *low*

These risks are **medium**. These hazards have intermediate levels of frequency and severity. Hazards classified as moderate are more urgent than medium low hazards and are often common place concerns. Given this, moderate level hazards should be addressed with an appropriate level of urgency.

These risks are **medium high**. These hazards warrant review and development of mitigation actions to reduce the risk to an acceptable level. But these hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

These risks are **very high**. These hazards are both frequent and are of high severity. These hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

Hazards

This HRVA is designed to provide an assessment of the hazards that may present risks to the Sikkim. However, the following hazards are most likely to occur and may result in significant consequences. Each hazard is examined to assess the relative risks to the community and to highlight opportunities for mitigation and coordinated response. In this analysis, extensive background and historical research was compiled and considered in the context of severity and likelihood to assess the hazard risk.

Components for Assessment of Multi Hazards Risk Vulnerability Assessment (MHRVA)

MHRVA are being undertaken where the following hazards are considered district wise for the state of Sikkim as per IS codes and other requisite data from the field, which is required for Multi Hazards Risk Vulnerability Assessment Study as below:-

- a) Landslide hazards.
- b) Earthquake hazards.
- c) Fire hazards.
- d) Flood/ flash floods hazards.
- e) Snow Avalanches hazards.
- f) Drought hazards.
- g) Hailstorm, Thundering and lightening hazards.
- h) Riots and stamped.

LANDSLIDE

The term landslide describes a wide variety of processes, including debris avalanches, debris flows, and other rapid mass wasting events which result in the rapid downward and outward movement of soil, rock and vegetation under the force of gravity. Rock falls occur when rocks fall freely from a cliff face. A submarine slide is the movement of materials involving water charged and coarse-grained sediment flowing rapidly on underwater slopes or channels. If the volume of sediment is sufficient, submarine slides can potentially displace enough water to generate destructive surface waves, also known as local marine tsunamis. Landslide events occur when the slope reaches a critical level of instability and may be triggered by rains, flooding, seismic events, and other factors. Slope instability may be variable (i.e. caused by such factors as heavy rain and changes in ground water levels), it may be transient, as in the case of seismic activity or it may be inherent due to the weak composition of the soil or rock structures. New environmental conditions such as those resulting from the removal of vegetation due to construction may also create instability in slopes. Landslides may damage or destroy critical infrastructure such as power and telephone lines, municipal water facilities, waste water facilities, and hazardous materials storage sites.

Landslide Hazard Zonation Mapping (LHZ)

The aim of LHZ mapping, which is needed for risk assessment, is to determine the spatial and temporal extent of a landslide hazard. In general the LHZ map divides the landslide prone hilly terrain into different zones according to the relative degree of susceptibility to landslides. This requires the identification of those areas that are, or could be affected by landslides, and the assessment of the probability of such landslides occurring within a specific period of time. Commenting on the time domain of landslide occurrence through zonation mapping is a difficult task. Due to conceptual and operational limitations, landslide hazard zonation is conceptually stated as Landslide Susceptibility Zonation (LSZ). The spatial prediction of landslides is termed as landslide susceptibility, which is a function of landslide and landslide related internal factors (i.e., ground characteristics). The aim is to identify places of landslide occurrence over a region on the basis of a set of physical parameters. LSZ can be formally defined as the division of the land surface into near-homogeneous zones and then ranking these according to the degree of actual or potential hazard due to landslides. The LSZ maps do not directly incorporate the time and magnitude of landslide occurrences. Since LSZ is conceptually accepted as LHZ, it is popularly referred to as LHZ all over India. A landslide risk zonation map integrates the landslide hazard, vulnerability, and a quantification of the elements at risk. It cannot be developed unless an LHZ map is prepared. An important input for the preparation of an LHZ map is a landslide inventory database, which is not yet available in India. Thus, a landslide hazard assessment broadly involves the preparation of a landslide inventory, a landslide hazard zonation map, followed by a landslide risk zonation map. An LHZ map requires the division of an area into several zones, indicating the progressive levels of the landslide hazard. The number of zones into which a territory is divided is generally arbitrary. Landslide hazard zonation entails the mapping of all the possible landslides and landslide-induced hazards in the required detail. The hazard maps are designed to limit the information to the users' requirements, and to present it in a form comprehensible to them. Indeed, the users' maps ought to be different from those prepared by, or for Graded landslide hazard maps are required by, among others, specialists. developmental planners as tools for the efficient management of land and its resources. Landslide hazard maps are also essential for the assessment of damage potential, and for the quantification of risks. Scientific forecasting of a landslide for early warning finds its first clue in the landslide hazard map of the area. It is necessary to understand the conditions and landslide control, and to determine existing landslide hazards if future landslide occurrence is to be estimated. A map of existing landslides serves for understanding these the basic data resource conditions and landslides and their relationship with other key processes. Existing parameters—nature of the slope forming material, slope inclination and aspect, land cover, land use, climate, and hydrology-form the basis for hazard assessment. An all-inclusive approach to mapping landslides, starting with the assessment of the regional, geological and geomorphological settings, and then focusing on a detailed scale is recommended. A comprehensive view of the terrain is needed to identify all the possible problems associated

with slope conditions, including existing and potential instability. It is necessary to review the impact of geological features located beyond the boundaries of the site that could influence the status of the hazard in the future. There may be vital evidence of instability processes outside the area in consideration that may not be evident on the site itself, but could have a future impact on the site. The available geological and geomorphological maps form the basic inputs for LHZ mapping. It is not possible to prepare all the thematic maps covering a huge area solely through field work. This problem can be solved with the help of aerial photographs or satellite imagery, followed by limited field checks. The preparation of maps showing landslide hazards includes:

- I. The generation of thematic maps by compiling and collating the observations on geology, geomorphology, land use, land cover, and the distribution of landslide processes, including the use of local records, interpretation of aerial photographs, and high-resolution imagery.
- II. The collection of relevant information on existing landslide hazards and the analysis of potential landslide hazards, including first time landslides.
- III. The identification of areas that could be affected by landslide hazards in future.
- IV. The transformation of process maps into hazard maps identifying the potential for spatial impact and the probability of occurrence of hazards.

Methodology:

In the development of Landslide Hazard Risk and Vulnerability Assessment extensive historical research was conducted along with continuous successive field visit with the development and analysis of the following maps:

- Slope Morphometry Map
- Geological/Lithological Map
- Soil Type Map
- Hydrological Map
- Soil Thickness Map
- Landslide Inventory Map
- Relative Relief Map
- Land Use / Land Cover Map
- Rainfall Map
- Drainage Density

EARTHQUAKE

Earthquakes may cause a number of phenomena, including ground motion, surface faulting, ground failure, and liquefaction. An earthquake's magnitude reflects an earthquake's strength. Damage to buildings generally begins to

occur at magnitude six, while an earthquake above magnitude seven may be a major disaster if it occurs near a populated area. - Sikkim placed in Zone IV/V of the earthquake zonation map of India is subject to high magnitude earthquake tremors. Most of the loss of life in past earthquakes has occurred due to the collapse of buildings, constructed in traditional materials like stone, brick, adobe and wood, which were not particularly engineered to be earthquake resistant. In view of the continued use of such buildings in most countries of the world, it is essential to introduce earthquake resistance features in their construction.

Socio-Economic Considerations in Seismic Safety of Buildings

From the results of studies on the performance of buildings during past earthquakes, it appears that (i) certain building types should entirely be ruled out in seismic zones having probable seismic intensity of VIII or more on Modified Mercalli or the MSK Intensity Scales. This would include earthen houses, random rubble masonry as well as brickwork in-clay mud mortar, and the like; (ii) Rich mortars involving cement and lime should be used in fired brick and coursed stone masonry; and (iii) substantial steel reinforcement should be introduced in the walls in both directions of the building. But there are a number of socio-economic constraints such as the following which do not permit the adoption of high level of safety in the buildings for the masses:

- (i) Lack of concern about seismic safety due to infrequent occurrence of earthquakes;
- (ii) Lack of awareness that buildings could be made earthquake resistant at small additional cost only, hence lack of motivation;
- (iii) Lack of financial resources for additional inputs for meeting earthquake resistance requirements in building construction;
- (iv) Other normal priorities on financial inputs in the daily life of the people;
- (v) Scarcity of cement, steel as well as timber in the developing countries in general; and
- (vi) Lack of skill in a seismic design and construction techniques and unorganized nature of the building sector.

Methodology:

In the development of Earthquake Hazard Risk and Vulnerability Assessment extensive historical research was conducted along with continuous successive field visit with geo-technical assessment of the area.

- Earthquake Inventory Map
- Soil Type Map

- Soil Liquefaction Map
- PGA Map
- Lineament Density Map
- Geological/structural map
- Slope Morphometry

FIRE (FOREST/HUMAN INDUCED)

The most common hazard in forests is forests fire. Forests fires are as old as the forests themselves. They pose a threat not only to the forest wealth but also to the entire regime to fauna and flora seriously disturbing the biodiversity and the ecology and environment of a region. During summer, when there is no rain for months, the forests become littered with dry senescent leaves and twinges, which could burst into flames ignited by the slightest spark. The Himalayan forests have been burning regularly during the last few summers, with colossal loss of vegetation cover of that region.

Causes of Forest Fire

Forest fires are caused by Natural causes as well as manmade causes **Natural causes**- Many forest fires start from natural causes such as lightning which set trees on fire. However, rain extinguishes such fires without causing much damage. High atmospheric temperatures and dryness (low humidity) offer favourable circumstance for a fire to start. **Man made causes**- Fire is caused when a source of fire like naked flame, cigarette or bidi, electric spark or any source of ignition comes into contact with inflammable material.

Methodology:

In the development of Landslide Hazard Risk and Vulnerability Assessment extensive historical research was conducted along with continuous successive field visit with the development and analysis of the following maps:

- Base map
- Fire Inventory Map
- Forest Type Map
- Slope Analysis Map
- Moisture Content Map
- Aspect Analysis Map
- Average Annual Rainfall

DROUGHT

Drought is a period or condition of unusually dry weather within a geographic area where rainfall is normally present. During a drought there is a lack of precipitation. Droughts occur in all climatic zones. However, its characteristics vary significantly from one region to another.

Drought usually results in a water shortage that seriously interferes with human activity. Water-supply reservoirs empty, wells dry up, and crop damage ensues. Its seriousness depends on the degree of the water shortage, size of area affected, and the duration and warmth of the dry period. In many underdeveloped countries, such as India, people place a great demand on water supply. During a drought period there is a lack of water, and thus many of the poor die.

Most precipitation depends on water vapour carried by winds from an ocean or other source of moisture. If these moisture-carrying winds are replaced by winds from a dry region, or if they are modified by downward motion, as in the centre of an anticyclone, the weather is abnormally dry and often persistently cloudless. If the drought period is short, it is known as a dry spell. A dry spell is usually more than 14 days without precipitation, whereas a severe drought may last for years.

Methodology:

In the development of Drought Hazard Risk and Vulnerability Assessment extensive historical research was conducted along with continuous successive field visit with the development and analysis of the following maps:

- Soil Type Map
- Slope Analysis Map
- Surface/Sub-Surface Water Regime Map
- Land Use/Land Cover Map
- Average Annual Rainfall Map

SNOW AVALANCHE

The snow avalanche, a common occurrence in snow covered mountainous regions, is a slide of snow mass down a mountainside. This is a rapid down slope movement of a large detached mass of snow, ice, and associated debris such as rocks and vegetation. Small avalanches, or scuffs, occur in large numbers, while large avalanches that may encompass slopes a kilometre or more in length with millions of tons of snow, occur infrequently but cause most of the damage. Humans have been exposed to the threat of sliding snow for as long as they have inhabited mountainous regions. A large avalanche can run for many kilometres, and result in massive destruction of forests and anything else that comes in its way. These threats are felt in the Indian context as well. Most recently, snowfall of up to 2m occurred at many places on the higher reaches of the Pir Panjal range between 16-20 February 2005, resulting in avalanches at several places in Anantnag, Doda, Poonch, Pulwama, and Udhampur districts of Jammu and Kashmir. Over 300 people lost their lives.

Types of Avalanches

There are two basic types of avalanches, loose snow avalanches and slab avalanches. These are further sub-divided according to whether the snow involved is dry, damp or wet, whether the snow slide originates in a surface layer or involves the whole snow cover (slides to the ground), and whether the motion is on the ground, in the air, or mixed. Loose snow avalanches form in

snow masses with little internal cohesion among the individual snow crystals. When such snow lies in a state of unstable equilibrium on a slope steeper than its natural angle of repose, a slight disturbance sets progressively more and more snow in downhill motion. If enough momentum is generated, the sliding snow may run out onto level ground, or even ascend an opposite valley slope. Such an avalanche originates at a point and grows wider as it sweeps up more snow in its descent. The demarcation between sliding and undisturbed snow is diffuse, especially in dry snow. Though very common, most dry, loose snow avalanches are small and few achieve sufficient size to cause damage. With the onset of melting, wet loose snow avalanches become common. Most of the latter, too, are small, but they are more likely to occasionally reach destructive size, especially when confined to a gulley. Slab avalanches originate in snow with sufficient internal cohesion to enable a snow layer, or layers, to react mechanically as a single entity. The degree of this required cohesion may range from very slight in fresh, new snow (soft slab) to very high in hard, wind drifted snow (hard slab). A slab avalanche breaks free along a characteristic fracture line, a sharp division of sliding from stable snow whose face stands perpendicular to the slope. The entire surface of unstable snow is set in motion at the same time, especially when the cohesive snow lies on top of a weak layer. A slab release may take place across an entire mountainside, with the fracture racing from slope to slope to adjacent or even distant slide paths. The mechanical conditions leading to slab avalanche formation are found in a wide variety of snow types, new and old, dry and wet. They may be induced by the nature of snow deposition (wind drifting is the prime agent of slab formation), or by internal metamorphism. Slab avalanches are often dangerous, unpredictable in behaviour, and account for most of the damage. Avalanches composed of dry snow usually generate a dust cloud when the sliding snow is whirled into the air. Such slides, called powder snow avalanches, most frequently originate as soft slabs. Under favourable circumstances, enough snow crystals are mixed with the air to form an aerosol which behaves as a sharply bounded body of dense gas rushing down the slope ahead of the sliding snow. This wind blast can achieve high velocities, to inflict heavy destruction well beyond the normal bounds of the avalanche path. Wet snow avalanches move more slowly than dry ones and are seldom accompanied by dust clouds. Their higher snow density can lend them enormous destructive force in spite of lower velocities. As wet slides reach their deposition zones, the interaction of sliding and stagnated snow produces a characteristic channeling. Direct action avalanches are the immediate result of a single snow storm. They usually involve only fresh snow. Climax avalanches are caused by a series of snow storms or a culmination of weather influences. Their fall is not necessarily associated with a current storm or weather situation.

Causes of Snow Avalanches

Avalanches form as soon as the force of gravity on the snow cover exceeds its mechanical strength. To be caused, an avalanche needs a steep slope, snow cover, a weak layer in the snow cover, and a trigger to initiate movement. Snow avalanches may occur on any slope where enough snow is deposited in the right circumstances. Snow does not accumulate significantly on steep slopes; also, snow does not flow easily on flat slopes. Most avalanches of dangerous

size therefore originate on slopes with inclinations of between 30 degrees and 45 degrees. On slopes from 450 to 500, scuffs and small avalanches are common, but snow seldom accumulates to sufficient depths to generate large snow slides. Convex slopes are more susceptible to avalanches than concave slopes. Avalanches are released (spontaneously or artificially) by an increase in stress (e.g., by fresh snow) and/or a decrease in strength (e.g., by warming or rain). Though internal metamorphism or stress development may sometimes initiate a snow rupture, avalanches are often dislodged by external triggers. Ice fall, falling cornices, earthquakes, rock falls, thermal changes, blizzards, and even other avalanches are common natural triggers. Avalanches can also be triggered by loud sounds such as shouts, machine noise, and sonic booms. In the absence of external triggers, unstable snow may revert to stability with the passage of time as long as no avalanche occurs. The theology of snow cover is similar to that of ice as both are visco-elastic materials that exhibit creep behaviour over time. Snow deforms continually without fracturing as the load on top of it increases. However, the loading rate is critical. Heavy snow fall over a short duration leads to a greater probability of avalanche occurrence. A snow fall of 1m in one day is far more hazardous than 1m over three days. When the snow pack becomes unstable, it is released suddenly and descends rapidly down slope, either over a wide area or concentrated in an avalanche track. Avalanches reach speeds of up to 200 km an hour and can exert forces great enough to destroy structures coming in their way and uproot or snap off large trees. It may be preceded by an 'air blast' capable of damaging constructions and forest cover. The complete path of an avalanche is made up of a starting zone at the top where the unstable snow breaks away from the more stable part of the snow cover, a run-out zone at the bottom where the moving snow and entrained debris stop, and a track that runs between the two zones. The air blast zone is usually in the vicinity, but not necessarily continuous with the lower track or run-out zone. In some cases it may even run way up the slope across the valley from the avalanche path. In general the run-out zone is the critical area for land use decisions because of its otherwise attractive setting for development. Avalanches run on the same paths year after year, the danger zones often being well known in normal circumstances. Exceptionally uneventful weather intervals lasting for many years may produce exceptional avalanches which overrun their normal paths and even break new ones where none existed for centuries. Avalanche prone lands may pass many winters or even decades without a serious avalanche. Avalanches are not confined to specific terrain features: they may follow narrow gullies or ravines for all or a part of their path; they may occur on broad, uniform slopes or even ridges and spurs. The longitudinal profiles of the paths may be concave, convex, or stepped. On stepped paths, small avalanches will often stop on a bench some distance down the tract while larger ones will run the full length of the path.

The Impact of Snow Avalanches

The forces generated by moderate or large avalanches can damage or destroy most man-made structures. The debris from even small avalanches is enough to block a highway or rail-road. Avalanches are extremely destructive due to the great impact forces of the rapidly moving snow and

debris and the burial of areas in the run-out zone. Structures not specifically designed to withstand these impacts are generally totally destroyed. Where avalanches cross highways, passing vehicles can be swept away and destroyed, killing their occupants. In general, land use within an avalanche area should not include buildings intended for winter and early spring occupancy. Ordinarily, use of avalanche areas in the summer does not constitute any hazard. Structures including power lines, highways, railroads, and other facilities that are placed in avalanche paths and run-out zones should be designed for expected impact even if other preventive measures are implemented.

Early Warning Systems against Snow Avalanche Hazards

There are two basic methods of anticipating an avalanche hazard. One is the examination of the snow cover structure for patterns of weakness, particularly those leading to slab avalanches. The second method is the analysis of the meteorological factors affecting snow depositions. In practice the two methods overlap and both are used. Emphasis on either one or the other depends on the local climate, pattern of snowfall, snow type, and avalanche characteristics. Both apply principally to winter avalanches in dry snow. Forecasting wet spring avalanches depends on knowledge of the heat input to the snow surface. Rising temperature during a storm accompanied by rising new snow density tends to cause avalanching, while falling temperatures have the opposite effect. New snow precipitation intensity is a significant factor, as it represents the rate at which the slopes are being overloaded. Wet snow avalanches are generated by the intrusion of percolating water (rain or snow melt) in the snow cover. The rapid rise in temperature quickly alters snow behaviour, while the water itself reduces snow strength. Water accumulating on an impervious crust provides an especially good lubricating layer for slab release. The most extensive wet snow avalanching occurs during winter rains or the first prolonged melt period in spring, when water intrudes into previously sub-freezing snow. Snowmelt due to solar radiation is the most common cause of wet snow avalanches. Snow cover, terrain and atmospheric parameters are the major inputs for forecasting of snow avalanches. It is difficult to obtain the required information from the remote regions of the Himalayas using conventional ground based techniques, as there are several limitations due to the inaccessibility and ruggedness of the terrain, the facilities, and limited information on the region. infrastructure Satellite remote sensing is the most efficient tool for these purposes, especially for large, rugged, and remote areas. For gathering the latest terrain on avalanche-prone areas, snow cover and optical [MODIS, AVHRR, AWiFS, WiFS. parameters, LISS-III, Cartographic Satellite (CARTOSAT), IKONOS, Quick-bird] and microwave (AMSR-E, SSM/I, Radar-sat, ENVISAT) imagery can be used. The latter is useful in weather conditions where cloud cover obstructs remote observation by other means.

Avalanche Control Strategies

The need for study of snow bound areas has increased manifold with the increasing necessity of developing communication routes, development of winter tourism, construction of hydroelectric projects and transmission lines in snow bound areas. Snow avalanches have long posed a threat to the indigenous populations of the Himalayan and Trans-Himalayan mountains. Land use intensification due to population growth, new transportation routes, defence related activities and tourism are raising this level of risk. Obviously, the most desirable and effective protection against avalanches is to situate buildings, roads, and other valuable developmental projects in areas free from avalanches. However, as the population grows and more hazardous sites are considered for development, advanced planning and strictly enforced zoning and construction practices appear to be the best solutions. In some cases, even these are not adequate to completely eliminate the risk of avalanches, and acceptable risks must be defined, especially in the case of roads, power lines These risks can, however, be reduced considerably if appropriate structural controls are employed. Since avalanche prone areas can be identified, the safest and probably best mitigation procedure is to avoid construction of buildings or any type of structure involving winter use in these areas. Agricultural and recreational activities that take place during the non-avalanche months are relatively safe. Other uses that could be considered are those that do not involve permanent unprotected structures in the avalanche path or those that could be moved or closed down during high avalanche-risk periods. Methods of avalanche control include structural terrain modification to deflect the sliding snow away from the fixed facilities to be protected, or to actually prevent the avalanche release, and the planned release of small snow slides with explosives before snow accumulation increases their destructive potential to unmanageable proportions. Explosive techniques have been used for the deliberate release of avalanches for many vears. The theory behind this technique is to cause many avalanches and thus avoid large unpredictable destructive avalanches. Explosive control has been very effective in areas with easy access to avalanche starting zones and ones that can tolerate many small snow slides without causing damage. Detailed information in the form of an inventory on current and past snow-packs and avalanche conditions should be made available for this technique to be safe and effective. However, explosive control may be unfeasible in areas with human habitation. Engineering structures for the control of snow avalanches are of the following four types:

i. Supporting structures in the starting zone built on the upper part of the avalanche path to prevent avalanches from initiating, or to retard movement before it gains momentum. Massive earth or stone walls and terraces; rigid structures made from wood, steel, aluminium, pre-stressed concrete, or a combination of these materials; and flexible supporting structures called 'snow nets' constructed of steel cables or nylon straps and held up by steel poles, are examples of these.

- ii. Deflecting and retarding structures in the run-out zone to keep the moving snow of an avalanche away from structures in critical locations. These are massive structures usually made of earth, rock, or concrete located in or near the avalanche track or run-out zone.
- iii. Retarding structures are usually earth mounds or large concrete structures called breakers or tripods. The additional roughness and cross currents set up by these structures usually stop all but large, dry snow avalanches.
- iv. Direct protection structures are built immediately adjacent to the object to be protected, or in a few cases, incorporated into the design of the object itself. Avalanche sheds or shelters are merely roofs over roads or railroads that allow avalanches to cross the road/railroad without interrupting or threatening the traffic. In actual practice it is common for many different types of structures to be used on a single path.

In India, the responsibility of dealing with the different aspects of avalanches rests with the SASE. The BRO, with a vast network of roads in the high altitude snow-bound areas of Leh in Jammu and Kashmir, Sikkim, Arunachal Pradesh, Himachal Pradesh, and Uttarakhand, plays a major role in the operation of snow-avalanche clearance. The BRO strives to keep vital lines of communication open in these snow-bound regions through a slew of measures like the use of modern snow cutting equipment/snow cutters/snow sweepers, conventional dozers, experienced work-force, total station survey instruments, etc. Summer snow clearance is carried out every year on a 50 km stretch across the Zojilla-Pass on the Srinagar-Leh road (the approximate road length that remains closed to traffic from mid-November to mid-May every year) and on a 100 km stretch on the Manali-Leh road across the Rohtang Pass and Baralachla Pass. These two routes have many avalanche prone zones, which are cleared with the utmost caution. In addition, it clears the Khardungla Pass at an altitude of 18,300 ft in the Ladakh region, the Nathula Pass in Sikkim, and numerous other passes in the Great Himalayas. Moreover the BRO keeps a record of these avalanche zones and appraises the SASE about the fresh occurrence of avalanches. The SASE and BRO will be responsible for the identification and monitoring of snow avalanches. The SASE will be responsible for the zonation of avalanche prone areas and the forecasting of snow avalanches. Central and state governments in association with the BRO will be responsible for implementing clearance and control strategies against identified snow avalanches.

Search and Rescue Operations for Snow Avalanches

Search and rescue operations mean either externally organised search and rescue services or the capabilities the affected group itself has for dealing with an avalanche emergency. The latter is known as self-rescue or companion rescue. Even small avalanches can present a serious threat to life. As per the data available, between 55 and 65 per cent of victims buried in snow avalanches are killed and only 80 per cent of the victims remaining on the surface survive. Research indicates that the percentage of survivors depends

on the response times. It varies from 92 per cent for a response times of 15 minutes to only 30 per cent for a response time of more than 35 minutes, as most of the victims die of suffocation. After two hours, most of the victims die of injuries or hypothermia. In snow avalanches, the survivors among the victims are the first responders. For this reason, self-rescue or companion rescue is vital, more so since organised help takes time to arrive. The chances of a buried victim being found alive and being rescued increase when victims carry and use standard avalanche equipment. The equipment used in Western countries include avalanche cords, beacons, probes, shovels and other devices like Emergency Position-Indicating Radio Beacons (EPIRB) containing the Global Positioning System (GPS), and mobile phones. A first aid kit and equipment is useful for assisting survivors who may have cuts, broken bones, or other injuries, in addition to hypothermia. The SASE is presently not involved in carrying out search and rescue operations. Therefore, the district administration will identify organisations/institutions that can take up programmes to educate the communities living in avalanche prone areas, to prepare them with the latest techniques of self-survival, and to equip them with simple and essential tools. Similarly, the organisations engaged in development and strategic tasks at high altitudes will be educated on initial search and rescue operations and the use of basic equipment necessary for these operations. Quick Response Teams (QRTs) equipped with the latest rescue equipment like snow clearing tools, probes, communication capability, and medical emergency aids will be organised. These teams will have the capability to be mobilised at very short notice and reach the affected sites within the shortest possible time. The ORTs shall include trained personnel drawn from different arms of the local administration and the National Disaster Response Force (NDRF).

FLASH FLOOD

Flash floods are dangerously fast moving floods caused by a large amount of heavy rain in a localized area. This torrential downpour may transform a normally calm area into a powerful river of death in only a few short minutes. Many people are caught unprepared for the power and speed of a flash flood. which results in dangerous situations. Flash floods are slightly different from normal floods. Normal floods involve water rising and overflowing from its normal path. However, flash floods appear quickly and move swiftly across land with little warning. Flash floods occur for a variety of reasons including concentrated rainfall during a slow moving thunderstorm, hurricanes, and tropical storms. The most devastating flash floods are from dam and levee failures. When either structure breaks, an enormous amount of water is suddenly unleashed, destroying everything in its path. The water in a flash flood moves at such a high velocity that it can move boulders, uproot trees, demolish buildings, and destroy bridges. The walls of water in such a flood and be anywhere from ten to twenty feet tall and usually carry a substantial amount of debris.

Methodology:

In the development of Flash flood Hazard Risk and Vulnerability Assessment extensive historical research was conducted along with continuous successive field visit with the development and analysis of the following maps:

- Drainage Map
- Base Map
- Slope Analysis Map
- Catchment area map.
- Average Annual Rainfall

RIOTS

A **riot** is a form of civil disorder characterized often by disorganized groups lashing out in a sudden and intense rash of violence against authority, property or people. While individuals may attempt to lead or control a riot, riots are typically chaotic and exhibit herd behaviour, and usually generated by civil unrest. Riots often occur in reaction to a perceived grievance or out of dissent. Historically, riots have occurred due to poor working or living conditions, government, oppression, taxation or conscription, conflicts between Ethnic groups, food supply or religions (see race riot, sectarian violence and pogrom), the outcome of a sporting event or frustration with legal channels through which to air grievances. Riots typically involve vandalism and the destruction of private and public property. The specific property to be targeted varies depending on the cause of the riot and the inclinations of those involved. Targets can include shops, cars, restaurants, state-owned institutions, and religious buildings.

Methodology:

In the development of Riots/Stamped Hazard Risk and Vulnerability Assessment extensive historical research was conducted along with continuous successive field visit with the development and analysis of the following maps:

- Household Density Map
- Location of police check post
- Police patrolling zone
- Sensitive area buffer zone
- Household Map

Multi-hazards:

Taking into account the different Hazards that may affect the region of Sikkim, developed a multi hazard map and a Risk Matrix Chart to assess the impact of each hazard in the respective District.

Risk Matrix Chart								
5		EVERY YEAR					LANDSLIDE	
4	/Likelihood	2-10 YRS	HAILSTROMS , SNOW & AVALANCHES			FIRE		Likelihood
3	/Like	11-20 YRS		RIOTS	DROUGHT	FLASH FLOOD	EARTHQUAKE	
2	ency	21-30 YRS						Frequency/
1	Frequency	31-50 YRS						Frequ
Score Of likely- hood		Score of Impact	1 TO 7	8 TO 14	15 TO 21	22-28	29-35	
Severity/ magnitude of damage								

RELATIVELY INCREASING RISK

	MEDIUM			
LOW	LOW	MEDIUM	HIGH	VERY HIGH

Methodology

In this analysis extensive background check was done with extensive historical research, as well as observational data. Different kinds of maps were created so as to assess the risk and vulnerability of the region. This information was then considered in the context of the seven impact criteria, which are outlined in Table 1 below. The impact criteria were individually ranked on an ascending scale from one to five, one being the least severe and five being the most severe. The sum of these scores was taken to create an overall consequence score, the score was then contrasted against a likelihood rating of one to five, one being the least likely and five being most likely. Details regarding the measure of likelihood are seen in Table 2. The aggregate score of each hazard, combined with the hazard impact consequence and likelihood provide the basis for a risk ranking of *low*, *medium low*, *medium high* and *very high*.

Table 1 – Seven Categories of Impact	
Categories of Impact	Score
Fatality	1 TO 5
Injury	1 TO 5
Critical Facilities (Hospitals, Fire/Police Services etc.)	1 TO 5
Lifelines (Water, Gas, Power, etc.)	1 TO 5
Property Damage	1 TO 5
Environmental Impact	1 TO 5
Economic and Social Impact	1 TO 5

Table 2 - Measure of Likelihood		
Measure of Likelihood	Return Period (yrs)	Score
Frequent or Very Likely Every	EVERY YEAR	5
Moderate or Likely Every	2-10 YRS	4
Occasional, Slight Chance Every	11-20 YRS	3
Unlikely, Improbable Every	21-30 YRS	2
Highly Unlikely, Rare Event Every	31-50 YRS	1

RISK RATING INTERPRETATION

These risks are *low*. Implementation of mitigation measures will enhance emergency preparedness, but it is of less urgency and highly unlikely to occur in that area than the following hazards.

These risks are **medium low**. Implementation of mitigation measures will enhance emergency preparedness, Hazards is highly unlikely to occur in that area, but is of more urgency than low.

These risks are **medium**. These hazards have intermediate levels of frequency and severity. Hazards classified as moderate are more urgent than medium low hazards and are often common place concerns. Given this, moderate level hazards should be addressed with an appropriate level of urgency.

These risks are **medium high**. These hazards warrant review and development of mitigation actions to reduce the risk to an acceptable level. But these hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

These risks are **very high**. These hazards are both frequent and are of high severity. These hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

4. Limitation of the MHRVA

Collection of data was a very challenging task as vital information required for the analysis is generally scattered between a plethora of agencies in the State and at the National Level agencies & departments. Items from restricted sources were needed to be acquired by the Land Revenue and Disaster Management Department & Sikkim State Disaster Management Authorities after the necessary statutory and security clearances which took much of time. The area for the study was very large therefore the individual components of HRVA were analysed district wise and accordingly MHRVA was constituted. A very limited resource in term of time past data and funds were made available.

5. Study Area

SIKKIM

(Map No -01)

(Map No-02)





Source: Arc Explorer Internet

Sikkim, (See map-01 & 02) a mountainous state, owes its modern origin way back in 1642 A.D. when its kingdom was ruled by its first monarch Phuntsog Namgyal who was consecrated as the first king of Sikkim by three monks: Lhatsun Chhenpo, Nga-Dag Lama and Kathog Lama at Yuksam in western Sikkim. At that time, the territory of Sikkim was extended up to Limbuwan in the west, Chumbi Valley and parts of Bhutan in the east and the entire Darjeeling district in south. Today, the state shares its southern boundary, which is delineated by Rangit and other rivers, with Darjeeling district of West Bengal. Three sovereign nations, the kingdom of Nepal in the west, Bhutan & China in the east and vast stretches of Tibetan plateau of China in the north bound the state. The state is situated between 27°04' 46" and 28°07' 48" north latitudes and 88°00'58" and 88°55'25" east longitudes. The state extends approximately 114 km from north to south and 64 km from east to west and has a total geographical area of 7,096 sq km. Rivers and mountains define the boundaries of Sikkim.

The state has four districts namely (a) East District, (b) West District, (c) North District and (d) South District with their headquarters at Gangtok, Gyalshing, Mangan & Namchi respectively. These districts are divided into nine subdivisions, 166 panchayat units, 453 revenue blocks including forest blocks and special areas. As per 2001 census, the state has nine towns. The following table shows the detail administrative set up of the state (Table 1).

Administrative Set up (Table no 01)

Dist/State	Total area in (Esq.)	No of Sub div	No of towns	Rev Block	Panchayat Ward	Panchayat Unit
North	4226	2	1	53	103	20
East	954	3	4	134	273	50
South	750	2	2	145	255	45
West	1166	2	2	121	274	51
Sikkim	7096	9	9	453	905	166

Source: Census of India 2011

PHYSICAL FEATURES

Sikkim has a very rugged topography and formidable physical features. The whole state is enclosed on three sides by lofty ranges and spurs of Greater Himalaya with varying heights on three sides. In the north, the Greater Himalaya is stretched in convex form while in the west, the Singalila range, which is a spur of great Himalaya, is extended from north to south. The Donkva range, forming the eastern boundary of Sikkim, is much segregated with only two gaps, Nathu la and Jalepa la, which provide trade routes between Sikkim and China. The crowning glory of the state is the world's third highest mountain Mt. Khangchendzonga (8,596 m). It has five satellite peaks: Jano (7,710 m), Kabru (7,338m), Pandim (6,691 m), Narsing (5,825 m), and Siniolchu (6,888 m). The other important peaks are Rathong (6,087m), Simvo (6,811m) and Tolung (7,349 m). The northern portion of the state, particularly beyond Chungthang, is the highest region of the state and cut into deep escarpment. This region has no populated area except Lachen and Lachung valleys. Southern Sikkim is low and more open and fairly cultivated in patches. It is subjected to erosion by River Teesta and its tributaries.

Although the map shows six altitudinal zones, but broadly it can be physiographically divided into the following zones:

- **A. Lower hills**: It stands between altitude from 300m-1800m and has hilly topography with flat cultivated lands in patches.
- **B. Upper hills**: The altitude of this area is from 1800m-3000m. Major forest areas are found in this zone.
- **C. Alpine zone**: The area between 3,000m-4,500m is termed as Alpine zone. It is covered with scrubs and grassland.
- **D. Snow land:** The area above 4,500m is perpetually snow covered and is without vegetation.

The general slope of the state is from north to south. However, the degree of slope varies from place to place. The slope in the whole North District, except Teesta valley below Chungthang and northeastern part of the East District, is 600 m per km. Towards South, Teesta valley below Chungthang and the area around Rabongla in the South District, the slope is between 300-600 m per km. The rest of the state consisting of whole West District, southern portion of South District and extreme southwest part of North District have slope of 150m-300 m per km.

Glaciers are the important physiographic features of the state. They are mostly found in North district. The most important one is Zemu Glacier, which is 26 km in length and is situated at the base of Mt. Khangchendzonga. Other glaciers like Rathong, Lonak, Tolung, Hidden etc. are in the north-western part of the state. Some are also situated in the north-eastern part of the state and are sources of important rivers of the state.

Teesta is the largest river of Sikkim. It flows essentially north-south across the length of Sikkim and divide the state into two parts. It is believed to originate from Pauhunri glacier (Teesta Khangse) near Khangchung lake (27059' N; 38⁰48' E; 7,128 m, above m.s.l.). Here, the river is known as Chhombo Chhu or Chumbu Chu. Flowing southward, the Teesta leaves the state and enter into West Bengal at Teesta-Rangit confluence near Teesta Bazaar and it ultimately joins Brahmaputra in Bangladesh. The narrow and serpentine Teesta in its upper part becomes swollen, swift, and muddy during monsoon and is full of rocks and hence is not navigable. Teesta and its tributaries receive the water from snow melting on the mountains as well as rain that accumulates during monsoon. River Teesta and its tributaries provide huge surface water resource for production of hydro-electricity in the state. Apart from small tributaries, Teesta receives the water of Zemu and Rangyong rivers on its right bank and Lachung (Sebojung), Dik Chhu, Rongni and Rangpo rivers on its left bank. The Great Rangit which is the most important right hand tributary of Teesta, is another important river of the state. Its major tributaries are Rathang, Kalej, Reshi and Rangbhong. Based on Central Soil & Water Conservation Research & Training Institute, nine sub river basins/catchments have been demarcated on the map. These sub-basins may be very useful for the purpose of land use planning particularly in the state like Sikkim.

Sikkim is a hilly state with deep valleys and has different altitudinal zones. It possesses all the climates, right from the tropical to the tundra. The climate varies from the hot tropical in the valleys to alpine cold in the higher altitudes. The climate of the state can be roughly divided into five climatic zones:

- 1. Tropical climatic is experienced below 610mtrs.
- 2. Sub Tropical in the deep valleys with elevations above 610mtrs to 1524mtrs.
- 3. The temperate climatic zone having elevations between 1524mtrs to 2743mtrs
- 4. Sub Alpine climatic zone having elevations between 2743mtrs to 3962mtrs.
- 5. Above 3962mtrs is the alpine climatic zone up to 5128mtrs. Above 5128mtrs it is perpetually snow bound.

The temperature in the state varies according to altitude, rainfall and nearness to snow line. The winter, which extends from November to March, is extremely cold and the minimum temperature in some places, particularly in north falls below the freezing point. Gangtok, the capital of the state shows some higher range of temperature in winter. Gyalshing, which represents the west, is little

bit warmer than Gangtok. On the contrary, summer is short, mild and pleasant and lasts from April to May but the heat is quite oppressive in deep valleys during this period.

Like physiographic, the rainfall also shows variations. The state experiences monsoon from June to October, when it rains heavily. March witnesses the onset of thunderstorms and its frequency increases till the rainy season sets in. Rainfall varies spatially according to terrain. It is heavier in central region consisting East District, southeast portion of North District, central part of South District, central and southwestern part of West District. These areas receive more than 2,400mm rainfall. The adjacent areas receive 1,200mm to 2,400mm of rainfall. The rainfall decreases substantially towards the north where it is almost dry and monsoon cannot reach easily. There is not much rainfall from November to February and the weather is clear in November and December. During winter, snowfall is common in high altitudes. However, the humidity is quite high in the morning and afternoon during the greater part of the year.

SOIL TYPE

The pre-cambrian gneissic and Daling group of rocks with some intermediatories cover the major portion of the state. Gneissic group constitutes mainly of Himalaya. The Daling group consists of predominantly phyllites and schist. The slopes on these rocks are highly susceptible to weathering and prone to erosion and landslide. Number of important and some lesser known occurrences of minerals are found in the state. Copper, limestone, dolomite, graphite, asbestos and coal occur in the different parts of the state.

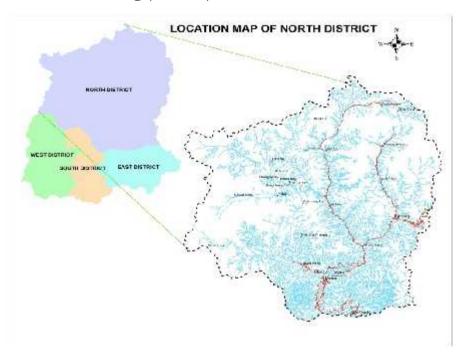
As the major part of the Sikkim lies on Darjeeling gneiss, the soil developed from this rock is brown clay, generally shallow and poor in lime, magnesia, phosphorous and nitrogen. However, it is quite rich in potassium. The texture of soil is loamy sand to silty clay loam. The depth of the soil varies 30 cm to 150 cm and in some cases even more than 150 cm. The soils are typically coarse with poor organic mineral nutrients. The soil map of Sikkim is drawn on the basis of IS Code for landslide Hazard Zonnation in hilly terrain and required data for preparation of hazard zonnation mapping was taken into consideration.

NORTH SIKKIM

The State of Sikkim comprise of four districts. The North Districts constitutes 59.55% of the area [4226km]. Large part of the area with an elevation range between 494m amsl to 8598m amsl is desolate and bleak without any sign of healthy vegetation and prospect for scale are cultivation Ice, glaciers and glaciated area with ice [819.84km² and barren land, rock exposure and talus fields [1033.16km²] and glaciated valley, moraines & alpine meadow [1200km²] constituted 19.40%, 24.45%, and 28.40%, respectively, of this bleak scenario. Despite geological complexity, diversity, niche and rigorous climate, the weather in the lower valleys of Teesta basin is surprisingly pleasant throughout greater part of the year and whereas, at higher altitude (above 4000masl) and latitude, thin air and strong radiation combined produces sharp temperature contrasts between day and night as well as between summer and winter. Living within such diverse and extreme physical environment is 31240 persons of North Sikkim who are mostly Bhutias and Lepchas. Majority of the people live within an ethnographic area of about 125 Km² (2.96%) as farmers of cultivable area 125.72 Km² (3.16%) and as businessmen or Govt. Servants.

North district is a part of the upper most Teesta basin. The main tributary of Teesta river within the district are Lachen chu, Lachung chu and Tholung chu. Existing glacier complexes and other inputs such as rain and snow maintain the hydrological system in the watershed. Considering the predictions made by experts worldwide, the future of Himalayan glaciers in general and existence of upper Teesta watershed in particular appears bleak. It has been mentioned that within the next 25 years, some 3 billion people will have no access to source of fresh water, (BBC, Aug, 1999) and Himalayan glaciers could vanish within 40 years due to global warming (Hasnain, S, 1999). Barring Ice Age (Pleistocene glaciations) which ended some 10,000 years ago, peak position of glaciers in the Himalayas, including Sikkim was noted during 1850 (little Ice Age). Since than there has been a general retreat of glaciers in the region (Mayewski and Jeschake, 1979). As of today, Lachen chu is fed by 27, Lachung chu by 12 and Tholung chu by 9 glaciers (Jeyaram A.et el., 1998), all of which are in a state regression, as indicated by moraine dammed ponds or lakes at lower latitudes than the snout area and downstream bend of end moraines damming the ice melt. Glacier lake outburst floods which are attributable to warning episodes during interglacial periods, tremors as well as slight increases in temperature above normal during summers are common phenomena in the area. The most destructive flood of such nature on record, which changed the course of Teesta River from flowing into the Ganges to Brahmaputra after destroying parts of Rangpur district of West Bengal, was in 1787, well before the Little Ice Age. An indication of recent episodic glaciers Lake Outburst floods of lesser destructive nature exists along the Lachen and Lachung rivers. However, their influence appears to have been not below Tsungthang (98kms from Gangtok). Road transport is the only mode of communication within, to and from North Sikkim. Difficult accessibility to point of interest is a specific condition of Sikkim Himalayas. Smooth and uninterrupted motor journey to Mangan - the district Headquarter from

Gangtok (67Kms) is a luxury even during dry seasons. From Mangan to Tsungthang (30kms) is a nightmare and only bravehearts can survive the whimsical slides of Relli and Toong and rushing-gushing truant of Meyong chu. Tsungthang to Lachen (26Kms) and to Lachung (21Kms) by road is usually smooth. Motorable dirt road from Lachen to Thangu (30Kms) is subject to frequent landslides, especially between Zema & Yathang. Thangu to Gurudongmar (30Kms) and from Gurudongmar to Tsolhamu (7Kms) can prove very rough and slow journey because of extreme climatic & terrain conditions. Similar conditions exist for road travel from Lachung to Yumthang and from Yumthang to Yumesamdong (30Kms).



GEOLOGY

Sikkim and Darjeeling Himalayas have been divided into four geological belts, namely: the Foot hill belt, Inner belt, Axial belt and Trans Axial belt. Foot hill belt successively lie over the Siwaliks separated by contact known as main boundary fault and comprise of the rock of lower Gondwana and Buxa sequences. The Inner belt lie over the Foot hill belt which and is made up of the low grade metamorphic represented by rocks of Daling Group [Gorubathan Formation] with isolated pockets of Gondwana and Buxa rocks. These isolated rock pockets are known as the 'windows zones' which were exposed due to subsequent erosion of overlaying rock sequences. The Axial belts overlie the Inner belt and are separated by a thrust known as MCT (Main Central Thrust). This belt consists of rock sequences of high grade Metamorphic represented by high grade gneisses, high grade schists, graphitic schist, Calcareous gneiss or marble, calc granulites, pegmatite, aplite, migmatite etc. Overlying the Axial belt are the rocks of the Trans axial belt represented by rocks of the Tethyan sequence with Sand-stone, Limestone and Fossils shells.

The area of study comprise of the rock of inner, Axial and Trans axial belts in flowing order of super position.

Tsho-lhamu Series: - Fossil bearing shales, Limestone, Sandstones.

Latchi Series: - Sandstone, Pebble beds, Carbonaceous Shell, Slates, Limestone and Quartzite.

Chhubakha Series: - Fine grained granite with Garnet, Tourmaline and Hornblende inclusions, Pegmatite, Lime Silicates etc.

Granulites, Quartz-biotite-gneiss/schist and Pegmatite. Tsungthang series overlie the rock of Daling/ Darjeeling series. These series in the area of study are marked by presence of Quartzite, high grade Meta Sedimentaries, Calcareous Silicates (Calc. Genesis and Calc. Granulites) with marble bands, quartz biotite schist, Graphitic schist, high grade gneisses intruded by Pegmatite veins with inclusions of Tourmaline crystals. Tsungthang series (termed by V.K. Raina & V. Bhattacharya in 1996-62) starts from Meyong on Mangan-Tsungthang road, upto Leema on Tsungthang-Lachung road and upto Jorephul area on Lachen road section. The Quartzites in the area are exposed as alternating bands with the gneisses. The bands vary in thickness and have inclusions of Garnet at Bop area on Lachung road section. The gneiss show compositional bandings in the form of mineral lineation. They are seen as massive, well bedded to Augen gneiss. Graphite schist is present as thin folded Lensoidal bands attached to Quartzites or marble of Tarum area. The calcsilicate rocks of this area are marked by intense folding and characteristics of differential weathering.

The overlying sequence of Tsungthang series are the rocks of Chhubakha series (Raina & Bhattacharya 1962). The rock belongs to the Precambrian age just as that of the Tsungthang rock sequences. The rock types present in these sequences are Calc-gneiss, Granulites with intercalation of Quartzite, quartz biotite schist and Granite gneisses. These gneisses are noticed with inclusions of Tourmaline, Hornblende and Biotite, Graphite schist are absent in Chhubakha series.

Calcareous gneiss and Granulites of this sequence differ from Tsungthang rock sequence as Chhubakha rocks show grayish to greenish tint owing to predominance of feldspar and hornblende. The gneisses of Chhubakha series however, show rusty brown appearance in most of the exposures.

The rock types of Tsungthang and Chhubakha series can broadly be divided into following:-

Banded Gneiss: - They are massive and compact beds. The fabric is defined by oriented Quartz and Feldspar mineral lineation alternating with Biotite/Sillimanite layers.

Foliated gneiss: - Foliation in the gneiss is defined by the layer of Silicates and thin Feldspar/Biotite minerals.

Augen Gnesis: - The Augens in this gneiss are made up of Feldspar and Biotite mineral lineation is an added feature.

Tourmaline Bearing Pegmetite: - The high grade gneissic sequence is at places intruded upon by bands of tourmaline bearing pegmetite. They are

generally coarse grained, white to buff in colour consisting grains of quartz, feldspars, biotite and opaques.

Calc-Silicate/Calc-Granulites with marble bands: Calc-Silicates and Granulites associated with thin marble/calcite bands are found around Meyong Chhu and Theng on Mangan-Tsungthang road section, at Bop, Maltin, Bhim nala, Lemphaka, Khedum and at few places beyond Lachung on Tsungthang-Yumthang road section and at Menshithang, Tarum, Salep and at Zema area in Tsungthang-Thangu road section. These rocks are coarse grained, white to buff colored and composed of grains of quartz, feldspar, biotite and opaques.

Calc-Sillicate/Calc-Granulite with marble bands: Calc-Silicates and Granulites associated with thin marble/calcite bands are found around Theng on Mangan-Tsungthang road section, at Bop, Maltin, Bhim nala, Lemphaka, Khedum and at few places beyond Lachung on Tsungthang-Yumthang road section and at Menshithang, Tatum, Salep and at Zema area on Tsungthang-Thangu road section. These rocks are composed of course grained minerals especially of Calcite an added distinct feature. At places they are thinly bedded and highly jointed whereas the exposures at Salep and Maltin area are massive in nature.

The overlying sequences of Chhubakha series are the rocks of Lachi series. Lachi is a small hill-lock between Gurudongmar and Tso-Lhamu Lake. The rock types in this sequence are younger and are of Permo-carboniferrous age represented by sandstone, shale pebble beds carbonaceous shales, Slates, Limestones, Quartzites etc. Due to folding/faulting mechanical weathering of complex nature, the rocks are highly disturbed and are found in fragmented forms. Shales forming the base of this series are harder and slaty in nature. The overlying Ouartzites are gravish or brownish in colours and very hard. They are then overlain by the pebble bed. The pebble beds are the marker horizon of the rocks of Permo-carboniferrous age and are also found in the rocks of Gondwana sequences in South and West Sikkim. These rocks have angular fragments of quartz, shale and Sandstones etc. embedded in a Silicious matrix. Calcite veins are usually found cutting across these rocks. The pebble beds are overlain by carbonaceous shale and Calcareous sandstone which are generally coarse grained. Brachiopod fossil is reported to have been found in Sandstone of Lachi series. Overlying Lachi sequence are the rocks of Tso-Lhamu series which are of Triassic in age with Sandstones at the base followed by limestone and shales successively above. These series are reported to be rich in Triassic fossils, especially Brachiopods. Corals found mainly in Sandstones and Shales whereas Limestones of this sequence are barren.

GEOMORPHOLOGY

The geomorphological setting of Sikkim and North Sikkim in particular are complex. The complexity is produced by the continuing tectonics activity which began some 40 million years ago, Pleistocene glaciations which lasted some two million years, glaciations during Little Ice Age (LIA) and weathering, Tectonism is responsible for the existing thrust-fault and intense folding in

rock environment and glacial episodes produced their own effects and suits of deposits. Landscape and deposits of earlier glacial events were reshaped by later glacial advances. In this way, complex glacial and other landforms were reshaped by later glacial advances and retreat. Similarly complex glacial sequences were also produced due to glacier advance and retreat over the entire area. Sudden and catastrophic debris torrents as a result of glacial lake out burst flood [GLOF] had produced different valley shapes and sizes. Competent and massive high grade metamorphic rocks north of MCT show very rugged high mountain terrain. With increasing relief, rock and debris failures or falls become dominant, coarse and mixed colluviums, talus cones and mantle of soil (Table 6) are encountered on the lower slopes. At high altitudes, gentle slopes with mantles of colluviums/residual soil and /or glacial till are subject to solifluction and other processes such as gulling and sliding. Except structural scraps and cliffs, the steep upper slopes are dominated by more rapid form of alpine denudation, especially avalanches and rock and debris falls. Extensive glacial deposits and glacial lakes within the drainage basins and catchment areas of Lachen and Lachung rivers pose constant threat of high hazards to the areas at lower levels of the region.

The morphogenetic systems as of today can be divided into following zones or types:

Arctic of Frigid Zone

Arctic condition above 4000m asml. are dominated by glacial peri-glacial, mesomorphological and fluvioglacial processes and climate induced distinctive micro-mesomorphological features are glacial valleys, cryoplanated surface, rock scarps, arêtes, tors, kettles, soil/rock polygons, terraces, glacial deposits & flood plains. Part of higher altitude level of this zone is characterized by perpetual snow. The lowest limited of perpetual snow is estimate to be above 4500 m amsl. And it appears to vary inversely to latitudes of locations and modified to some extent by local climate conditions and topographic pattern.

Alpine snow (Forest) or Alpine meadow or Tundra Zone

Alpine meadow or Tundra zone exhibit similar micro and mesomorphological feature as that of Frigid Zone. However, fluvial processes are playing an important role in topographic changes as mostly scalped by major streams and glacial lake outburst floods.

Temperate Zone

Fluvioglacial & fluvial processes are the main agents in landform evolution in the temperate zone. The terrain is rugged due to high rate of denudation, down cutting by river, tectonic activity, flooding and so on.

Sub-tropical humid type to semi-temperate zone

Sub-tropical humid to semi-tempered morphogenetic system is affected by rain and snow and fluvial process. The terrain is as rugged as rest of the areas due to combined effect of the process.

SLOPE ANALYSIS

Slope stability analysis is extremely important in hilly and mountainous areas for any type of infrastructure development. Both failed and unfailed slopes must be analysed so that the level of risks and the associated remedial measures can be decided before deciding any type of engineering structures in the hills. Climate related adverse events or disasters constantly plague the hills and there is no short term or quick fixes to mitigate the topical ingenuity and constant exposure to natural slope failure hazards have learnt to adapt and live with the dynamic natural mountain environment. Their resilience may change when developmental activities exceed beyond the carrying capacity of the mountain ecosystems. A thorough slope stability analysis is difficult to achieve because of the complexity of the analysis that involves thorough theoretical understanding and experienced/educated judgement of the geological processes, soil and rock mechanics, climate and practical site specific corrective measures. The level of analysis required depends upon the size and nature of the problem. A modification or natural processes must understand the basic principles and techniques of stability analysis of soil and rock slopes.

Some of the main purposes of slope stability analysis are as follows;

- i. To assess the potential hazard associated with natural slopes.
- ii. To determine stable slope angle for cut slopes under a seismic and prevailing climatic conditions.
- iii. To determines likely behavior of cut slopes under different climatic conditions, such as intense rain or heavy snow or loaded upslope or undermined/unloaded.
- iv. To determine the stress relief effect after a slope is cut or loaded.
- v. To assess the geological competency of soil and rock slopes before they are modified.
- vi. To determines appropriate and cost effective site specific remedial measures for failed or cut slopes.

HYDROGEOLOGY AND DRAINAGE MORPHOMETRY

Hydrogeology is the study of water found in pores and fissures of rocks beneath the earth's surface. This includes the origin, distribution, migration, qualitative and quantitative variations of ground water in time and geological effects. By using measurements of groundwater levels obtained from boreholes/wells and observing the levels at which springs discharge, it is possible to create a groundwater contour map showing the form and elevation of the water table. Groundwater flows at various speeds depending upon its flow path. Water table fluctuate the most where there are marked seasonal changes in rainfall. This phenomenon is useful for identification of permanent

and intermittent water tables. Ground water levels are rarely static due to varying cycles of recharge and discharge. A uniform distribution of rain also rarely occurs and hence some areas receive more recharge than others and further more a uniform distribution of rain rarely results in uniform infiltration. Therefore, the level of ground water will usually be greater in some areas than in others. Almost the entire South District of Sikkim which is rich in aguifers such as sand stones, dolomite, pebble beds, coal and fractured metamorphic rocks and yet the district is still groundwater deficient. Parts of West and East Sikkim also experience groundwater deficiency. Complex geological setting and climatic conditions account for the uneven distribution of the groundwater resource of the State. To understand this phenomenon and develop groundwater resources, the State Government of Sikkim started the Dara Vikas programme from the year 2010. The programme is being handled by the Department of Rural Development and Management. Drainage pattern or drainage morphometry of Sikkim is defined by a number of factors. These factors influence the number, size and frequency of streams in the State. The North to South flowing Teesta and Rangeet are the two main rivers of the State and both of them are fed by a large number of upto 4th. Order streams. The drainage pattern is mainly of dendritic but there are evidences of control by high relief, varied lithology, Tectono-stratigraphic setting; geological and geomorphological history, and climate/rainfall regime. The amount of surface water runoff from the Teesta and Rangeet watershed or drainage basin and the amount of sediments carried out of the system vary significantly [visual estimate. The variation is dictated mainly by the existing physiographic factors such as the prevailing climate; the shape of the drainage basin; the relief and slope characteristic; the basin orientation to storm events; the drainage pattern etc. The principal human influences affecting the pattern, amount and intensity of surface- water runoff and sedimentation are quite a few. However, in a highly energized mountain ecosystem as in Sikkim, quantitative assessment of such influences becomes almost impossible. The Central Water Commission [CWC] in Sikkim maintains a record of variations in natural sediment yield, the flow and discharge rates of the Teesta and Rangeet rivers. As mentioned earlier, the two main rivers of the State are fed by a large number of tributaries. These tributaries and the main rivers begin their journey humbly from their sources at high altitude and as they grow in volume their journey becomes much faster and ferocious till they reach the Sub-tropical and Tropical eco-regions from where they meander into the plains. The main rivers have left behind a number of riverine land forms, old and new, in the form of river terraces, knick points etc. At high altitude locations where glaciated valleys still exist are remodelled by fast flowing streams continuously and glacier lake outburst floods at times.

LAND-USE AND LAND-COVER

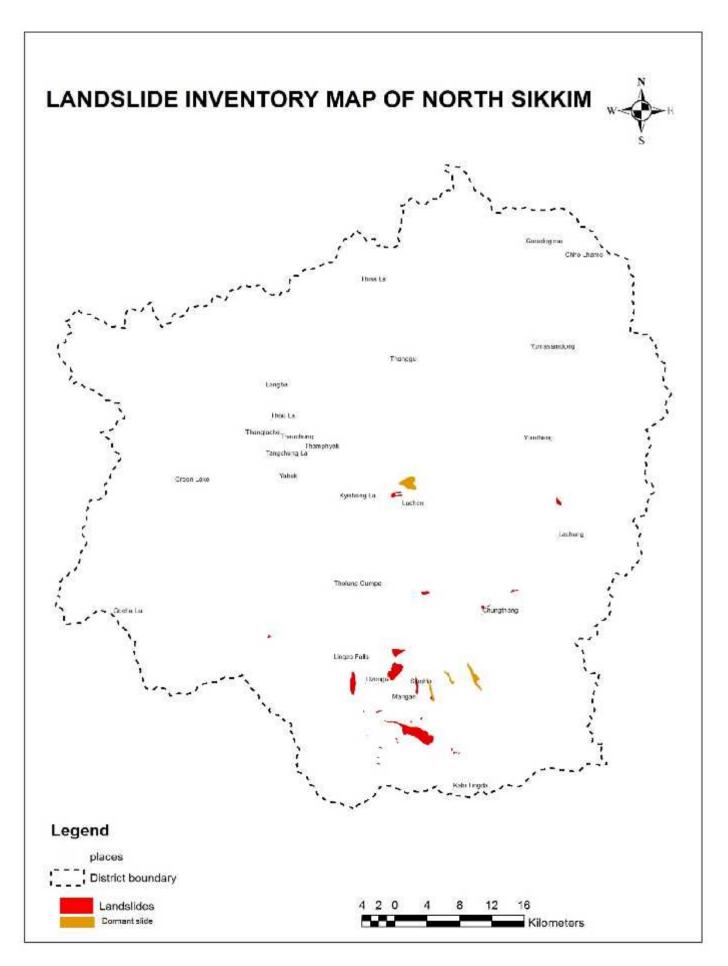
The total geographical area of the State stands at 7096 sq. kms today.

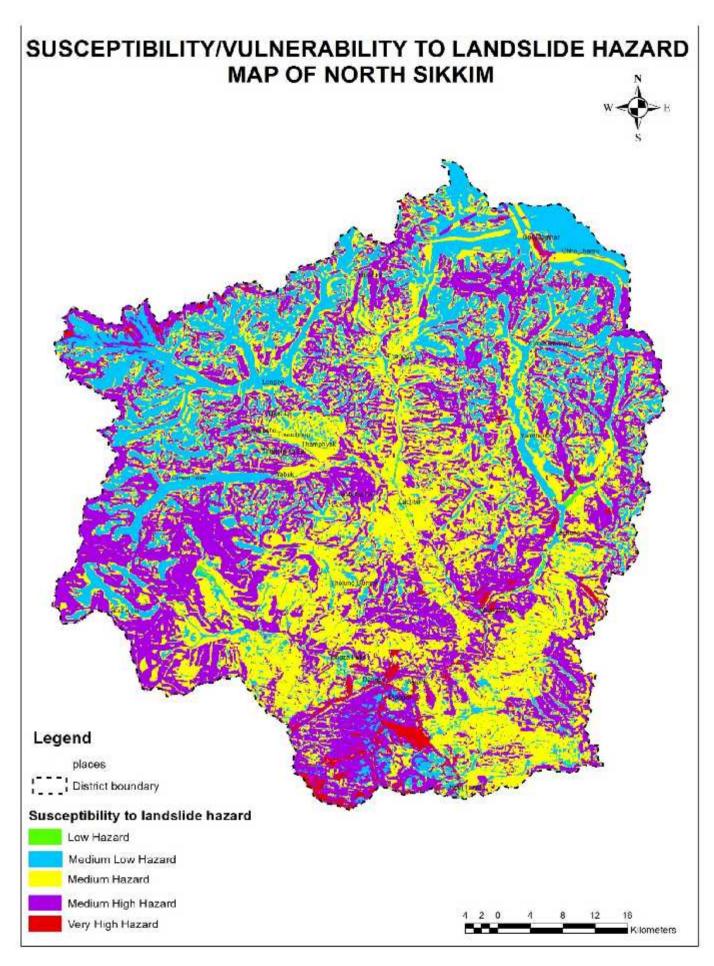
According to 1958-60 Survey Operations and the Gazetteer of Sikkim, the total area under different categories of utilization was pegged at 7299 Sq. Kms. and their detailed break - up was shown as follows;

Landuse pattern Area (in %)	Area (Sq. Kms)
Barren Land: 28.28	2090.10
Land put to Non-agricultural use: 9.58	69.96
Permanent pasture & grazing land including cultivable waste: 14.40	102.49
Land under miscellaneous tree crops & grasses: 0.57	4.17
Forest land: 36.34	265.21
Land under operational holding: 10.83	79.06
Total 100%	7299

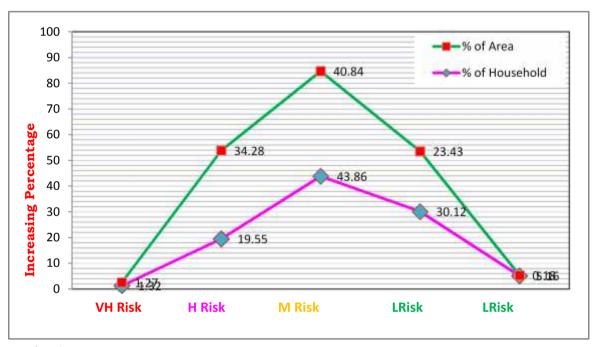
According to the State of Environment, Sikkim-2007 and Remote Sensing Data of 1988, the landuse and cover of Sikkim was shown as under;

Landuse Class Area (in %)	Area (Sq. Kms.)
Crop land (Terraced/Semi Terraced) 8.52	604.85
Fallow/Scrub in Revenue blocks 2.19	155.69
Sal dense forest 0.09	6.07
Sal open forest 0.25	17.47
Sal degraded forest 0.06	4.03
Mixed dense forest 8.50	603.34
Mixed open forest 10.81	766.75
Mixed degraded forest 6.05	429.62
Dense conifer forest 5.19	368.08
Open conifer forest 5.10	362.18
Degraded conifer forest 2.44	173.19
Oak- Rhododendron forest 1.78	126.58
Scrubs in reserve forest 1.44	101.87
Forest blanks 1.28	90.56
Alpine scrub 9.01	639.16
Alpine pastures 6.08	431.32
Alpine barren 11.53	818.15
Snow 14.43	1023.64
Glaciers 2.93	208.23
Lakes 0.47	33.00
Rivers/ Major streams 0.91	64.31
Dry river beds 0.57	40.59
Built-up Area 0.05	3.54
Landslide Area 0.15	10.53
Miscellaneous 0.19	13.23
Total 100 %	7095.98





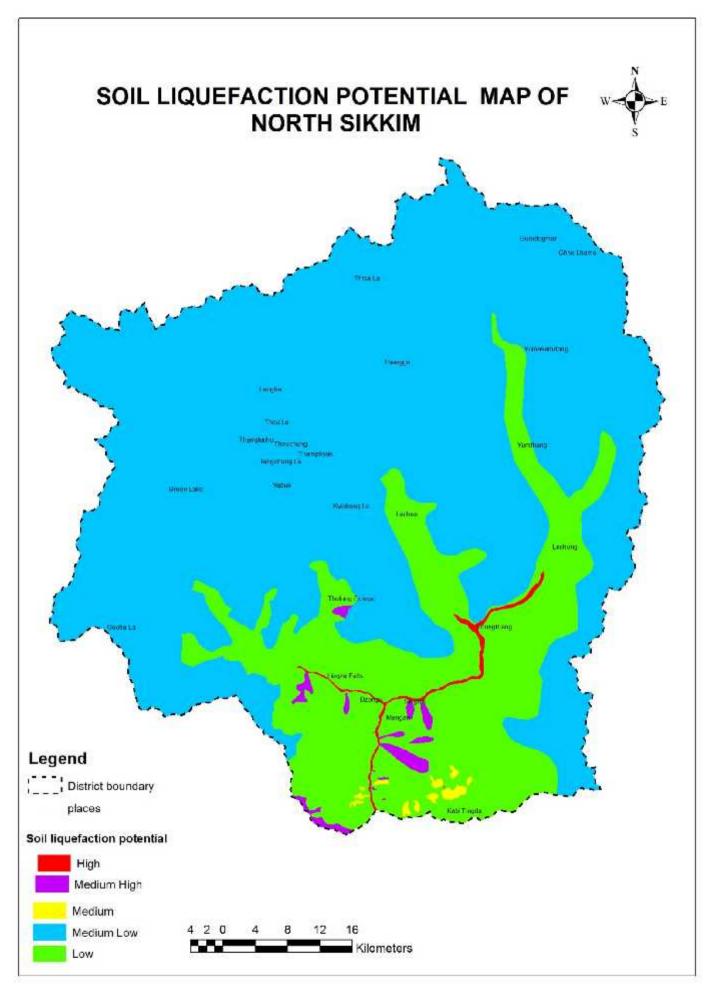
Landslide Hazards						
Hazards Category	% of Area	% of Household	hold Risk type			
Very High Hazards	1.27	1.32	Very High			
Medium High Hazards	34.28	19.55	High			
Medium Hazards	40.84	43.86	Medium			
Medium Low Hazards	23.43	30.12	Low			
Low Hazards	0.18	5.16	Low			

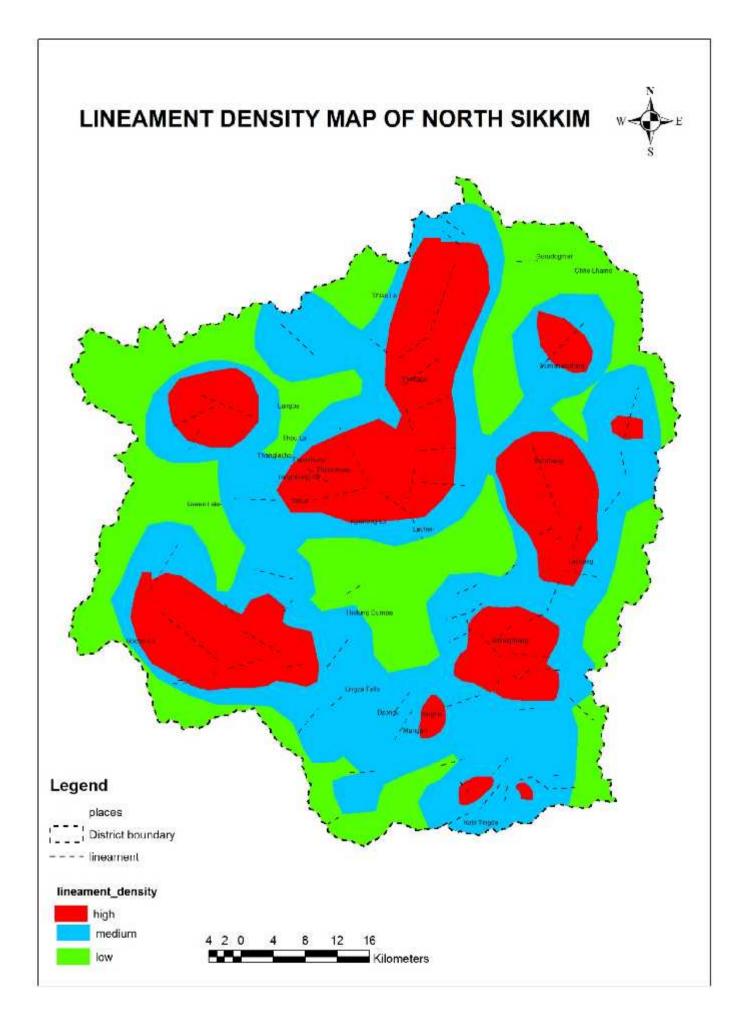


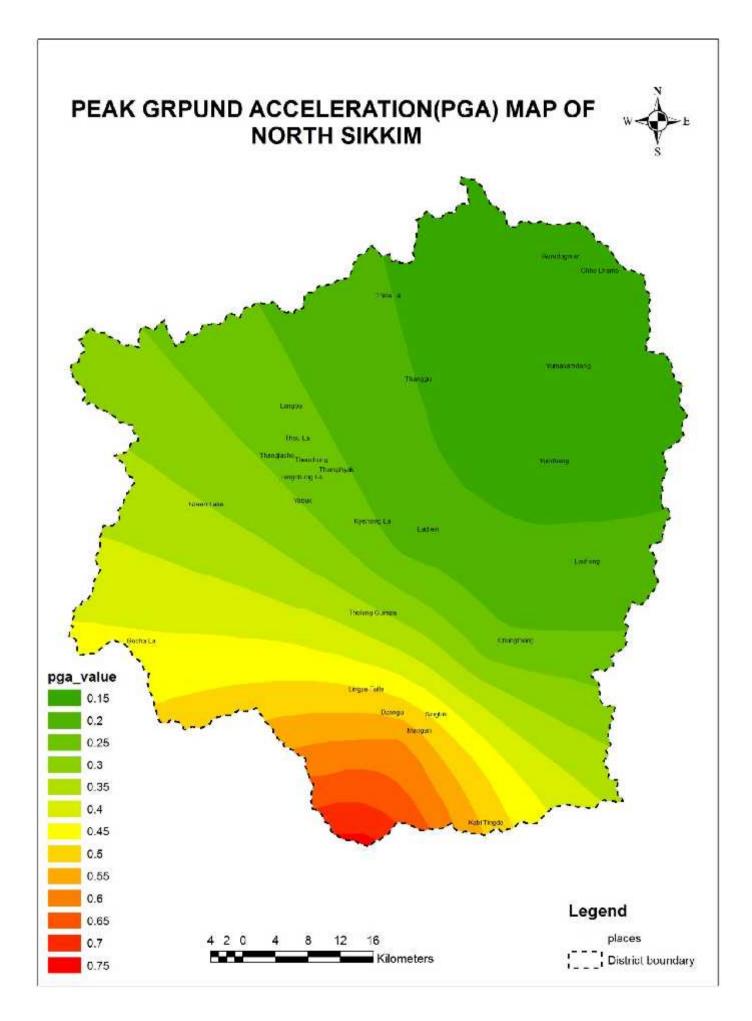
Conclusion:

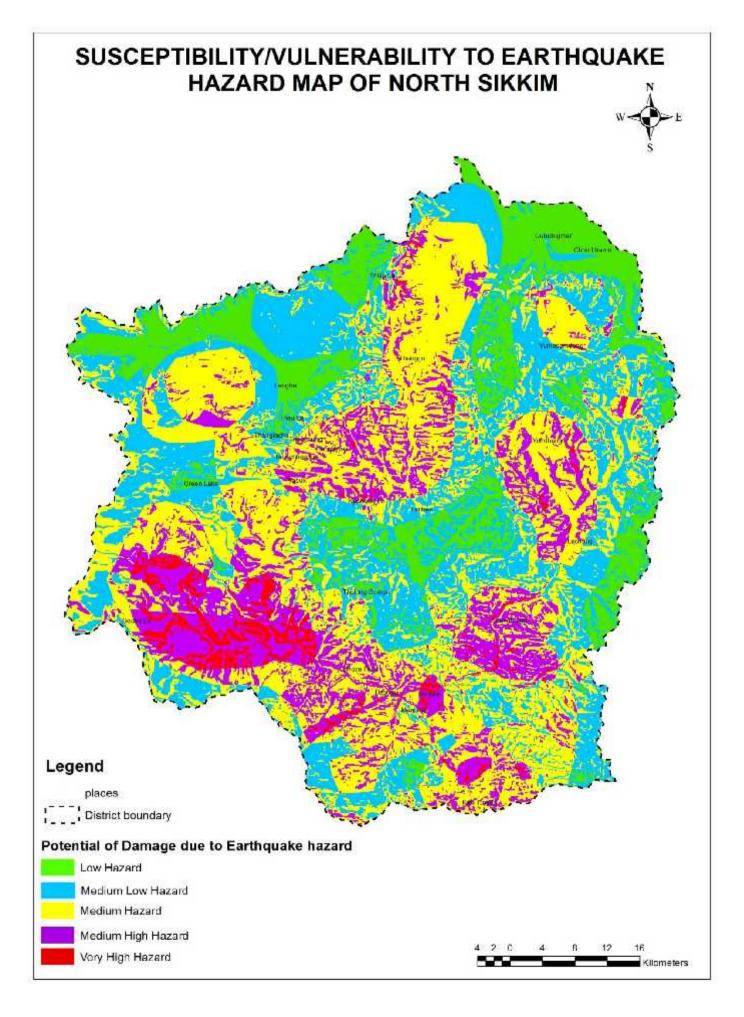
After extensive study and research of various maps and data it was possible to develop Landslide Hazard Risk and Vulnerability Map for the South District. The study leads to the following conclusions:

- 1.27% of the area fell in very high risk zone with 1.32% of the total settlement to be affected
- 34.28% of the area fell in very medium high risk zone with 19.55% of the total settlement to be affected
- 40.84% of the area fell in very medium risk zone with 43.86% of the total settlement to be affected
- 23.43% of the area fell in very medium low zone with 30.12% of the total settlement to be affected.
- 0.18% of the area fell in very low risk zone with 5.16% of the total settlement to be affected.

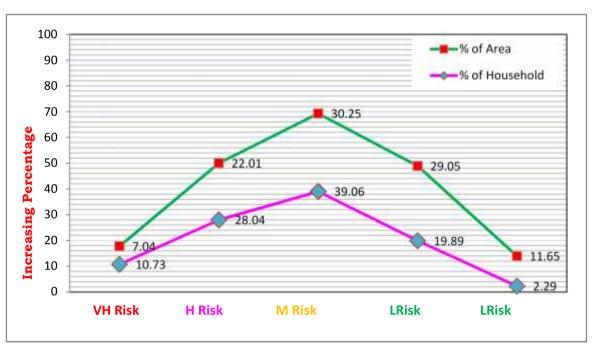






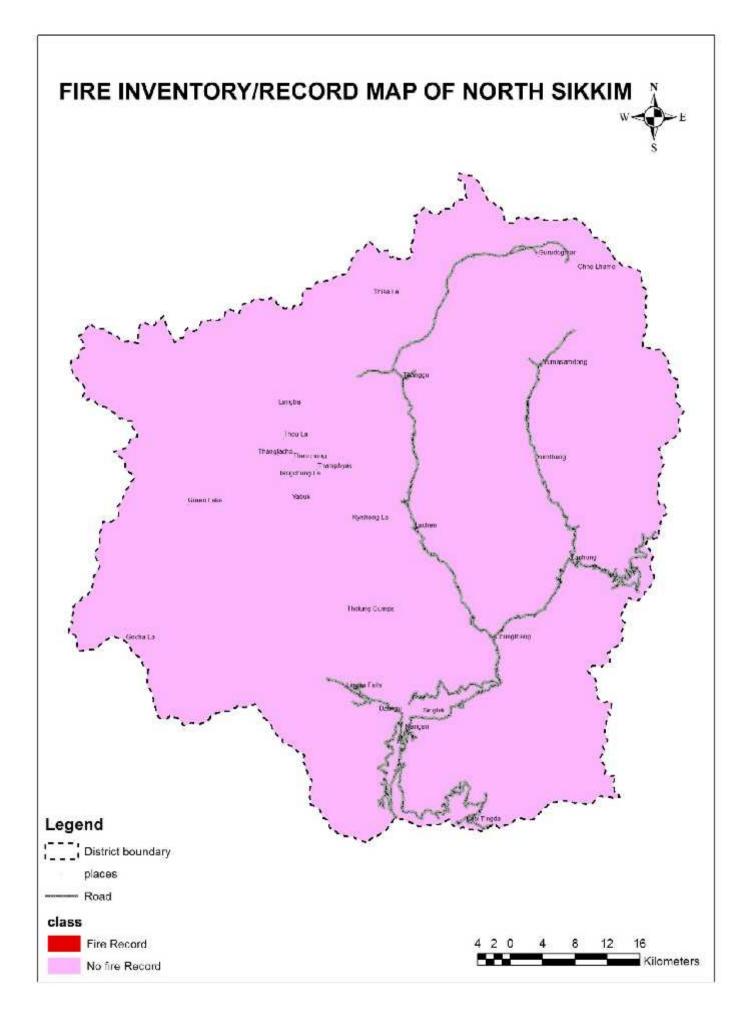


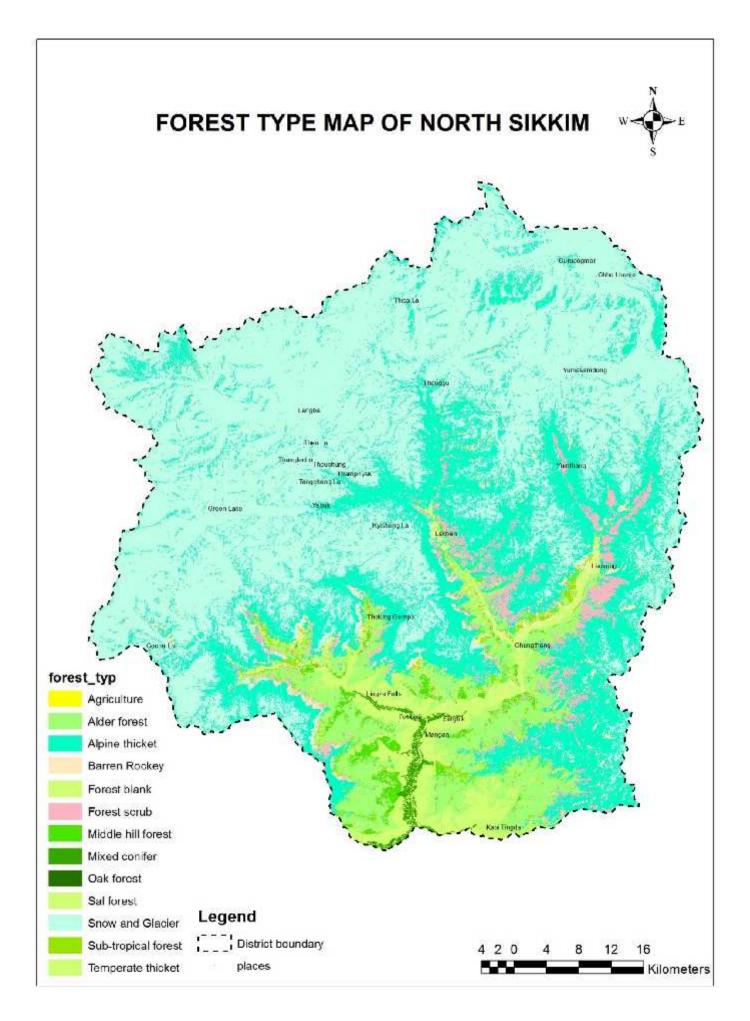
Earthquake Hazards						
Hazards Category % of Area % of Household Risk type						
Very High Hazar	7.04	10.73	Very High			
Medium High Hazards	22.01	28.04	High			
Medium Hazards	30.25	39.06	Medium			
Medium Low Hazards	29.05	19.89	Low			
Low Hazards	11.65	2.29	Low			

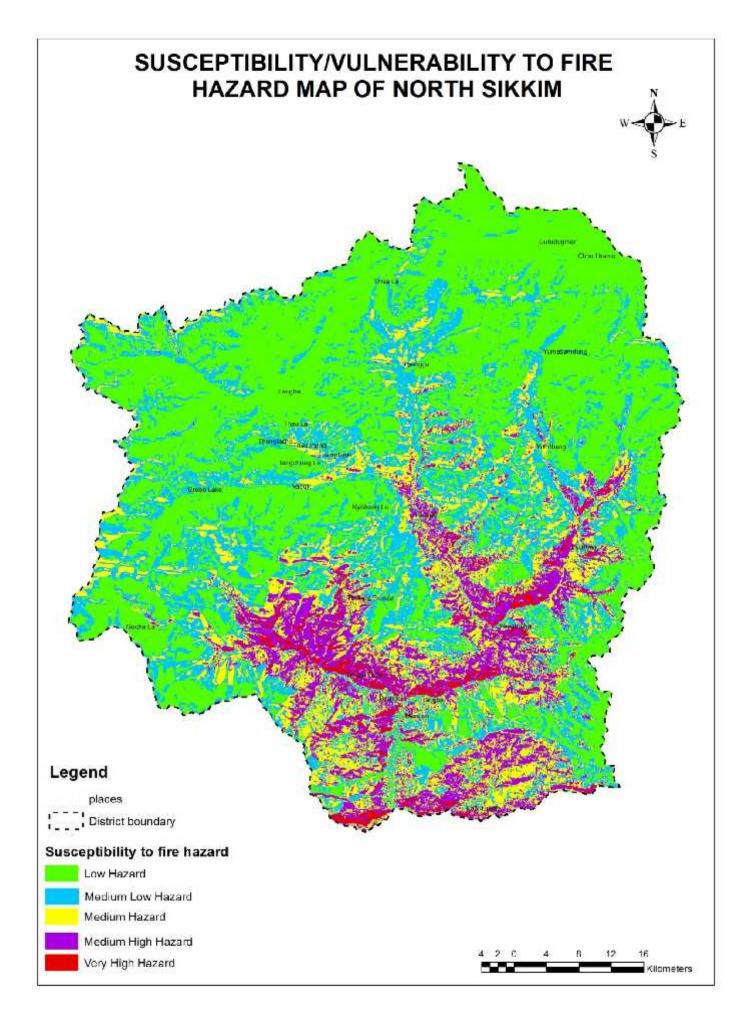


After extensive study and research of various maps and data, develop Earthquake Hazard Risk and Vulnerability Map for the North Sikkim. The study leads us to the following conclusions:

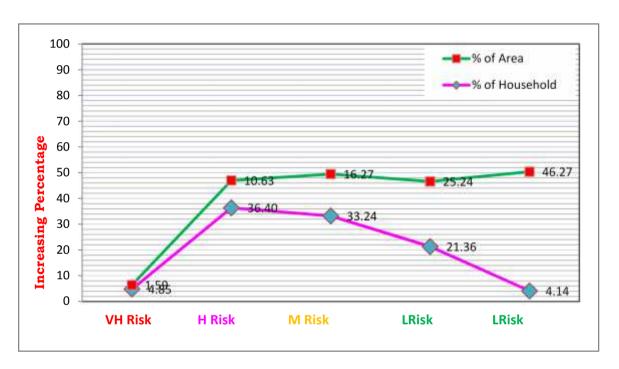
- 7.04% of the area fell in very high risk zone with 10.73% of the total settlement to be affected
- 22.71% of the area fell in very medium high risk zone with 28.04% of the total settlement to be affected
- 30.25% of the area fell in very medium risk zone with 39.06% of the total settlement to be affected
- 29.05% of the area fell in very medium low zone with 19.89% of the total settlement to be affected
- 11.65% of the area fell in very low risk zone with 2.29% of the total settlement to be affected





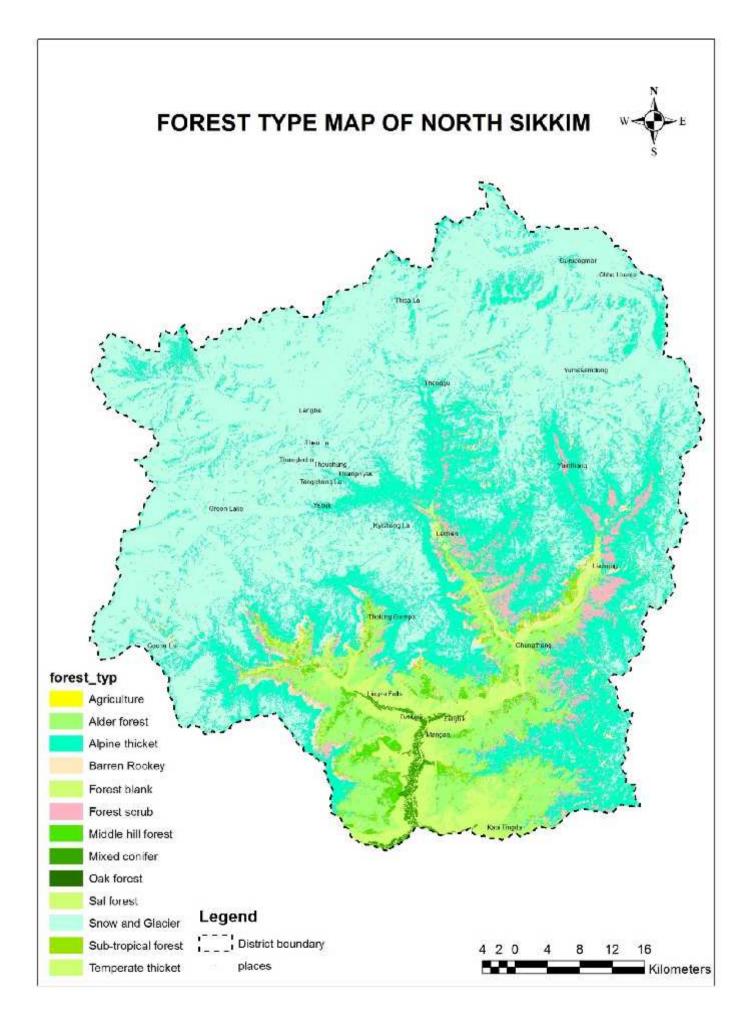


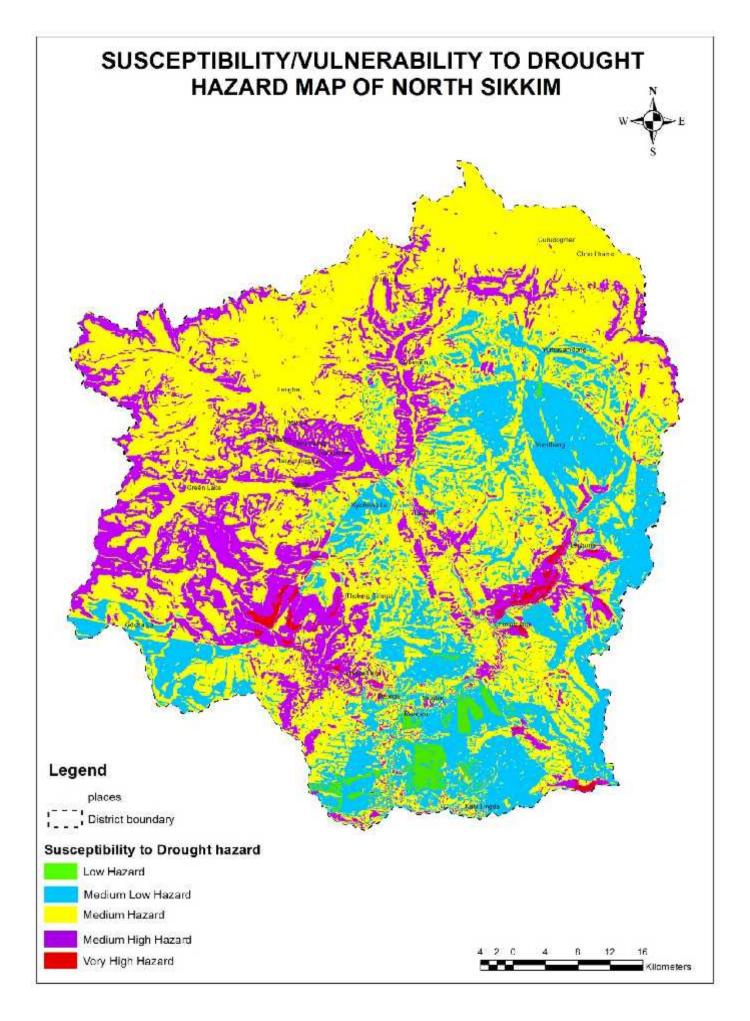
Fire Hazards						
Hazards Category	% of Area % of Household Risk type					
Very High Hazards	1.59	4.85	Very High			
Medium High Hazards	10.63	36.40	High			
Medium Hazards	16.27	33.24	Medium			
Medium Low Hazards	25.24	21.36	Low			
Low Hazards	46.27	4.14	Low			



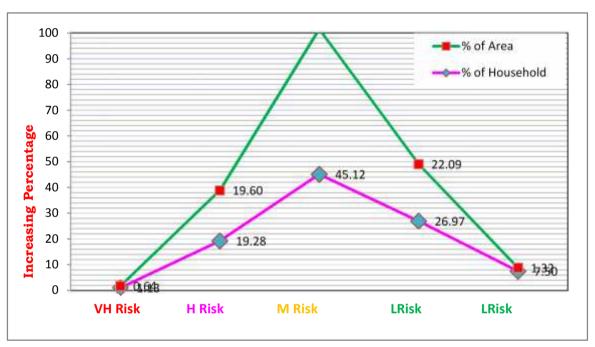
After extensive study and research of various maps and data, develop Fire Hazard Risk and Vulnerability Map for the North District of Sikkim. The study leads us to the following conclusions:

- 1.59% of the area fell in very high risk zone with 4.85% of the total settlement to be affected
- 10.63% of the area fell in very medium high risk zone with 36.40% of the total settlement to be affected
- 16.27% of the area fell in very medium risk zone with 33.24% of the total settlement to be affected
- 25.24% of the area fell in very medium low zone with 21.36% of the total settlement to be affected
- 46.27% of the area fell in very low risk zone with 4.14% of the total settlement to be affected



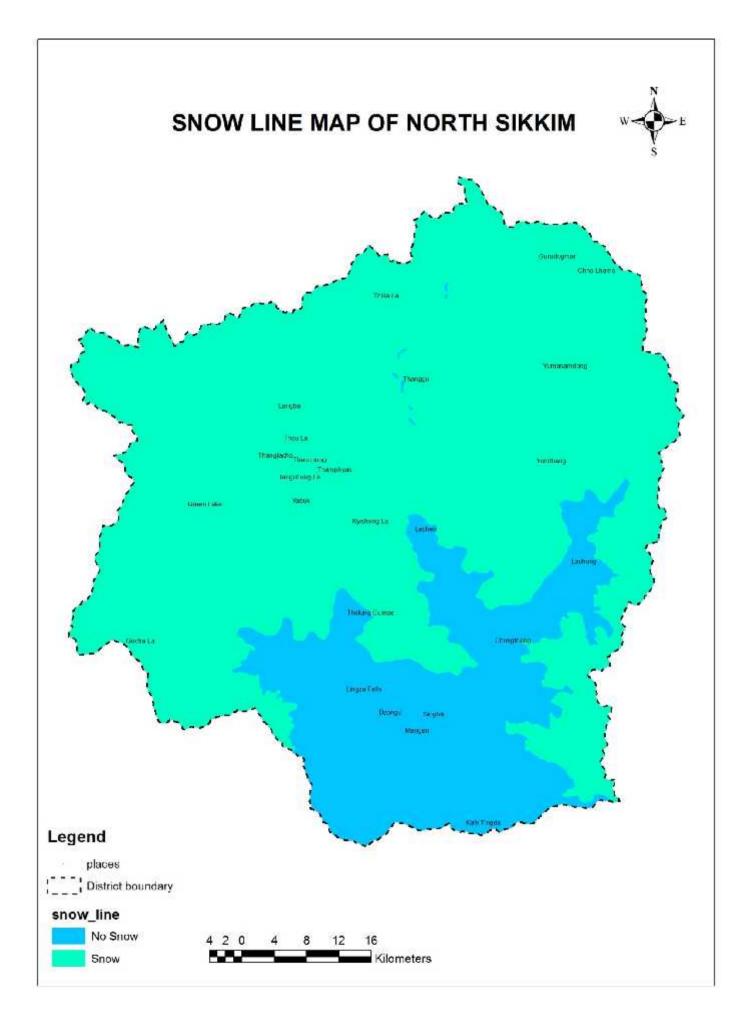


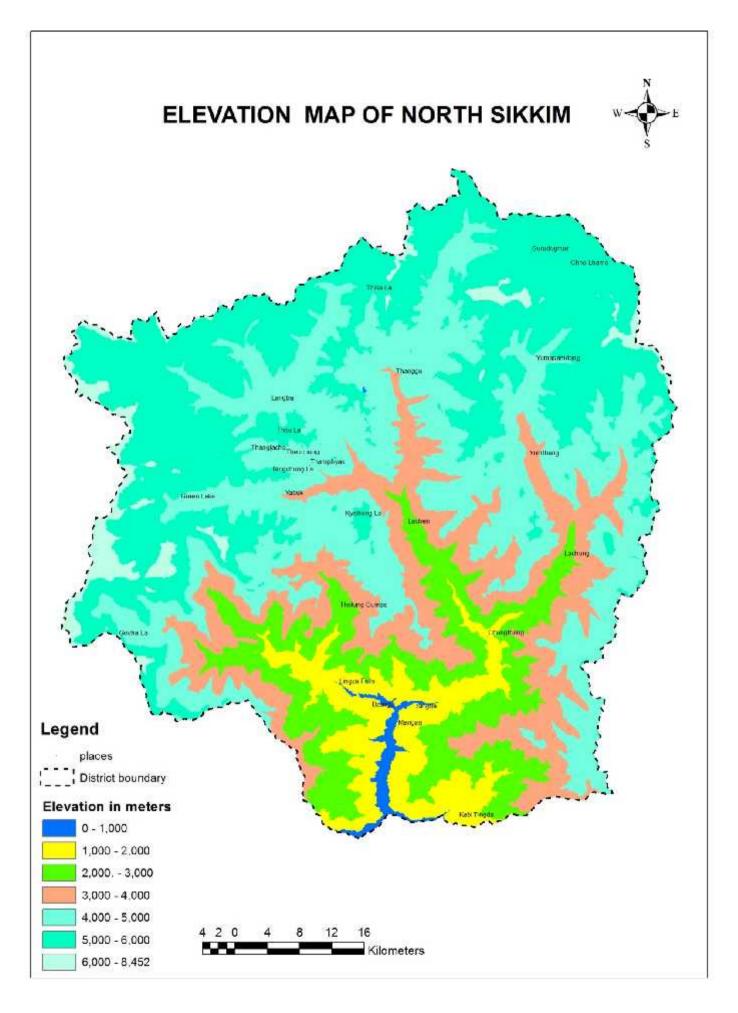
Drought Hazards						
Hazards Category % of Area % of Household Risk type						
Very High Hazar	0.64	1.13	Very High			
Medium High Hazards	19.60	19.28	High			
Medium Hazards	56.35	45.12	Medium			
Medium Low Hazards	22.09	26.97	Low			
Low Hazards	1.32	7.50	Low			

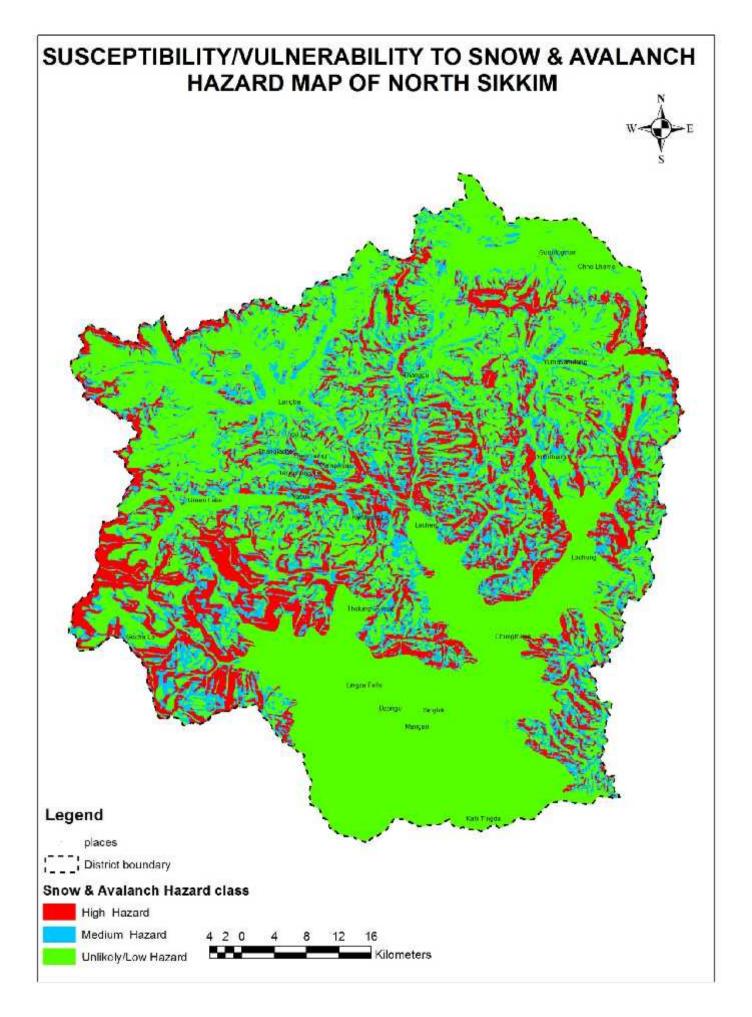


After extensive study and research of various maps and data, develop Drought Hazard Risk and Vulnerability Map for the North district of Sikkim. The study leads us to the following conclusions:

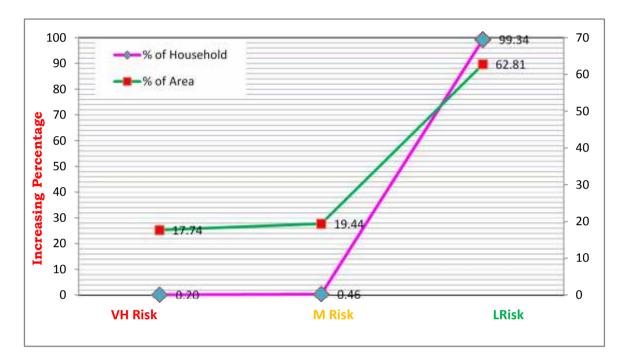
- 0.64% of the area fell in very high risk zone with 1.13% of the total settlement to be affected
- 19.60% of the area fell in high risk zone with 19.28% of the total settlement to be affected
- 56.35% of the area fell in medium risk zone with 45.12% of the total settlement to be affected
- 22.09% of the area fell in very low risk zone with 26.97% of the total settlement to be affected
- 1.32% of the area fell in very low risk zone with 7.50% of the total settlement to be affected





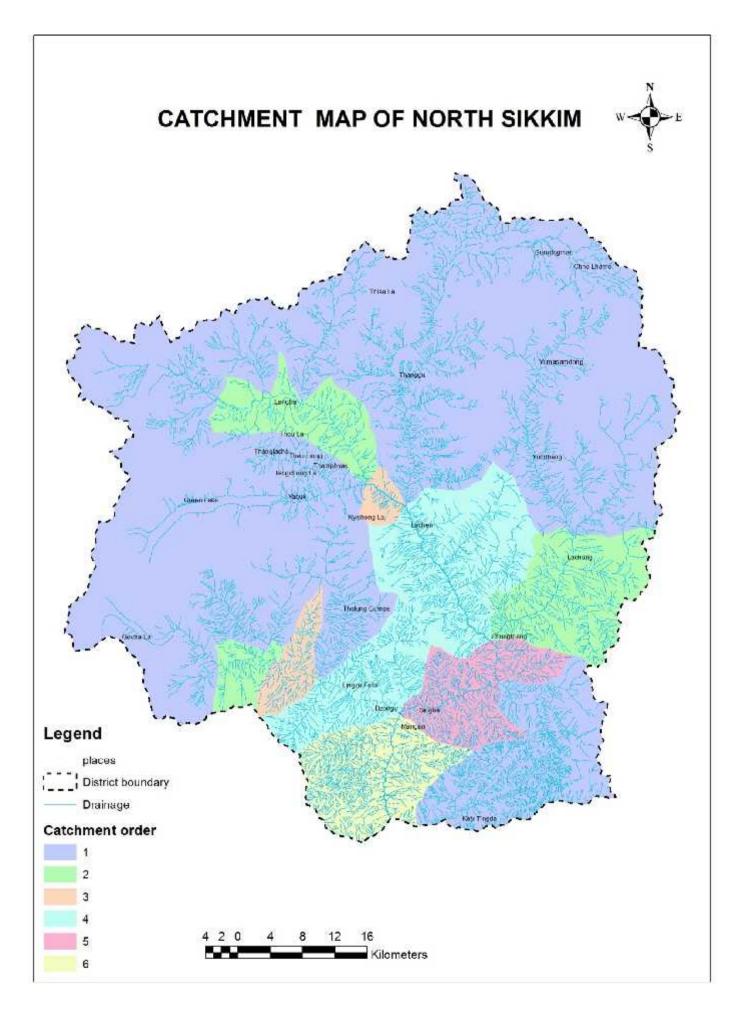


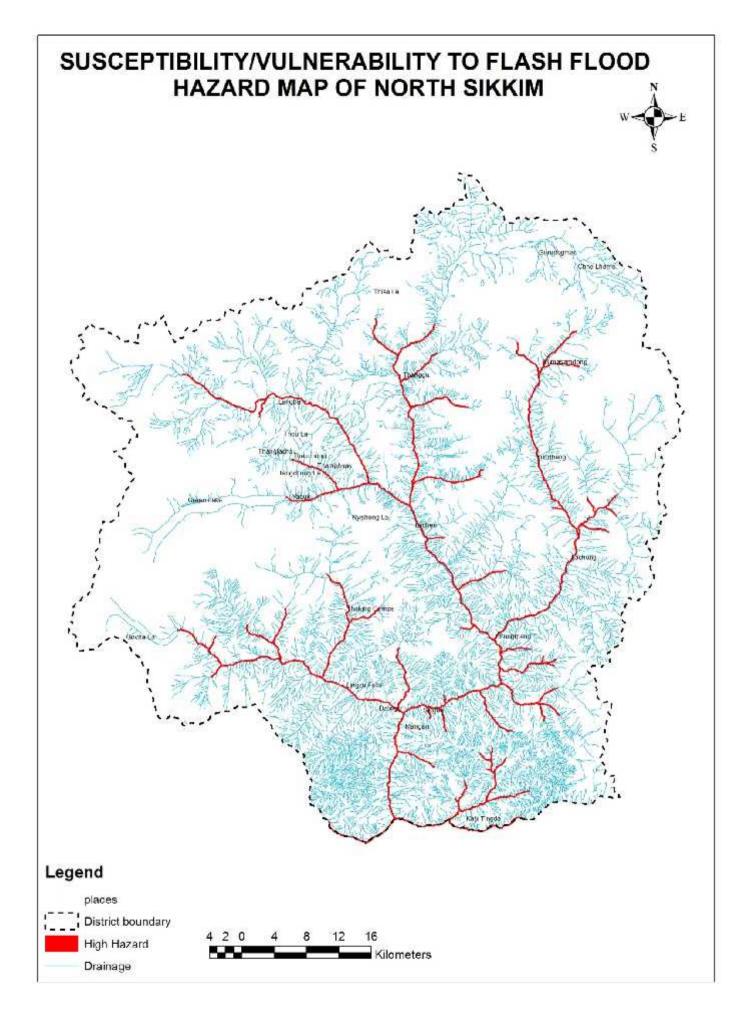
Snow and Avalanched Hazards						
Hazards Category % of Area % of Household Risk type						
Very High Hazards	17.74	0.20	Very High			
Medium Hazards	19.44	0.46	Medium			
Low Hazards	62.81	99.34	Low			



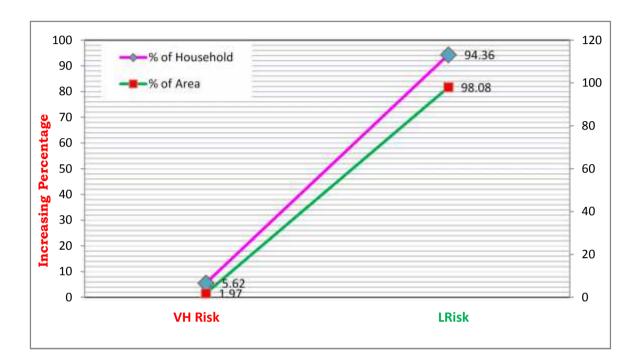
After extensive study and research of various maps and data, develop Snow and Avalanche Hazard Risk and Vulnerability Map for the North District of Sikkim. The study leads us to the following conclusions:

- 17.74% of the area fell in very high risk zone with 0.20 % of the total settlement to be affected
- 19.44% of the area fell in medium risk zone with 0.46% of the total settlement to be affected
- 62.81% of the area fell in very low risk zone with 99.34% of the total settlement are in this category



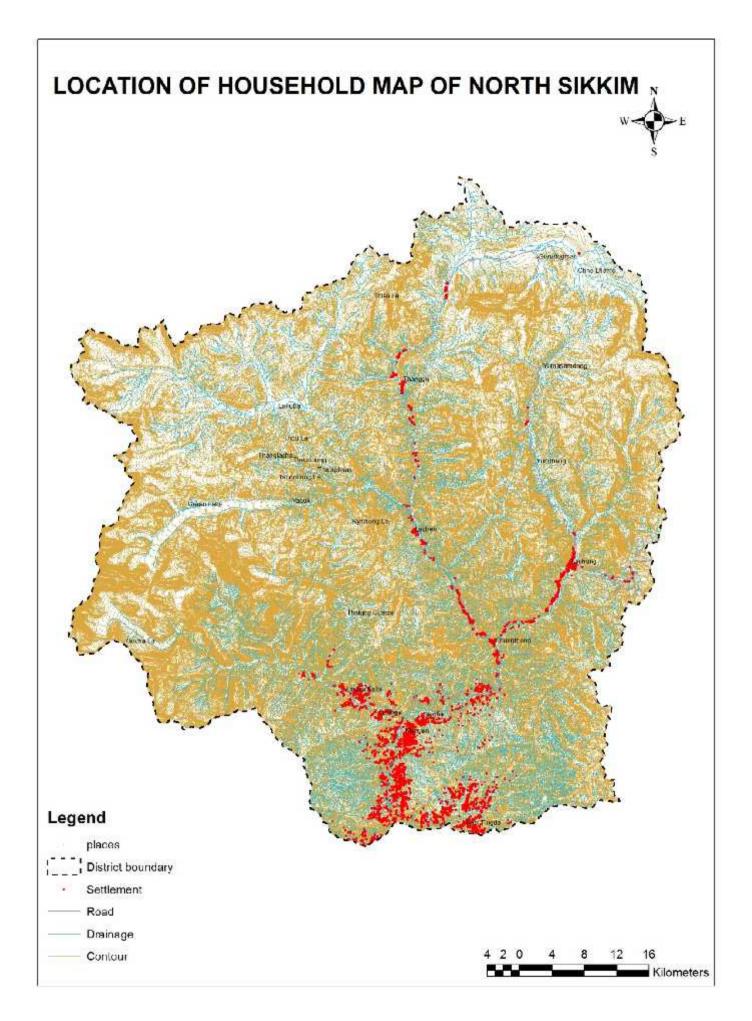


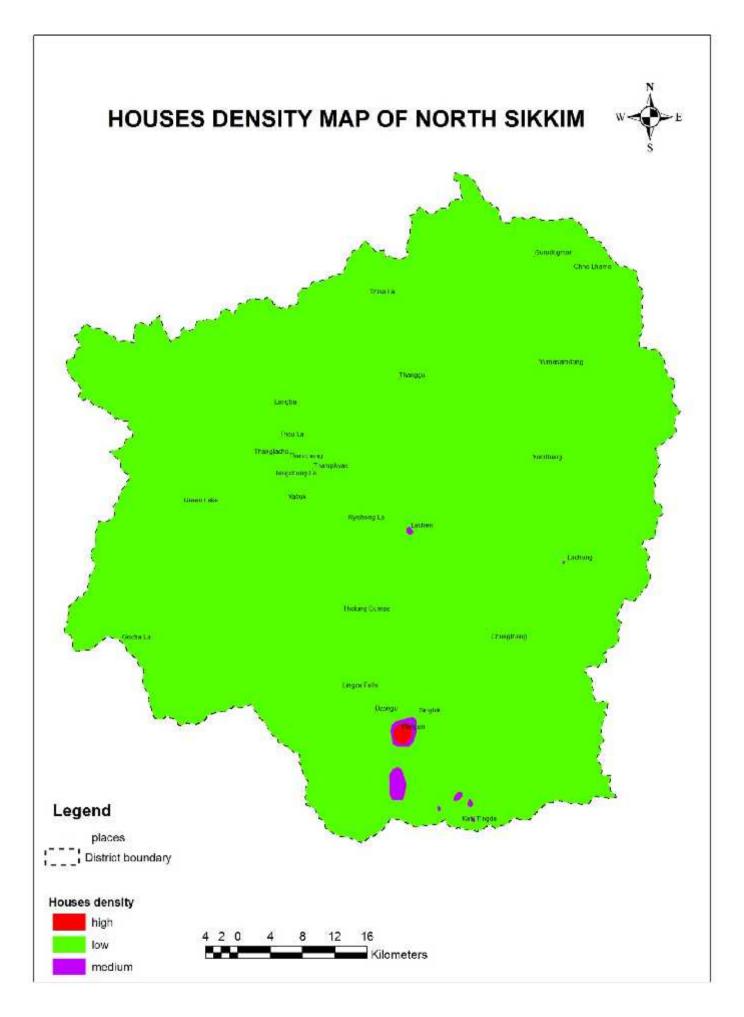
Flashflood Hazards					
Hazards Category % of Area % of Household Risk type					
Very High Hazar	1.97	5.62	Very High		
Low Hazards	98.08	94.36	Low		

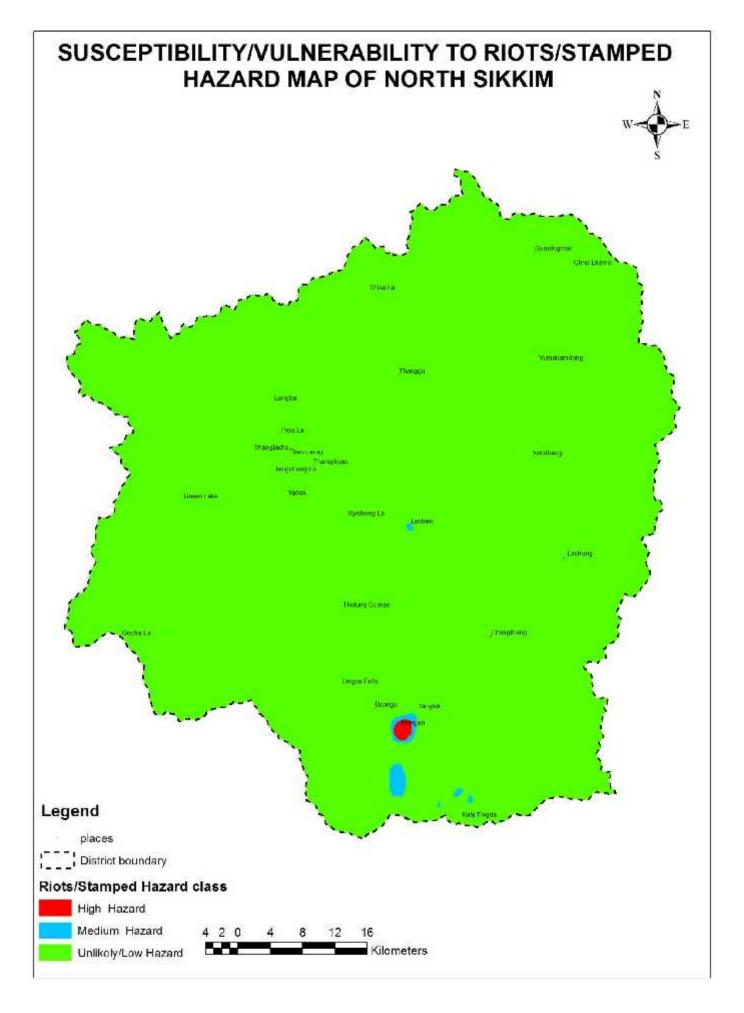


After extensive study and research of various maps and data, develop Flash flood Hazard Risk and Vulnerability Map for the North District of Sikkim. The study leads us to the following conclusions:

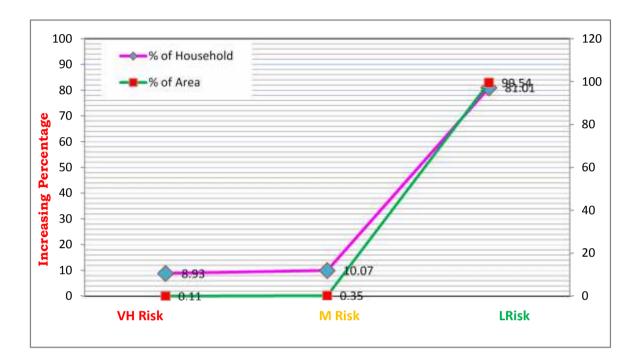
- 1.97% of the area fell in very high risk zone with 5.62% of the total settlement to be affected.
- 98.08% of the area fell in very low risk zone with 94.34% of the total settlement to be affected.







Riots/Stamped Hazards						
Hazards Category % of Area % of Household Risk type						
Very High Hazar	0.11	8.93	Very High			
Medium Hazards	0.35	10.07	Medium			
Low Hazards	99.54	81.01	Low			



After extensive study and research of various maps and data, develop Riot Hazard Risk and Vulnerability Map for the North District of Sikkim. The study leads us to the following conclusions:

- 0.11% of the area fell in very high risk zone with 8.93% of the total settlement to be affected.
- 0.35% of the area fell in high risk zone with 10.07% of the total settlement to be affected.
- 99.54% of the area fell in very low risk zone with 81.01% of the total settlement to be affected.

Multi-hazards:

Taking into account the different Hazards that may affect the region of North District of Sikkim, developed a multi hazard map and a Risk Matrix Chart to assess the impact of each hazard in the respective NORTH SIKKIM.

Risk Matrix Chart								
5		EVERY YEAR	HILLSTROMS, SNOW AND AVALANCHES				LAND SLIDE	lihood
4	pooq	2-10 YRS	DROUGHT	FIRE		FLASHFLOOD		Likel
3	keli]	11-20 YRS		RIOTS			EARTHQUAKE	
2	' /Li	21-30 YRS						ICV.
1	ency	31-50 YRS						uer
Score Of likely- hood	Frequency /Likelihood	Score of Impact	1 TO 7	8 TO 14	15 TO 21	22-28	29-35	Frequency/
					•			

Severity/ magnitude of damage

RELATIVELY INCREASING RISK							
MEDIUM							
LOW	LOW						

Methodology

In this analysis extensive background check was done with extensive historical research, as well as observational data. Different kinds of maps were created so as to assess the risk and vulnerability of the region. This information was then considered in the context of the seven impact criteria, which are outlined in Table 1 below. The impact criteria were individually ranked on an ascending scale from one to five, one being the least severe and five being the most severe. The sum of these scores was taken to create an overall consequence score, the score was then contrasted against a likelihood rating of one to six, one being the least likely and six being most likely. Details regarding the measure of likelihood are seen in Table 2. The aggregate score of each hazard, combined with the hazard impact consequence and likelihood provide the basis for a risk ranking of *low*, *medium low*, *medium*, *medium high* and *very high*.

Table 1 – Seven Categories of Impact		
Categories of Impact	Score	
Fatality	1 TO 5	
Injury	1 TO 5	
Critical Facilities (Hospitals, Fire/Police	1 TO 5	
Services etc.)	1 10 3	
Lifelines (Water, Gas, Power, etc.)	1 TO 5	
Property Damage	1 TO 5	
Environmental Impact	1 TO 5	•
Economic and Social Impact	1 TO 5	•

Table 2 - Measure of Likelihood		
Measure of Likelihood	Return Period (yrs)	Score
Frequent or Very Likely Every	EVERY YEAR	5
Moderate or Likely Every	2-10 YRS	4
Occasional, Slight Chance Every	11-20 YRS	3
Unlikely, Improbable Every	21-30 YRS	2
Highly Unlikely, Rare Event Every	31-50 YRS	1

RISK RATING INTERPRETATION

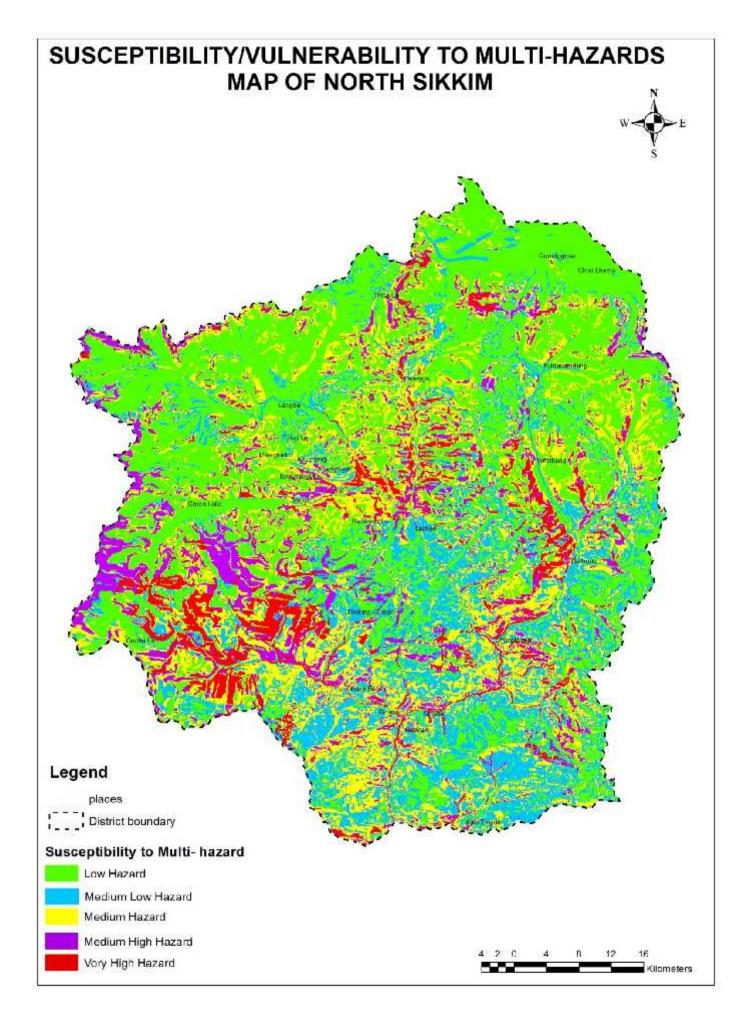
These risks are **low**. Implementation of mitigation measures will enhance emergency preparedness, but it is of less urgency and highly unlikely to occur in that area than the following hazards.

These risks are medium low. Implementation of mitigation measures will enhance emergency preparedness, Hazards is highly unlikely to occur in that area, but is of more urgency than low

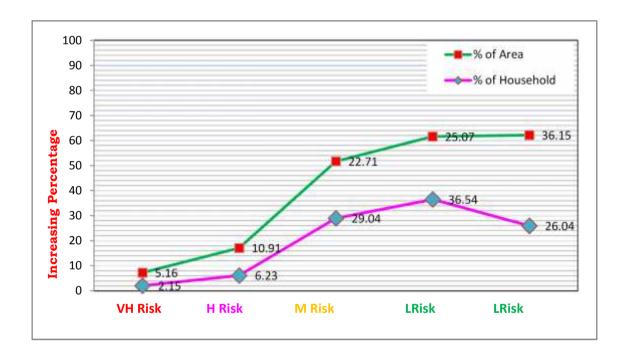
These risks are **medium**. These hazards have intermediate levels of frequency and severity. Hazards classified as moderate are more urgent than medium low hazards and are often common place concerns. Given this, moderate level hazards should be addressed with an appropriate level of urgency.

These risks are **medium high**. These hazards warrant review and development of mitigation actions to reduce the risk to an acceptable level. But these hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

These risks are **very high**. These hazards are both frequent and are of high severity. These hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

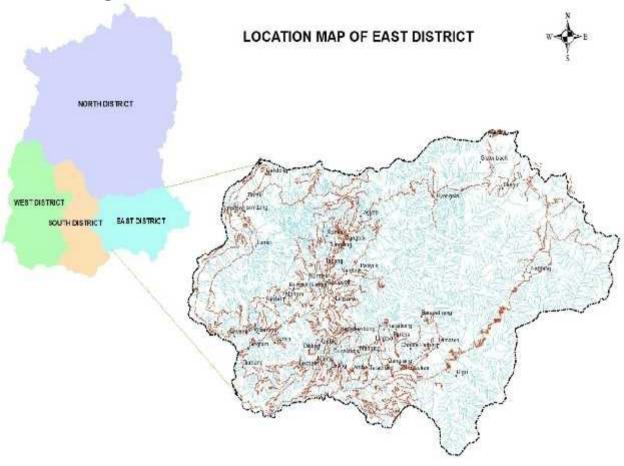


Multi- Hazards						
Hazards Category	% of Area % of Household Risk type					
Very High Hazar	5.16	2.15	Very High			
Medium High Hazards	10.91	6.23	High			
Medium Hazards	22.71	29.04	Medium			
Medium Low Hazards	25.07	36.54	Low			
Low Hazards	36.15	26.04	Low			



EAST DISTRICT

The area under investigation constitutes a part of the lesser Himalayas in Sikkim, with elevations ranging from 350mts to about 4,630mts characteristically; the terrain is highly dissected, with steep gorges, broad valleys, fairly sharp peaks and ridges. This area is bounded by latitudes 27° 08°N to 27° 23°N and longitudes 88° 25° E to 88° 45°E and covers an area of about 954 Km².



GEOLOGY

The Sikkim-Darjeeling geological complex has a more or less persistent lateral extent, with Himalaya occasional pinching and local truncation, due to Sedimentary facies change and tectonic overlaps respectively. Four well-defined tectonic belts are identified in the Sikkim-Darjeeling area (Sinha Roy, 1973). From south to north, these are:

(i) The Foothill belt – comprising Siwaliks, Gondwanas and impersistent Buxas. This belt is characterized by frequent repetitions of the stratigraphic units by close-spaced thrusts, thus representing a belt of Schuppen. The main Tectonic datum in this belt is the Main Boundary Fault between the Siwaliks and the Gondwanas. This dislocation zone

- often, as well, defines the contact of the Siwaliks and the Buxas, or the Dalings;
- (ii) The Inner Belt Comprises the Metamorphites of the Daling-Darjeeling sequence. Besides, it also contains isolated 'Tectonic window' in areas of deep erosion along zones of structural culminations. Pache Khola & Kali Khola windows of East Sikkim, where the Gondwana and the Buxa sequences are exposed below the covered unit of Daling Metamorphic sequence.

Moreover, there are a number of thrust controlled and highly tectonised granitoid gneissic bodies (Lingtse and Pendam granites), which occupy different tectonic and stratigraphic levels in the low to medium grade Metamorphics of Dalings. The present area, falling in a part of the Inner Tectonic Belt, also contains isolated occurrences of this type of gneisses.

(iii) The Axial Belt – is defined by the highest grade of Metamorphites and gneisses represented by the Chungthang Formation and Kanchendzonga Gneiss (Migmatite gneiss) and tourmaline-bearing gneiss occurring in the highest topographic levels of this region. This belt is separated from the Inner Belt by the Main Central Thrust, which is an important identifiable zone of separation all along the Himalayas.

Daling Formation: - The Greywacke is the most significant mapable unit in the area and is represented by Gritty Phyllite, Schist-Gritty Quartzite association. The elastic components comprise Quartzite, vein Quartz, Oligoclase, Microcline, Granite and Carbonate etc. The accessories include tourmaline, zircon, rutile, sphene, etc., which are set in an elastic Chlorite-Sericite matrix. The Psammitic unit is represented by a massive, pale green to buff and variegated Quartzite, Sericite (Chlorite) Quartzite, where the Quartz grains often show intense marginal granulation and re-crystallization. Intergranular Chlorite and Sericite occasionally define a crude schistosity. The semi-pelites and the low grade Metamorphics include variegated slates, purple phyllites and Chlorite-Sericitephyllites, with alternate bands of variable thickness of Micaceous Quartzite, with small amounts of fine-grained elastic Ouartz, feldspar and tourmaline. This unit is characterized by a rhythmic banding, with essential parallel laminations. Convolutions are rarely found in some less deformed rocks. The carbon phyllite consists of alternate thin layers of highly re-crystallized polygonal Quartz, with small dispersed grains of carbonate and stumpy Sericite with dispersed carbonaceous material defining the bedding. Sometimes, a few structural grains of garnet are arranged in zones parallel to bedding. This is suggestive of their detrital origin. In Quartz-Chlorite-Sericite-Schists, the schistosity is defined by chlorite and Sericite, and the compositional banding by opaque and colour laminations. The purple phyllite is very fine-grained and contains abundant opaque, which are responsible for the purple colour of this particular rock type.

Buxa Formation: The main rock types of this formation are Calcareous Quartzite, Dolomitic Quartzite and Variegated slates. This is exposed mainly in the Pache khola section. The carbonate phase in calcareous Quartzite occurs in octahedral grains, inter-locked with polygonal quartz, but is contained in some well-developed layers, which suggest primary banding. The accessories found in this rock type include apatite and epidotic. The Dolomitic Quartzite is purplish in colour. The rock is found to be composed of dolomite and of a small quantity of quartz in granular aggregates, with accessories like sphene, muscovite, etc. Variegated slates are grey, buff, purple and pale green in colour and consist of Chlorite, Sericite and Biotite with some detrital Quartz. Accessory minerals include sphene, leucoxene, limonite, calcite and apatite. All these minerals are embedded in a clayey matrix.

Streaky Biotite Gneiss (Lingtse Granite): Streaky Biotite Gneiss, known as Lingtse Granite, has been mapped in two areas – one in Pendam-Budang area, and the other to the east of Rhenok. This streaky gneiss is composed chiefly of two types of Quartz. The early re-crystallized Quartz has well-developed polygonal outlines, enclosed in a late an-hedral slightly strained type of Quartz grains. The plagioclase feldspar has been altered to Sericite. The green and brown biotite, the other constituent, marks a strong foliation. Epidote, tourmaline and opaque are the major accessories. The Lingtse Granite was previously considered to be intrusive in nature. But later it has been shown that it comprises allochthonous masses within the Daling rocks (Sinha Roy, 1996). The granitoid bodies here are thrust bound, and not intrusive, as found from their clear-cut contacts and the presence of granitoid-mylonite at the contact zones. These are characterized by a well-developed Biotite lineation. In the Pendam-Budang area, the contact of Lingtse Granite with Dalings appears to be gradational at places.

<u>Basic Rocks</u>: - Concordant sill likes bodies of Amphibolites-schist and Epidiorites are found occasionally in the Daling stratigraphy, particularly within the greywacke and semi-pelites. These vary considerably in thickness, due to pinching and swelling, and have limited lateral extents; attaining a maximum thickness towards the centre. The main constituent of this rock is a Coarse, Prismatic and Hornblende, Quartz and chlorite are the other minerals present. The hornblende defines a moderately well-defined schistosity. It is at places chloritised and is in some cases inter-leaved with Biotite. Secondary silicification and presence of quartz stringers is also noted. The basic rocks occasionally contain splashes and disseminations of sulphide minerals - mainly chalcopyrite, with some Pyrite and Pyrrhotite.

Gondwana Group: The Gondwana Group of rocks in this part of Sikkim is exposed in the 'depressions' formed by the intersections of two mutually perpendicular N-S and E-W cross fold axes, in the form of geological 'window' in Pache khola and Kali khola, surrounded by the Buxas and the Daling group of rocks successively. The rocks of the Gondwana Group are represented by coarse to medium-grained sandstone, grey shale, carbonaceous shale, pebble slate and

thin stringers of coal-possibly equivalent to the Lower Gondwanas of Peninsular India.

The Geological sequence of Juluk-Nathang-Kupup-Chhangu areas of East District of Sikkim indicate that Lithologically, the area comprises a sequence of high grade gneisses with interbands of Metasedimentaries. The high grade gneisses range in composition from types rich in quartz-feldspar with streaks of Biotite to Quartz-Biotite gneiss with frequent association of garnet, Sillimanite and Kyanite depending upon the original bulk composition of the rock. The gneisses show variation in textures from augen gneiss to streaky gneiss to banded gneiss despite broad compositional similarities. The passage from one variety to the other is gradational and not separated by any recognizable thrust plane. The gneisses are occasionally intruded both concordantly and discordantly by foliated and unfoliated tourmaline bearing Granites, Pegmatite and Epidotic-Quartz veins and some basic bodies. The Metasedimentaries are represented by a calcaremslitho facies comprising calc-silicates/marbles/calc-granulites.

Geomorphologically, the area consists of structural-cum-denudation and glacial land form units. Extensive sculpturing of the landscape by glacial agencies has been observed in the area with subsequent modification by glacis-fluvial and fluvial agencies. Imprints of at least three deformational phases have been observed in the area. The genisses show compatible deformational structures with the associated Metasedimentaries. Field and Petrographic studies indicate a main phase of regional prograde Metamorphism associated with the earliest deformation producing a dominant and pervasive planar fabric through Metamorphic reconstitution. The second phase of Metamorphism is accompanied by very little Metamorphic reconstitution and is mainly retrogressive in nature.

The similarity in the imprints of the deformational fabrics of the high grade gneisses and the associated Metasedimentaries point to a possible common mode of evolution through granitisation in response to the main phase of deformation and metamorphism.

GEOLOGICAL STRUCTURES

The rocks of the investigated area exhibit structures of at least three recognizable phases of deformation; each phase being distinguished from the others by a characteristic fold morphology, inter-relations, orientations and minerals paragenesis.

a. First generation structures: The bedding (So) defined by colour laminations, and grain-size variations are in most cases, quasi-parallel to the regional schistosity (S1), which is defined by a parallel arrangement of Sericite, muscovite and biotite, with an appreciable degree of refraction in alternating Pelitic and Psammitic layers (S1). The regional schistosity is axial planar to the earlier set of folds, and therefore represents the first generation planar structure; which, along with So, defines the form surface

of the later structure. Both So/S1 varies from N-S through NE-SW with moderate dips towards east, north and south. Swings in the attitude of S0 and S1 are mainly attributed to a set of NE-SW and E-W folds of the third generation. Despite near paralletism of So and S1 in a few places, intrafolial to rootless flattened flexure slip folds (F1) in thin Quartzite laminae are seen within phyllite (as seen in Rishi khola near Rishi khola – Rangpo Chu Confluence), where S1 truncates So at fairly steep angles to give rise to a prominent intersection lineation.

- **b. Second generation structures**: The second generation structures (F2) are the most penetrative structures of the area on all scales and are represented by flattened flexure-slip folds-isoclinals both recumbent to reclined types. These are often associated with a well-developed axial plane cleavage (S2), which varies in attitude from NE-SW to NNW-SSE, with a low to moderate dips towards east and west. (As seen in the Rhenok-Rongli Section). In low grade Metamorphic rocks, S2 is a crenulation cleavage, but with progressive re-crystallization of Phyllosilicates, it assumes the form of a truly pervasive schistosity, with a linear alignment of mica and flattened Quartz grains, replacing and obliterating the Phyllosilicates, which are mainly Biotite and Muscovite, and define a well developed mineral lineation. Intersections of S1 and S2, where at higher angles, define a pucker lineation on the S1 plane. A gradual increase in the tightness of F2 makes S2 nearly parallel to S1. The regional thrusts are near-parallel to S2, and therefore, it is likely that the rotation of F2 lineations and fold axes is related to thrusting. Besides, zones of mylonitisation and the foliation in the sheared gneiss (Lingtse Gneiss) are parallel to S2. This prominent Biotite lineation and stretched grain elongations of the 'Lingtse Gneiss' are parallel to the mineral lineation on S2, in the Metamorphites and have a strong preferred N-S orientation, suggesting a N-S tectonic transport during the second phase of deformation. Another important second generation lineation comprises mullions of both F2 folds and So/ S1-S2 intersection types, specially well-developed in fairly thick sequences of Quartzitephyllite deformations. In higher grade rocks, the mullions are replaced by a grove and striation lineation. Boudinage and pinch and swell structures are common, with their axes parallel to local F2 axes. The mineralized bands are affected by F2 folds and sow preferential thickening at the hinges, because of the flattened flexure slip nature of these folds.
- **c. Third generation structures**: The planar structural elements of this phase of deformation are attributed to a crenulation cleavage (S3), well-developed

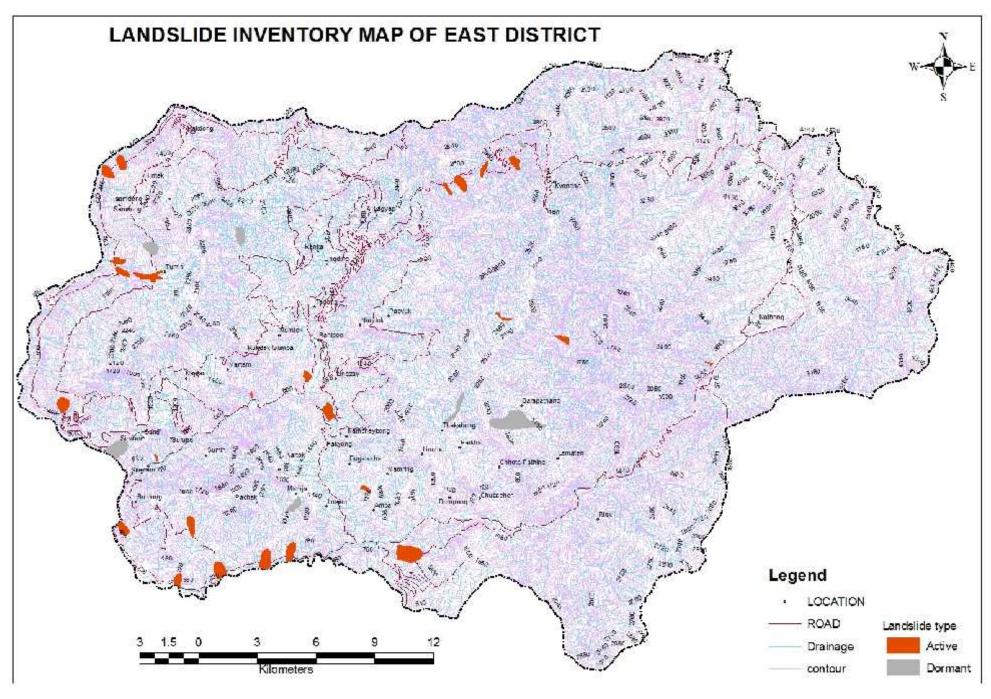
at the core of megascopic F3 folds, and are selectively observed in low grade phyllitic rocks. The attitudes of these S3 planes, along with axes of F3 folds and the regional attitudes of So/S1 and S2 suggest that the third generation folding took place in two mutually perpendicular direction, E_W and N-S, the two sets being, in general, mutually exclusive in occurrence, and hence considered contemporaneous. The E-W folds (F3) are the more dominant and penetrative type than the N-S (F3) folds. F3 minor folds show a variety of forms line kink, chevron, open flexures and monoclines. In contrast, the F3 folds are open flexure slip type and are associated with a faintly developed pucker lineation (in pelitic assemblage) and mullions (in psammites). However, the domal pattern near Pachekhani and Rorathang, giving rise to window structures, are due to rejuvenation of mutually perpendicular N-S and E-W folds of the third generation.

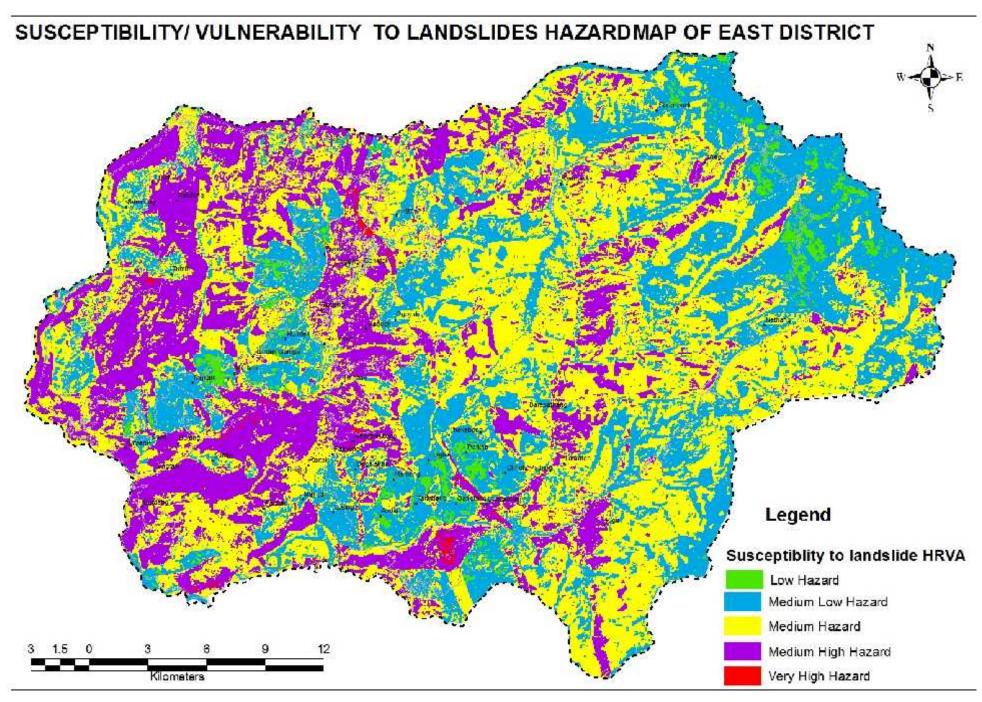
HYDROGEOLOGY AND DRAINAGE

The Tista River, running almost N-S in the western part of the area, is the major drainage channel, to which there are numerous tributaries of various orders. The main tributaries are the Rangpo Chu, Rishi Chu, Rongli Chu, Mandum Khola, Pache Khola, Khani Khola and Kali Khola. The major rivers and tributaries are characterized by arid meanders with well-developed scrolls and terraces of at least three levels. The hill slopes are covered with veneers of rock and soil debris, which are potential sources of landslide materials. The slopes are highly unstable, due to high slope angles, fairly heavy rainfall and significant toe-erosion by the rivers and streams, which are characterized by high discharge, particularly during the monsoons. The average yearly rainfall in the area varies from 400 to 500cms. The heaviest rainfall takes place generally during the period from July to September. Winter in higher altitude is quite severe. In the summer, these places are very pleasant; whereas in lower altitudes, e.g., in Rangpo, Rorathang, etc., in the vicinity of river beds, the summer is quite sultry.

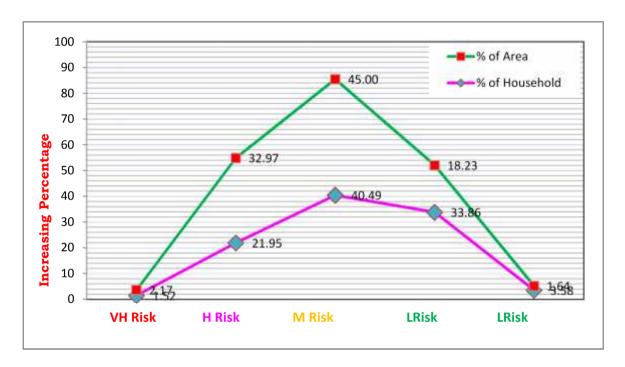
LAND-USE AND LAND-COVER

Gently sloping and flat areas throughout the eastern hill slopes are extensively used for paddy cultivation by Bundh irrigation system and steeper slopes with perennial source of water are being used for cardamom cultivations. The practice has lead to excessive seepage within the unconsolidated mass leading to worsening stability condition of the already fragile landscape. Deforestation both within private & forest area has lead to silt load in water bodies. Further the disturbance along the toe regions has jeopardized maintenance of the road which runs over subsidence zone. The alignment of the damaged road in the area seems to be contributing factor for initiation of destabilization of fragile landscape to lesser scale by disrupting natural water courses and concentration of surface run-off to a particular place.



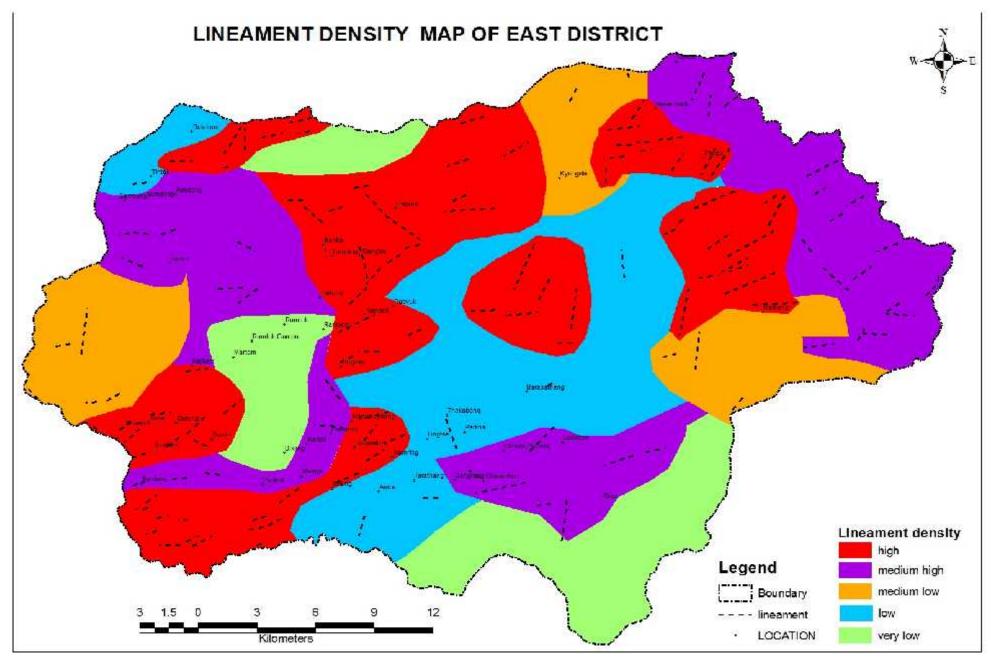


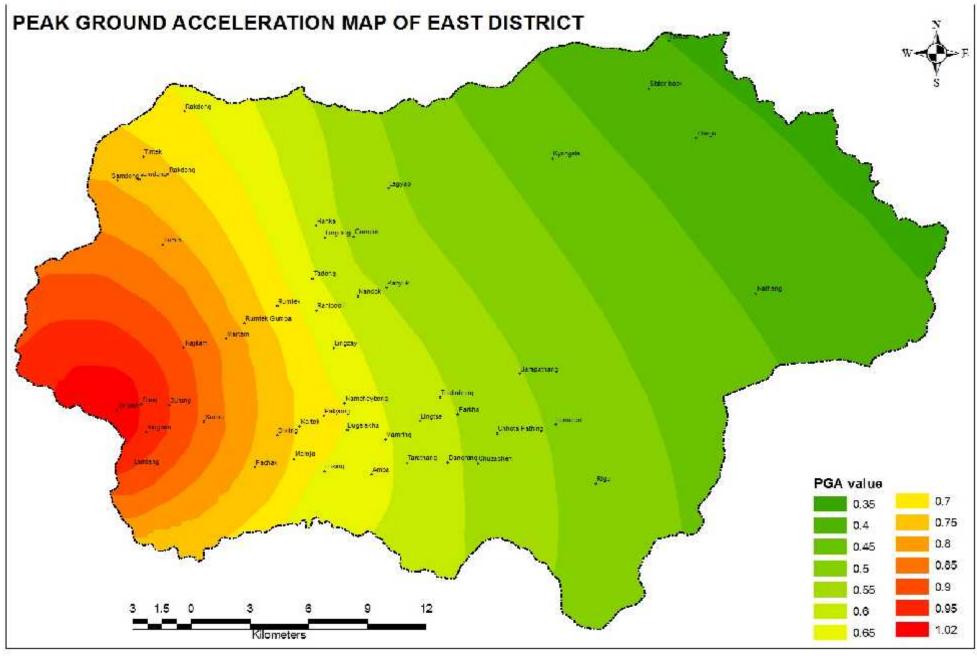
Landslide Hazards						
Hazards Category	% of Area % of Household Risk type					
Very High Hazard	2.17	1.52	Very High			
Medium High Hazards	32.97	21.95	High			
Medium Hazards	45.00	40.49	Medium			
Medium Low Hazards	18.23	33.86	Low			
Low Hazards	1.64	3.58	Low			

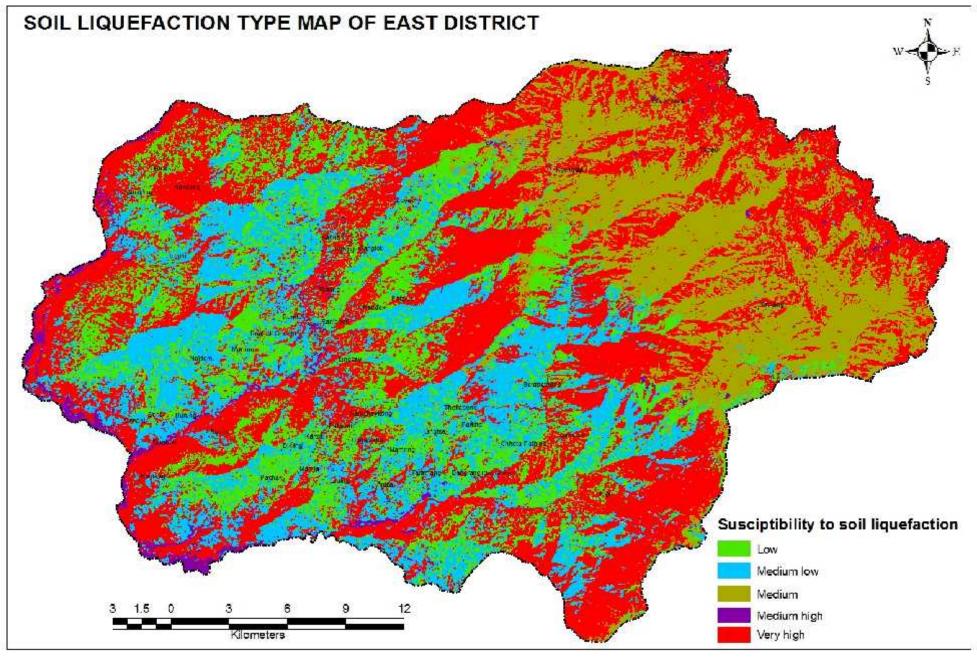


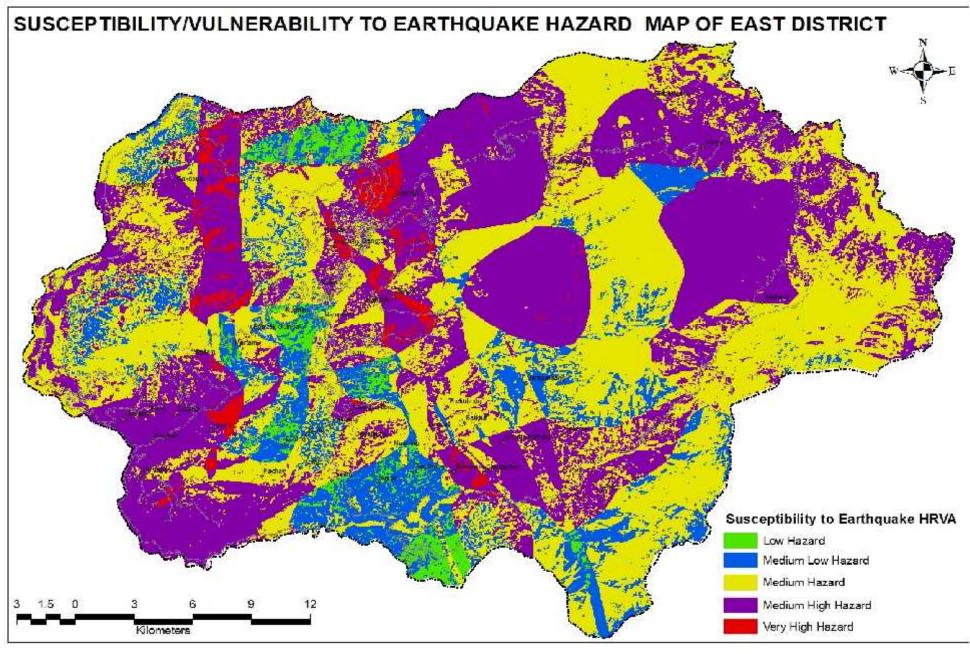
After extensive study and research of various maps and data it was possible to develop Landslide Hazard Risk and Vulnerability Map for the East District. The study leads to the following conclusions:

- 2.17% of the area fell in very high risk zone with 1.52% of the total settlement to be affected
- 32.97% of the area fell in very medium high risk zone with 21.95% of the total settlement to be affected
- 45% of the area fell in very medium risk zone with 40.49% of the total settlement to be affected
- 18.23% of the area fell in very medium low zone with 33.86% of the total settlement to be affected.
- 1.64% of the area fell in very low risk zone with 3.58% of the total settlement to be affected

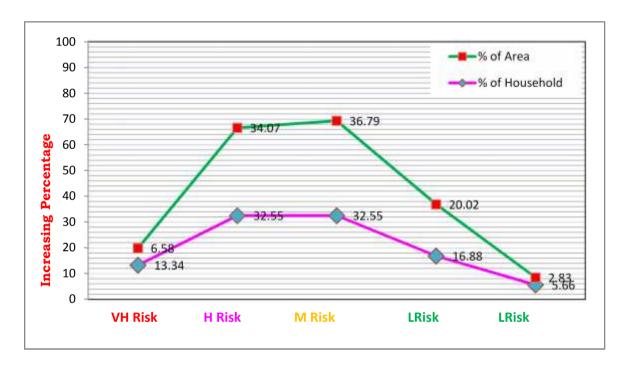






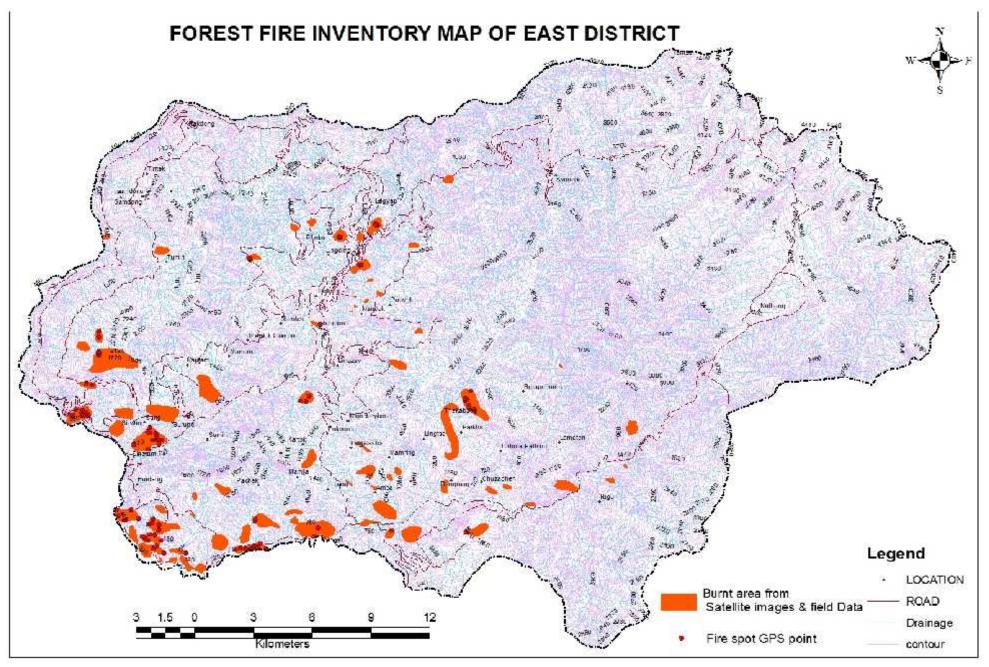


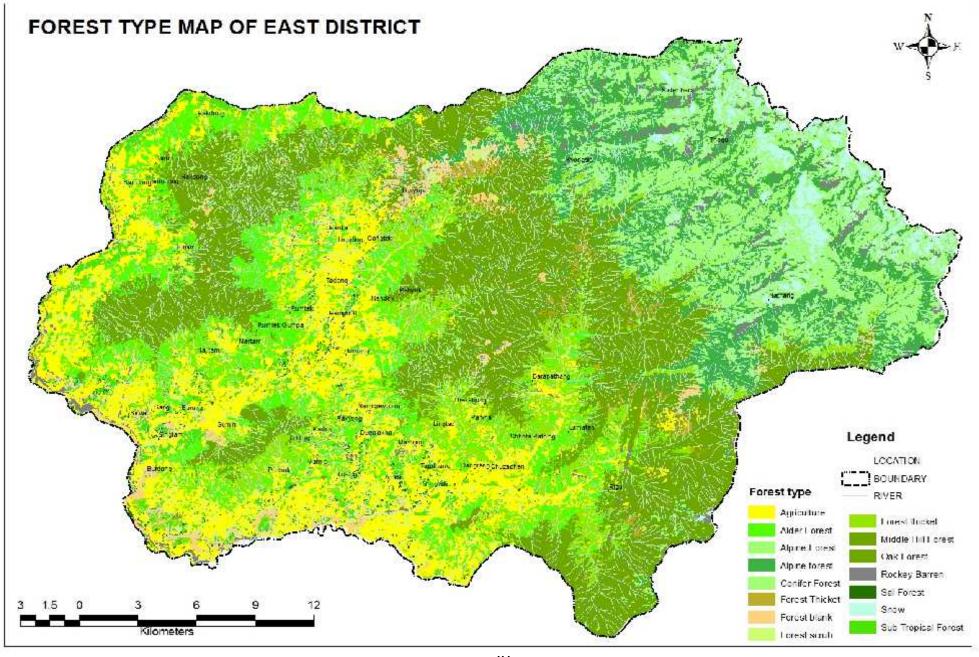
Earthquake Hazards						
Hazards Category	% of Area % of Household Risk type					
Very High Hazar	6.58	13.34	Very High			
Medium High Hazards	34.07	32.55	High			
Medium Hazards	36.79	32.55	Medium			
Medium Low Hazards	20.02	16.88	Low			
Low Hazards	2.83	5.66	Low			

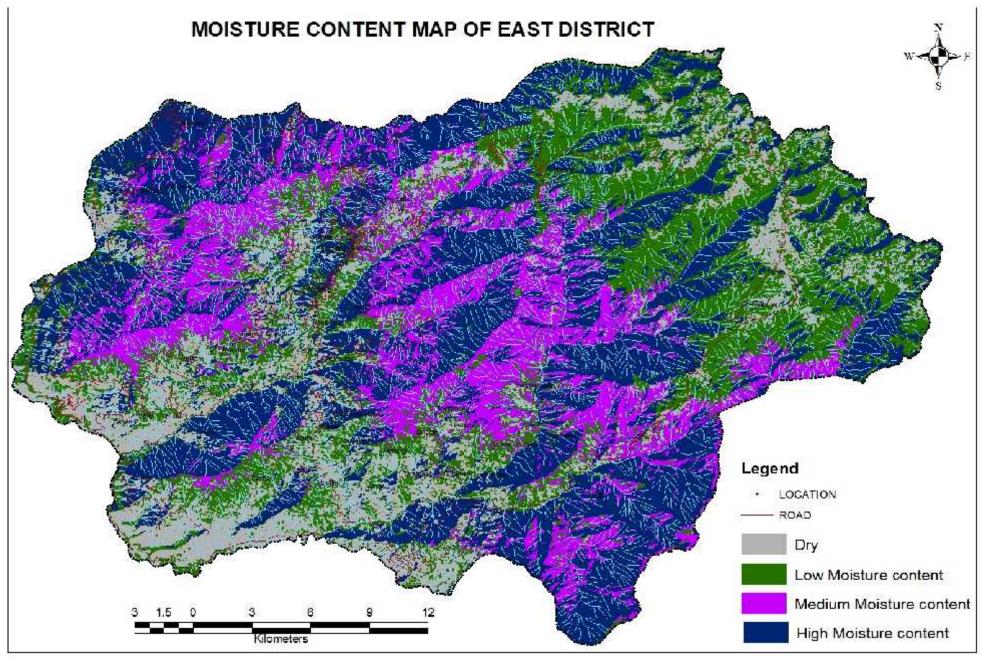


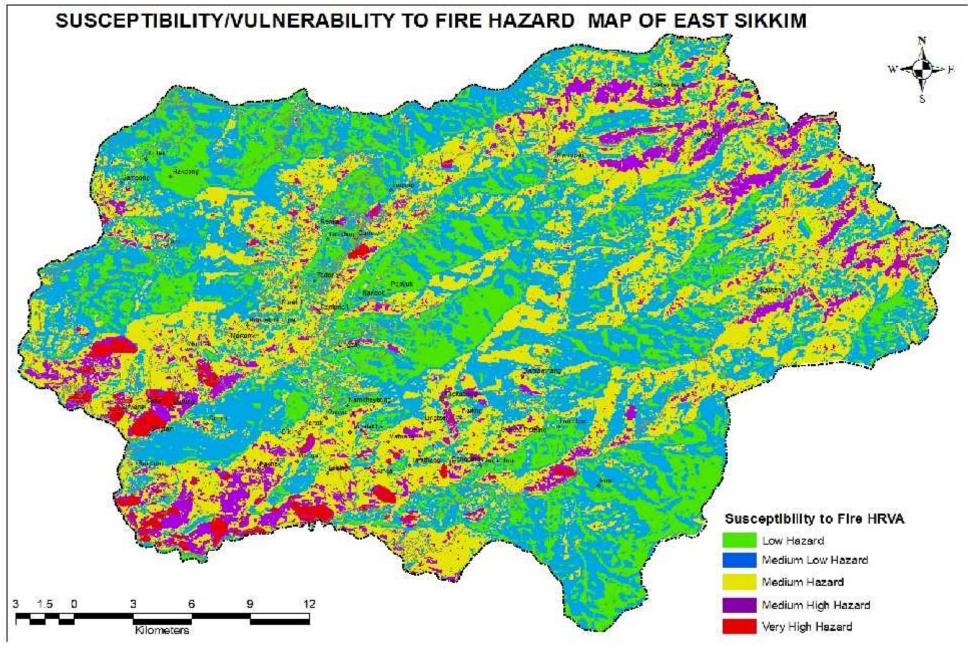
After extensive study and research of various maps and data, develop Earthquake Hazard Risk and Vulnerability Map for the Gangtok Municipal Corporation. The study leads us to the following conclusions:

- 6.58% of the area fell in very high risk zone with 13.34% of the total settlement to be affected
- 34.07% of the area fell in very medium high risk zone with 32.55% of the total settlement to be affected
- 36.79% of the area fell in very medium risk zone with 32.55% of the total settlement to be affected
- 20.02% of the area fell in very medium low zone with 16.88% of the total settlement to be affected
- 2.83% of the area fell in very low risk zone with 5.66% of the total settlement to be affected

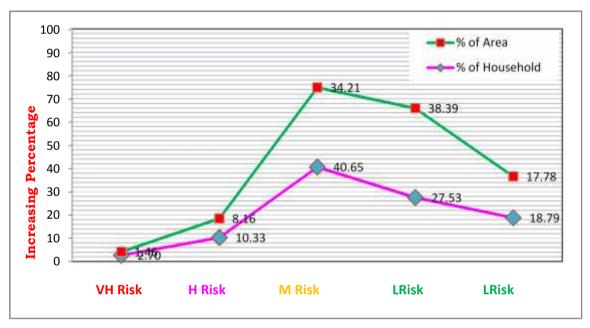






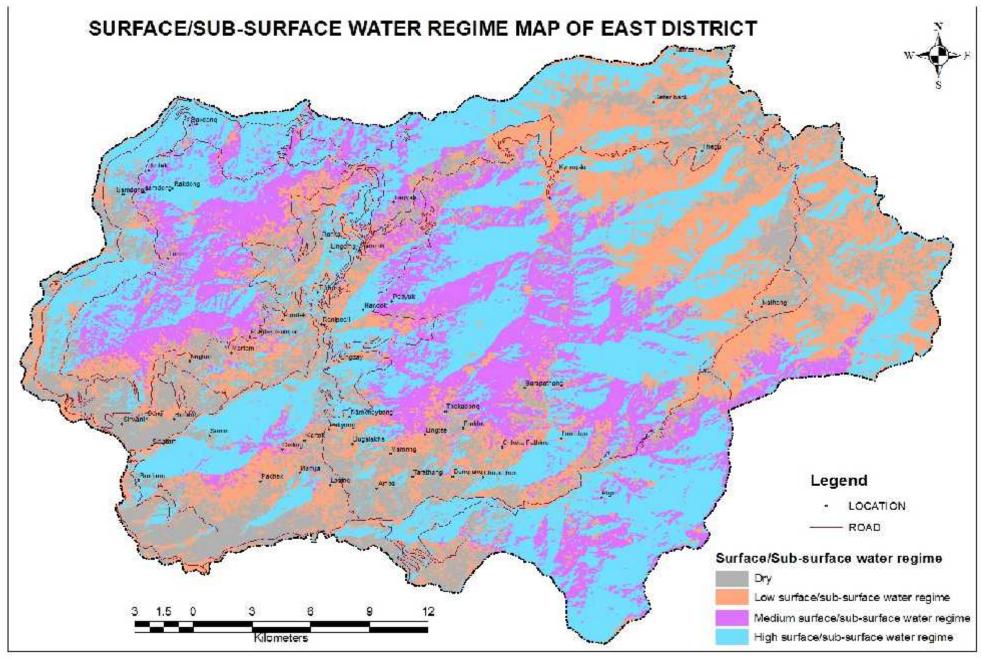


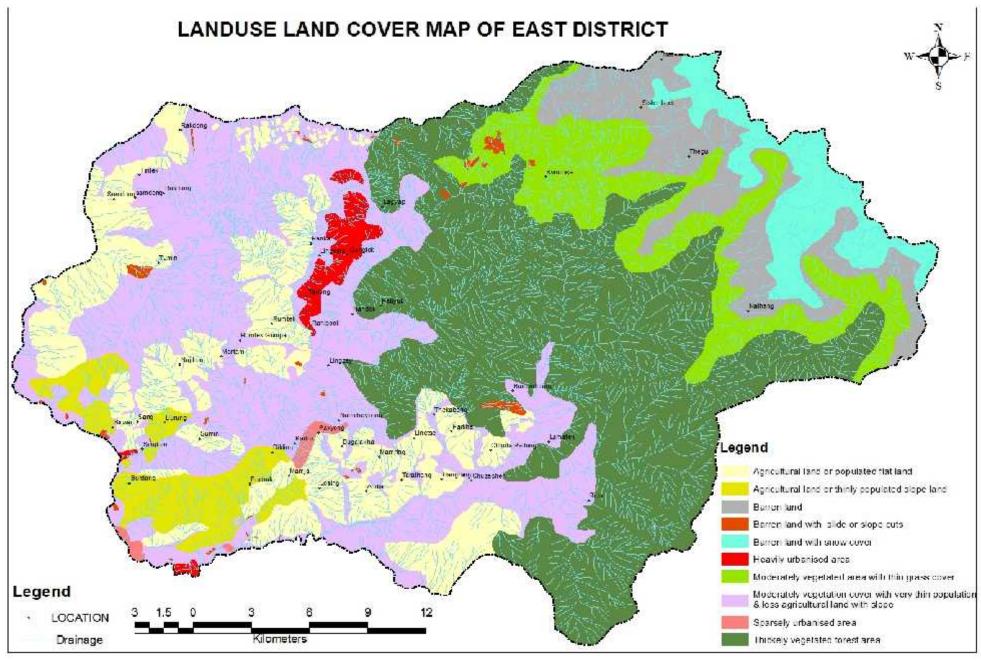
Fire Hazards						
Hazards Category	% of Area % of Household Risk type					
Very High Hazar	1.46	2.70	Very High			
Medium High Hazards	8.16	10.33	High			
Medium Hazards	34.21	40.65	Medium			
Medium Low Hazards	38.39	27.53	Low			
Low Hazards	17.78	18.79	Low			

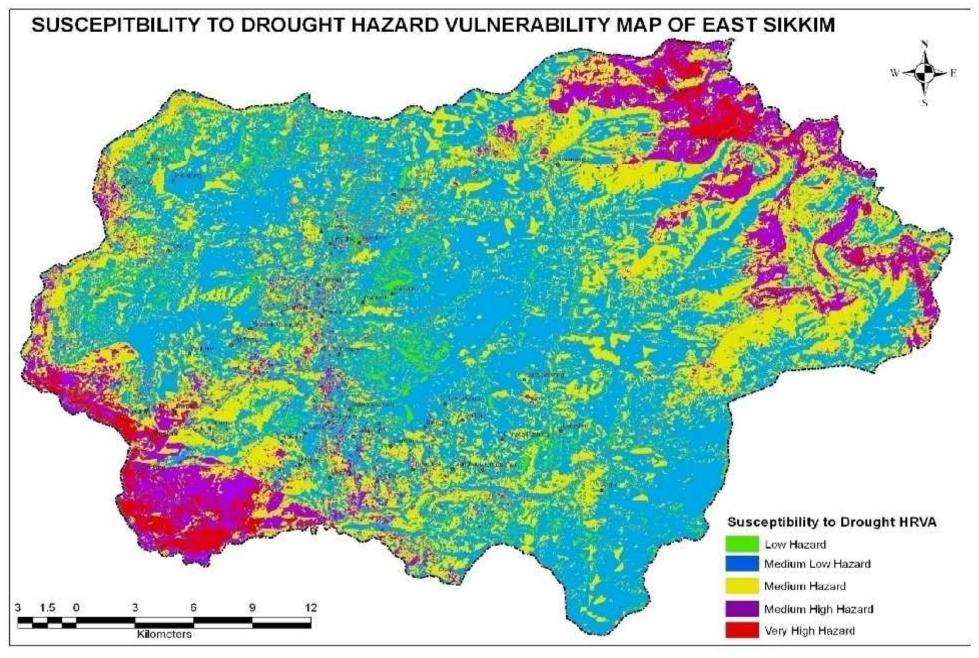


After extensive study and research of various maps and data, develop Fire Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

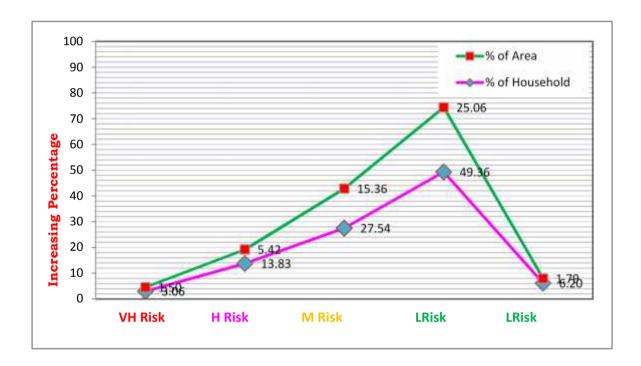
- 1.46% of the area fell in very high risk zone with 2.70% of the total settlement to be affected.
- 8.16% of the area fell in very medium high risk zone with 10.33% of the total settlement to be affected.
- 34.21% of the area fell in very medium risk zone with 40.65% of the total settlement to be affected.
- 38.39% of the area fell in very medium low zone with 27.53% of the total settlement to be affected.
- 17.78% of the area fell in very low risk zone with 18.79% of the total settlement to be affected.





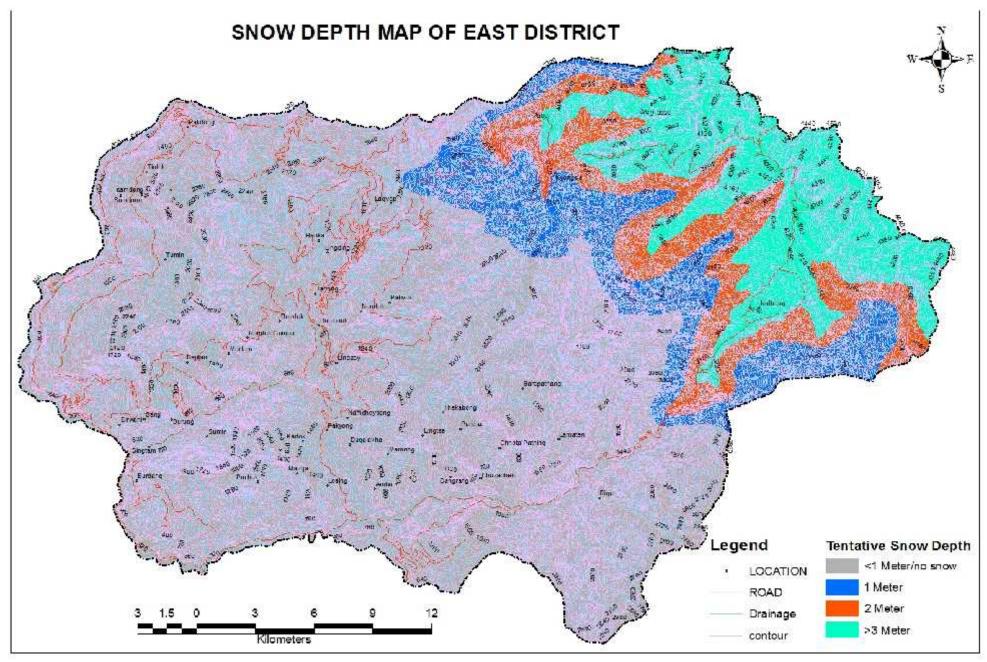


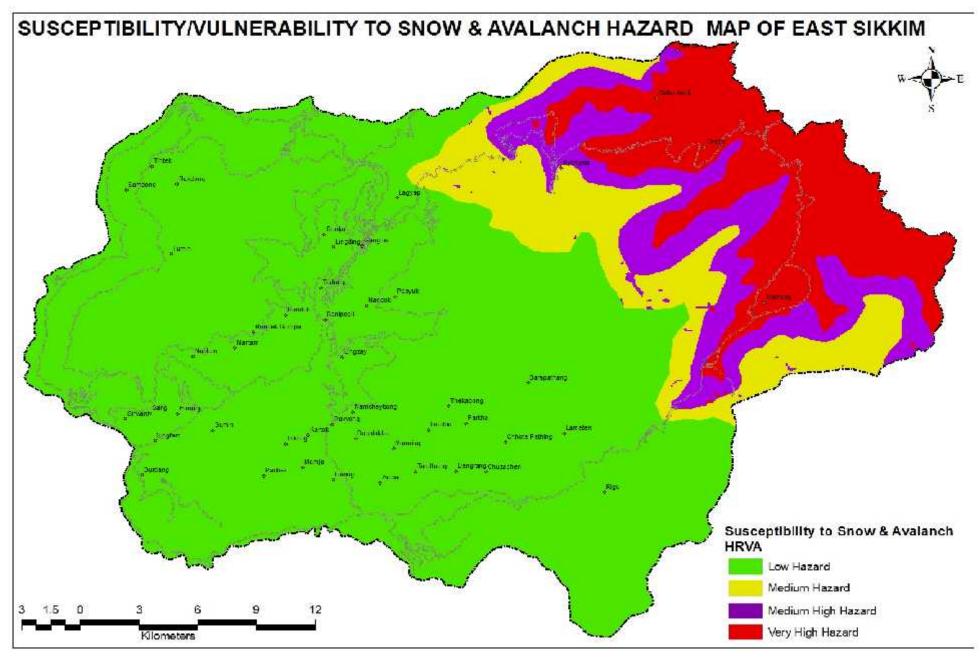
Drought Hazards							
Hazards Category	lazards						
Very High Hazar	1.50	3.06	Very High				
Medium High Hazards	5.42	13.83	High				
Medium Hazards	15.36	27.54	Medium				
Medium Low Hazards	25.06	49.36	Low				
Low Hazards	1.79	6.20	Low				



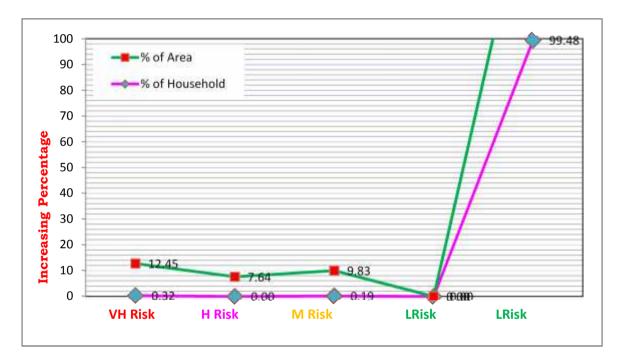
After extensive study and research of various maps and data, develop Drought Hazard Risk and Vulnerability Map for the GMC. The study leads us to the following conclusions:

- 1.50% of the area fell in very high risk zone with 3.06% of the total settlement to be affected.
- 5.42% of the area fell in high risk zone with 13.83% of the total settlement to be affected.
- 15.36% of the area fell in medium risk zone with 27.54% of the total settlement to be affected.
- 25.06% of the area fell in very low risk zone with 49.36% of the total settlement to be affected.
- 1.79% of the area fell in very low risk zone with 6.20% of the total settlement to be affected.



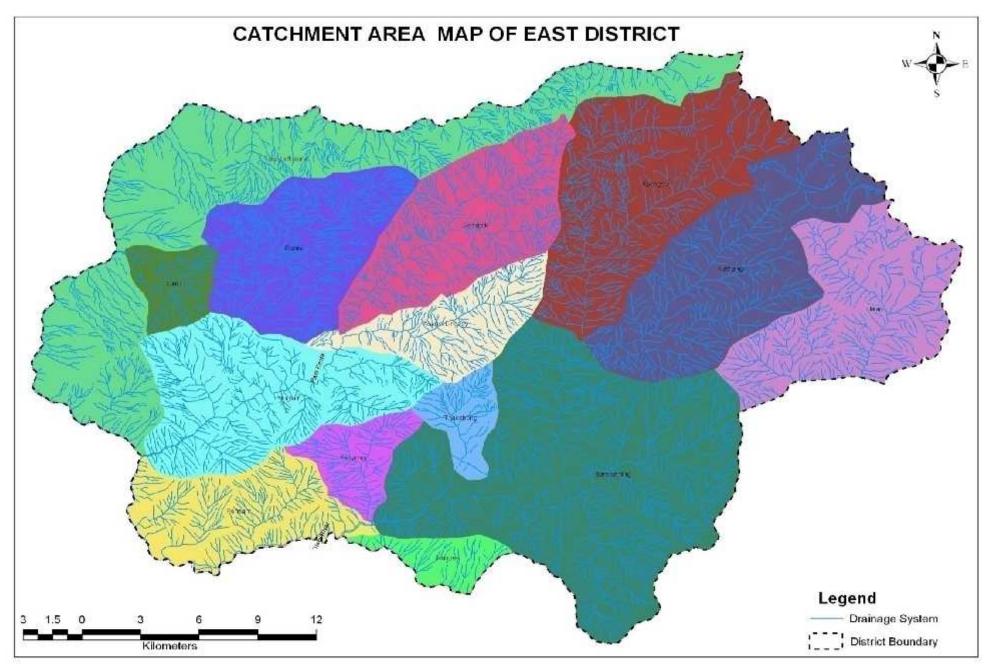


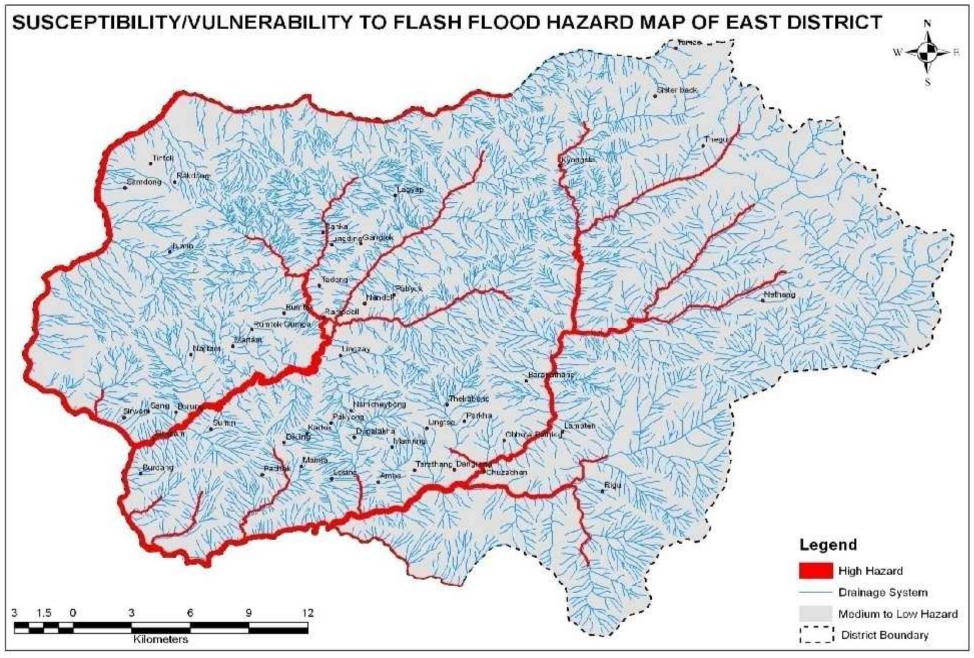
Snow & Avalanch Hazards						
Hazards Category % of Area % of Household Risk type						
Very High Hazar	12.45	0.32	Very High			
Medium High Hazards	7.64	0.00	High			
Medium Hazards	9.83	0.19	Medium			
Medium Low Hazards	0.00	0.00	Low			
Low Hazards	68.41	99.48	Low			



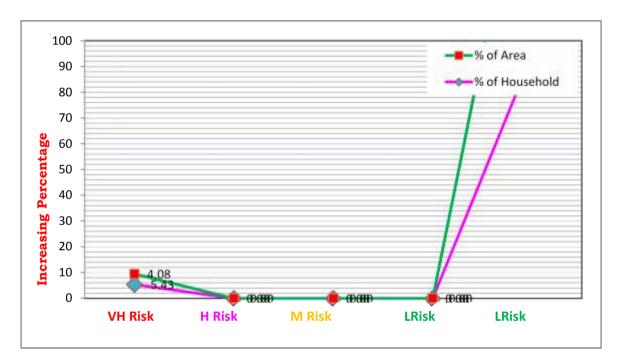
After extensive study and research of various maps and data, develop Snow and Avalanch Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

- 12.45% of the area fell in very high risk zone with .32% of the total settlement to be affected.
- 7.64% of the area fell in high risk zone with .00% of the total settlement to be affected.
- 9.83% of the area fell in medium risk zone with .19% of the total settlement to be affected.
- 68.41% of the area fell in very low risk zone with 99.48% of the total settlement to be affected



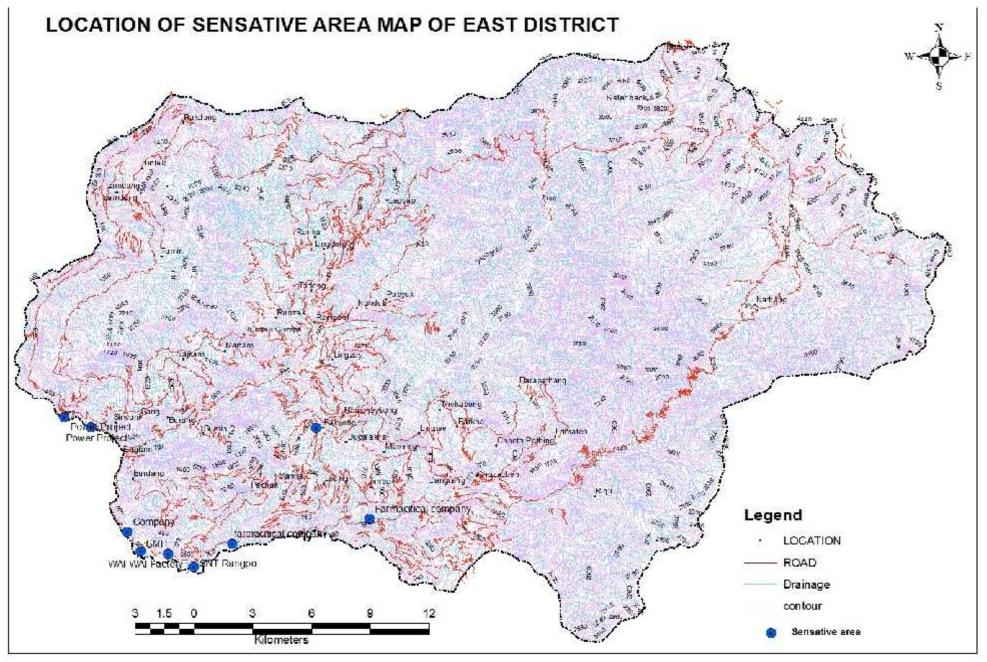


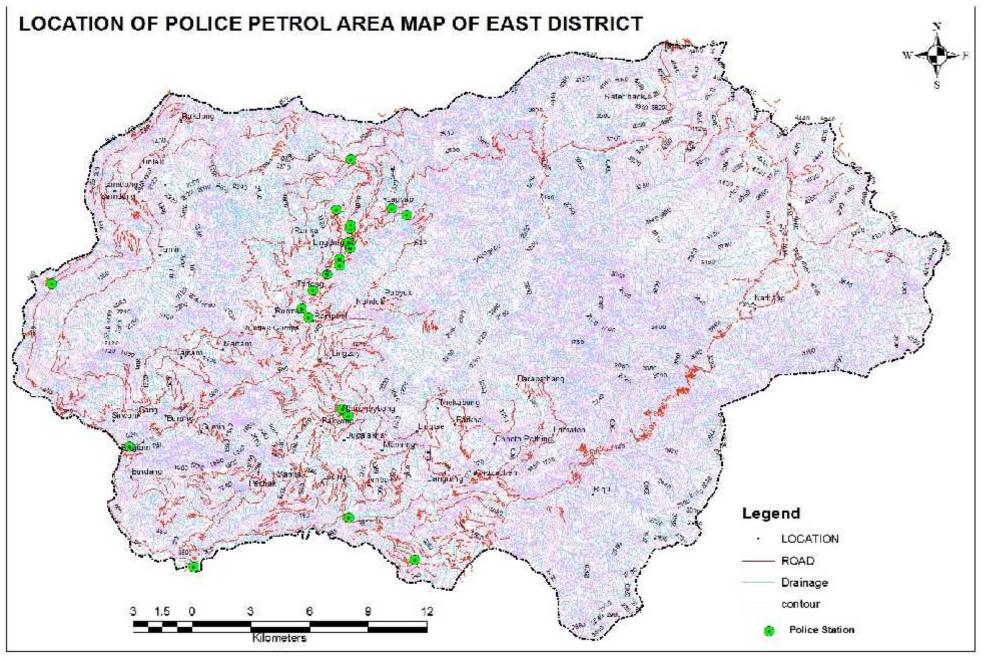
Flash flood Hazards							
Hazards Category							
Very High Hazar	4.08	5.43	Very High				
Medium High Hazards	0.00	0.00	High				
Medium Hazards	0.00	0.00	Medium				
Medium Low Hazards	0.00	0.00	Low				
Low Hazards	95.92	94.57	Low				

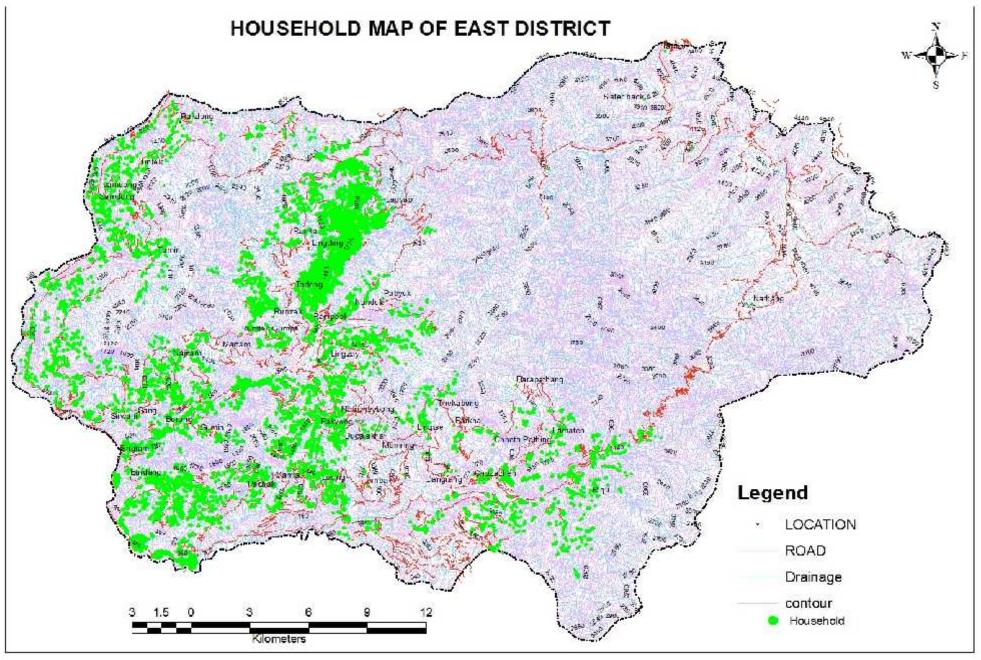


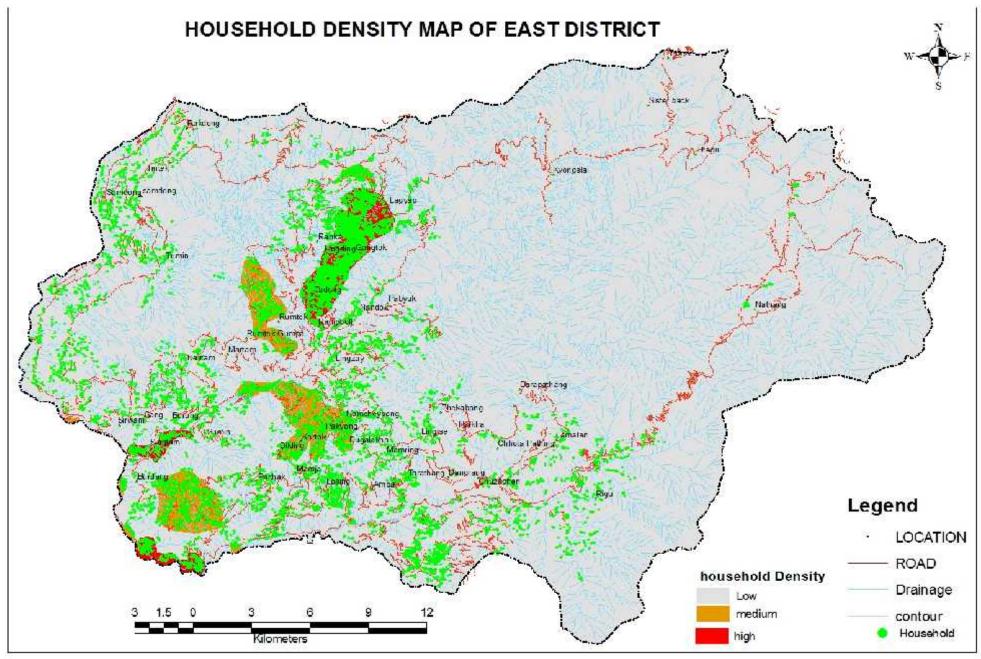
After extensive study and research of various maps and data, develop Flash flood Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

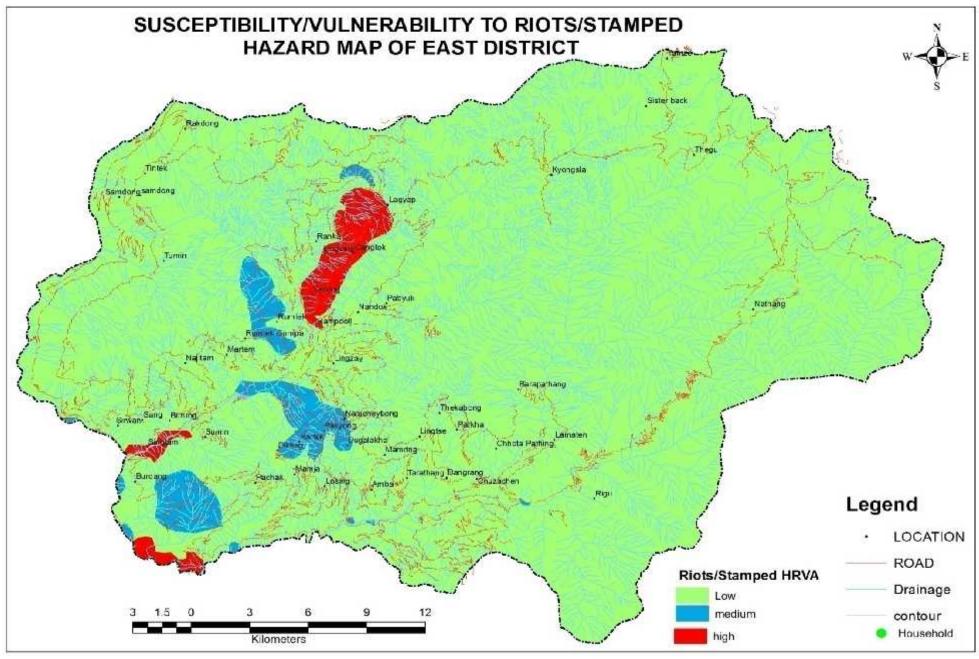
- 4.08% of the area fell in very high risk zone with 5.43% of the total settlement to be affected.
- 95.92% of the area fell in very low risk zone with 94.57% of the total settlement to be affected.



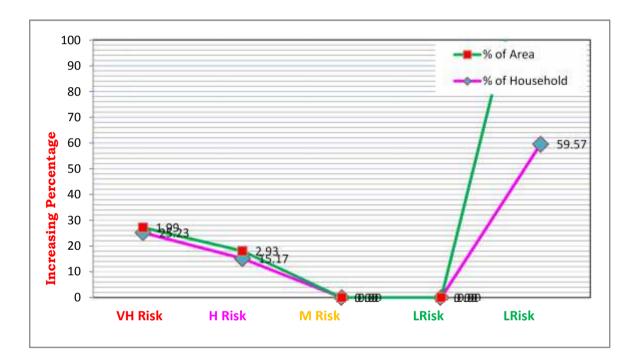








Riots/Stamped Hazards						
Hazards Category % of Area % of Household Risk type						
Very High Hazar	1.99	25.23	Very High			
Medium High Hazards	2.93	15.17	High			
Medium Hazards	0.00	0.00	Medium			
Medium Low Hazards	0.00	0.00	Low			
Low Hazards	94.87	59.57	Low			



After extensive study and research of various maps and data, develop Riot Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

- 1.99% of the area fell in very high risk zone with 25.23% of the total settlement to be affected.
- 2.93% of the area fell in high risk zone with 15.17% of the total settlement to be affected.
- 94.87% of the area fell in very low risk zone with 59.57% of the total settlement to be affected.

Multi-hazards:

Taking into account the different Hazards that may affect the region of Sikkim, developed a multi hazard map and a Risk Matrix Chart to assess the impact of each hazard in the respective EAST DISTRICT.

	Risk Matrix Chart							
5	Po	EVERY YEAR		RIOTS			LANDSLIDE	od
4	lihoc	2-10 YRS				FIRE		Likelihood
3	/Likelihood	11-20 YRS					EARTHQUAKE	Like
2		21-30 YRS		DROUGHT		FLASH FLOOD		ıcy/
1	Frequency	31-50 YRS	HAILSTROMS, SNOW & AVALANCHES					Frequency/
Score Of likely- hood	G.	Score of Impact	1 TO 7	8 TO 14	15 TO 21	22-28	29-35	F
	Severity/ magnitude of damage							

RELATIVELY INCREASING RISK

LOW	MEDIUM LOW	MEDIUM	нісн	VERY HIGH

Methodology

In this analysis extensive background check was done with extensive historical research, as well as observational data. Different kinds of maps were created so as to assess the risk and vulnerability of the region. This information was then considered in the context of the seven impact criteria, which are outlined in Table 1 below. The impact criteria were individually ranked on an ascending scale from one to five, one being the least severe and five being the most severe. The sum of these scores was taken to create an overall consequence score, the score was then contrasted against a likelihood rating of one to six, one being the least likely and six being most likely. Details regarding the measure of likelihood are seen in Table 2. The aggregate score of each hazard, combined with the hazard impact consequence and likelihood provide the basis for a risk ranking of *low*, *medium low*,

medium, medium high and very high.

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Table 1 – Seven Categories of Impact				
Categories of Impact	Score			
Fatality	1 TO 5			
Injury	1 TO 5			
Critical Facilities (Hospitals, Fire/Police Services etc.)	1 TO 5			
Lifelines (Water, Gas, Power, etc.)	1 TO 5			
Property Damage	1 TO 5			

Environmental Impact	1 TO 5	
Economic and Social Impact	1 TO 5	

Table 2 - Measure of Likelihood		
Measure of Likelihood	Return Period (yrs)	Score
Frequent or Very Likely Every	EVERY YEAR	5
Moderate or Likely Every	2-10 YRS	4
Occasional, Slight Chance Every	11-20 YRS	3
Unlikely, Improbable Every	21-30 YRS	2
Highly Unlikely, Rare Event Every	31-50 YRS	1

RISK RATING INTERPRETATION

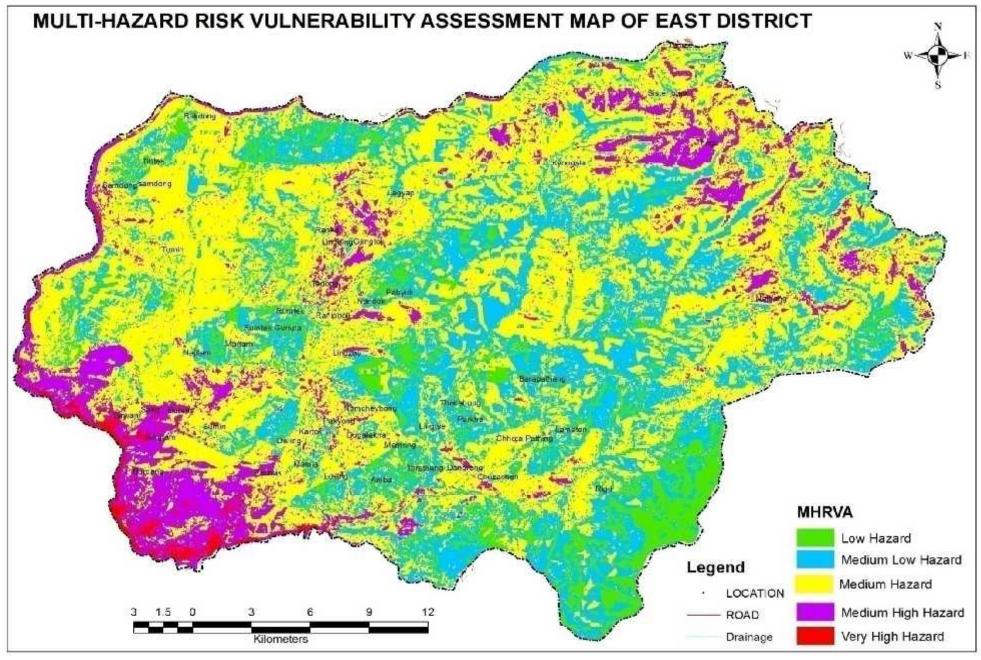
These risks are *low*. Implementation of mitigation measures will enhance emergency preparedness, but it is of less urgency and highly unlikely to occur in that area than the following hazards.

These risks are **medium low**. Implementation of mitigation measures will enhance emergency preparedness, Hazards is highly unlikely to occur in that area, but is of more urgency than low

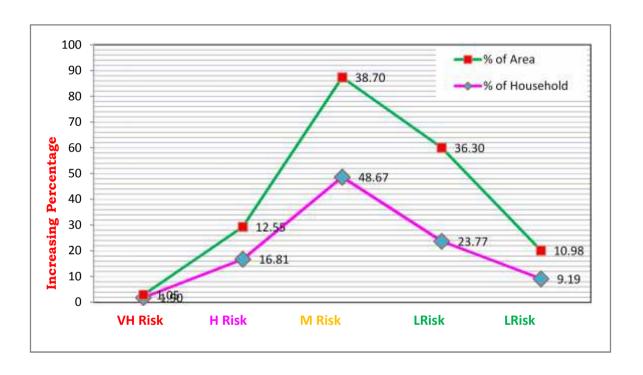
These risks are **medium**. These hazards have intermediate levels of frequency and severity. Hazards classified as moderate are more urgent than medium low hazards and are often common place concerns. Given this, moderate level hazards should be addressed with an appropriate level of urgency.

These risks are **medium high**. These hazards warrant review and development of mitigation actions to reduce the risk to an acceptable level. But these hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

These risks are **very high**. These hazards are both frequent and are of high severity. These hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

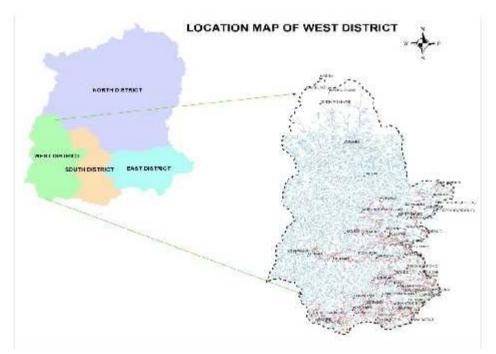


Multi-Hazard Hazards						
Hazards Category	% of Area % of Household Risk type					
Very High Hazar	1.05	1.90	Very High			
Medium High Hazards	12.55	16.81	High			
Medium Hazards	38.70	48.67	Medium			
Medium Low Hazards	36.30	23.77	Low			
Low Hazards	10.98	9.19	Low			



WEST SIKKIM

West Sikkim is a district of the Sikkim State, having two sub divisions Soreng and Gyalshing, with an area of about 1,166 km. square and population of 1, 23,174 and latitude ranging from 27° 06′ 35″ N – 27° 36′ 58″ N and longitude ranging from 88° 12′ 47″ E – 88° 21′ 36″ E, with its capital Geyzing, also known as Gyalshing. Gyalshing Sub division (Latitude: 27° 17′ 30″ N and Longitude: 88° 15′ 37″ E) is the west District Headquarter of Sikkim accessible by all weather roads from Gangtok via Ravangla and Jorethang. The most important commercial centre in the Sub-division today is Pelling (2000mts. amsl). The main resources of the area are recreational resources, cash crops such as cardamom, orange, ginger etc. and hydel power. Unlike Gangtok and Namchi, Gyalshing Bazaar (1543mts. amsl) has not grown dramatically over the past two decades mainly due to socio-economic, political and land capability constraints.



The district is almost entirely within the Lesser Himalayas, consisting mainly Daling group of rocks which have undergone several episodes of loading, unloading and uplift during mountain building processes (orogeny). The result is a hazardous combination of weak geology (micro-fractures, joints, fissures, separated foliation planes, faults etc) and high relief within short distances. Such a scenario challenges growth of knowledge and understanding of various causes and contributing factors of stability and instability in the area. To compound the existing natural adverse conditions that are subject to impact of intense monsoon precipitation, a crisis seem to be emerging as rising population and tourist industry in the region converge with the stressed resources. Visible consequence of such an environment is widespread instability and mass wasting in the area and vicinity. The effects of ill-conceived land-use and infrastructure building-up which are cumulative in nature adds to the misery.

GEOLOGY

Gyalshing, the study area falls within the Lesser Himalaya which is made up of essentially of the Daling Group of rocks. The litho-units have been divided into categories based on their mineralogy, and their area of distribution is as shown in the map (fig.1). The main litho-units are chlorite serecite phyllitic, phyllitic quartzite, milky white and ferruginous quartzite and Chlorite-Biotitic-Serecite schist/phyllite. Monotonous sequence of Chlorite-Serecite phyllite with and without quartzite intercalations is pervasive in the study area. A thin band of milky quartzite which occurs within this sequence has been taken as a marker horizon. Its occurrence has been traced from Toyang village to Chumbong via Middle Gyalshing, St-Mary's School, DFO quarter complex (West of Pema-Yangtse Monastery). West of this marked horizon show exposures of Chlorite-Biotite-Serecite schists and Biotite-Serecite schists with Few of Biotite-Serecite Litho-units show scattered Ouartz lens and rods. traces of garnet also. One prominent band of amphibolites or hornblende schist occurs within this Litho-unit as a sill. The rock unit is well foliated, blocky and brittle and consists mainly of oriented crystals of hornblende, giving rise to a pronounced linear schistosity. Further west of schist sequence is high grade metamorphic terrain characterized by Gneisses and schist with a pronounced litho-tectonic boundary with the lower grade metamorphic rocks. This litho-tectonic contact which is suspected as the MCT appears to vary in thickness from few centimeters to over several kilometers and found as a prominent lineament. After having undergone several episodes of orogenesis the rocks are intensely deformed. Deformation is expressed as micro fractures, fissures, joints, foliation surfaces, faults (shear) and several generations of folds. These planar or near planar discontinuities are the major source of instability in the area. Fifty percent of the study areas show rock exposures in the form of sheer cliffs, where foliation planes- intersect slopes, and gentle rocky slopes where foliation planes dip down the slopes.

The remaining fifty percent is occupied by Quaternary deposits such as eluvial, colluvial, alluvial soils and debris. Mature soils with distinct horizons and high clay content are confined within reserve forests, ancient Landscape such as Pelling, Pemayangtse, Rabdentse, Chumbong, Baluthang, Sakyong, Tikjuk, parts of Langang, Lingchom etc. These soils are sensitive to moisture, manipulation and seasonal weather changes.

Back and foot slopes are characterized by colluvial soil. Their maturity depended on slope stability. Human settlement and activity are confined within these areas. The toe slopes and river terraces are mostly made up of alluvial soils and debris fan (as failed slope, material and /or jhora borne material). Parts of Lower Middle Gyalshing, Toyang, Parbok Kyongsa, Legship etc. are occupied by debris fans. River terraces where alluvial soils occur are confined within ancient and recent course of Kalej khola and Rangit River.

LITHOLOGY

A Lithological study of the area has been made in addition to a geological map. The study is intended to indicate the degree of weathering of exposed rocks and their physical conditions and spatial distribution of soil-debris cover. The litho-units as described earlier are fined grained, repetitive in sequence and

foliated. The phyllites and schists at shallow depth show easy facility along foliation planes. Such weak geology is one of major source of instability around Gyalshing Bazaar, Kyongsa, Middle Gyalshing, Toyang etc. Quartzites though brittle in nature are the most competent rocks in the area. Their occurrences are, however, limited to few locations.

SLOPE ANALYSIS

In mountain areas, regional as well as local character of slopes play an important role in mass wasting processes and Land stability conditions. Slope analysis or slope morphometric maps are extremely important in mountain areas for urban development and scientific management of Land, for water supply, drainage schemes, alignment of roads, soil erosion, agriculture, Slopes are formed as a result of orogenesis and ageing process of the earth. Their rate of evolution or development differs from region to region and from one geo-environment to another. In highly dynamic geo-environment coupled with intense monsoon climate such as Sikkim slope evolution is quick. Slope stability in any given segment or facet depends upon relief, the type of slope forming material, bedrock geology, water regime and so on. Slope failure can be triggered by one or combination of many contributing factors. The rock and soil slopes around Gyalshing are subject to fail naturally as well as when natural constants are disturbed. Their rate of failure may depend on slope aspect, drainage patterns, Land-use etc. Slope characteristics are divided into facets and slope directions and degree of their inclination are indicated by arrows and numbers respectively. Slopes from Gyalshing Bazaar to Midway to Tashigang Resort constitute one slope facet. This particular slope facet area is under stress and part of it is likely to fail with disastrous effects. Similarly, part of slope facet between Gyalshing Bazaar and Tikjuk, which failed two years ago killing many people may fail again. The south easterly aspect slopes are rock controlled slope and likely to along foliation planes. The slopes facing east between Gyalshing Bazaar and Legship has several slope segments that are under failed and failing conditions. 9th Mile area of this slope has been and is notorious for frequent traffic disruption due to slope failure. Similarly slopes around Middle Gyalshing are subject to instabilities. within the study area have been divided into four categories, viz. less than 20°. 20°-30°, 30°-40° and greater than 40°. Steep slopes are not necessarily unstable and gentle slopes stable. A slope's stability is dependent upon bedrock geology, vegetal cover, impact of human activity etc.

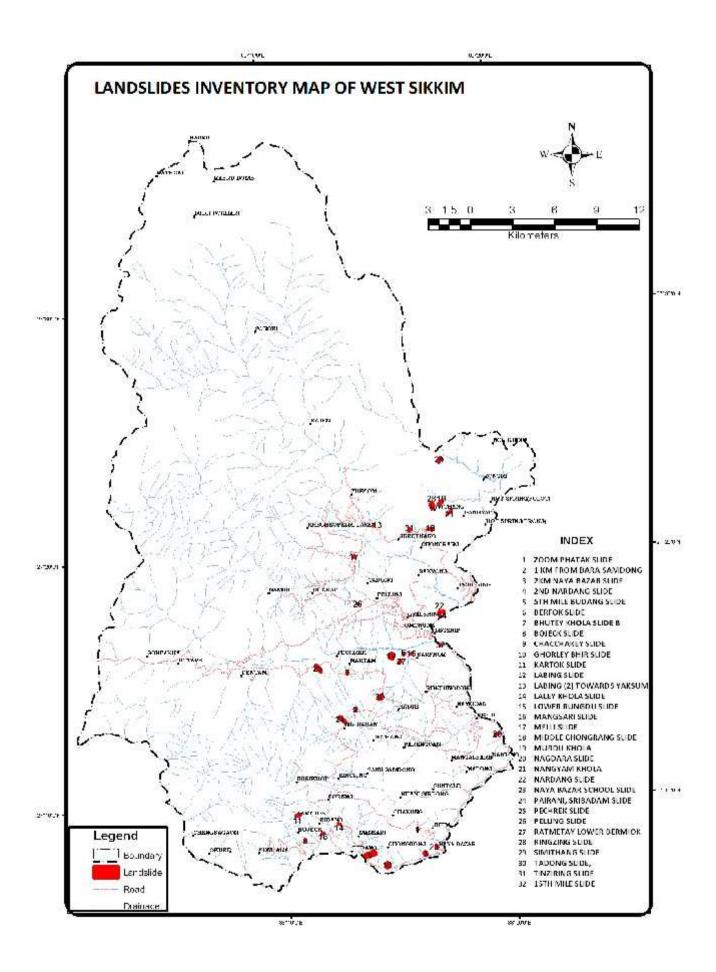
HYDROGEOLOGY AND DRAINAGE MORPHOMETRY

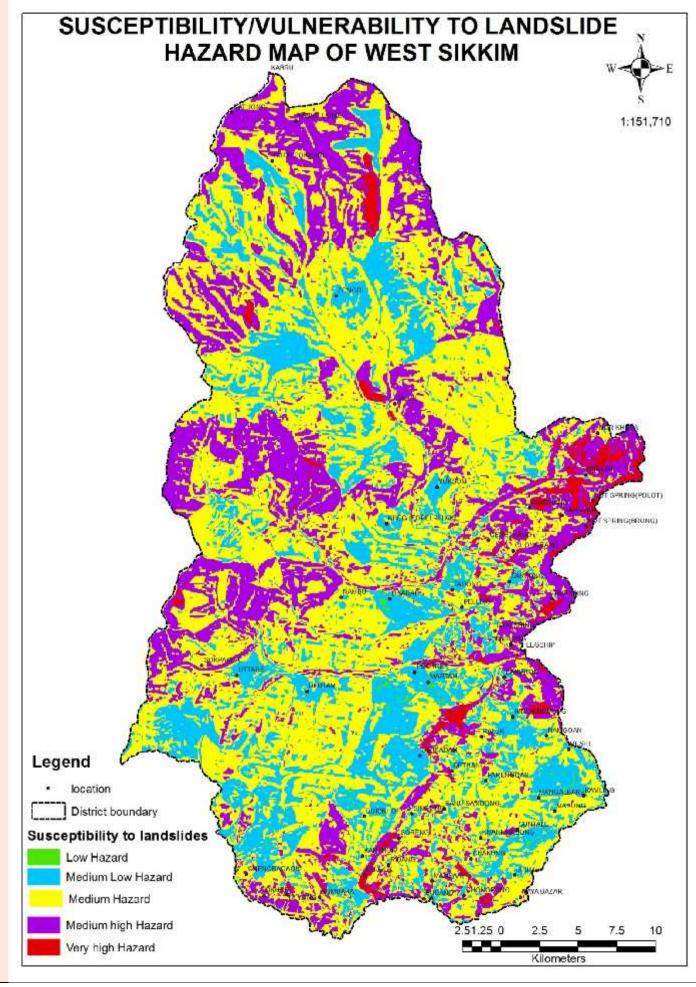
Water is one of the prime movers in causing instability of slopes. Its presence in pores and fractures of soils-rocks lessens the bonds that provide cohesion and reduces effective stress in the rock-soil system. An attempt has been made to collect and collate hydro-geological data of the study area. Seepage zones, springs, ponds, etc. are as shown in the maps. Drainage and drainage density and drainage basins are defined and mapped to the scale. Rainfall data and ground water levels are either not available or unreliable. Perennial springs at mid and Low altitude may be considered as either fault springs or stratum spring or valley springs. Overflow springs are many during and few weeks after monsoon. Drainage of water through jhoras and natural waterways is one of

the most important factors in design of infrastructure in mountain areas. Study indicates that the concerned authorities have not considered hydrology and hydraulics while designing waterways and drains. Under capacity and improper location and direction of drains is causing erosion (Middle Gyalshing, Langang, Tikjuk, Omchung School, 9th Mile slide, Toyang khola area etc). Customary road side drains are also not accordingly designed and it is below capacity and let to terminate at road zigs without considering the impact of its discharge over areas below and around. It has become imperative to redesign roadside drains and cross drains all over Gyalshing sub-division. Special attention may be given to road sections at Pelling, Pemayangtse and Rabdentse where failed red soil during monsoon can cause accident. Complete overhauling and increasing capacity may be done to roadside drains from Gyalshing Bazar to Legship town. Provisions may be made to maintain the jhoras and drains as frequently as possible. Main waterways from Gyalshing Bazar, Power complex, Rabdentse, Pemayangtse, St. Mary's School area and Yangthang Kothi to Toyang village and their tributaries requires training.

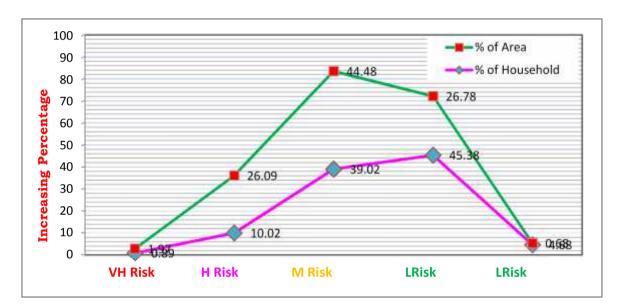
LAND-USE AND LAND-COVER

The Land-use pattern shows spatial distribution of Landforms and Land-over present in the study area. The Land-use pattern in Gyalshing Sub-division is still traditional. There are, of course, evidences of conversion of rural land to non-agricultural uses such as urban development, transportation networks and other utility services. The concept of multiple and sequential Land-use rather than permanent and exclusive use exists among the rural community and its practice is common in agriculture and horticulture. The Land-use planning on a regional scale does not exist in Sikkim. From the study it was found that, besides adverse geological conditions and soil cover, the type of land-cover and Land-use practices influences the stability condition of slopes. Thickly vegetated and forest cover areas around Pemayangtse Monastery, Rabdentse, Upper reaches of Sakyong-Baluthang, parts of Langang-Toyang etc. appear to experience less soil erosion and rock weathering. A fair amount of barren land, exposed rocky cliff with scrub exists in the study area which has been and still is the places for source of fuel and fodder. These locations and the wet cultivation belts are the prime areas where erosion activity and slope instability are more than anywhere else. Pelling, Tikjuk, Gyalshing Bazar, Koyngsa, Langang, Tikzak and Lingchom are areas where infrastructure built - up is concentrated without any plan and Land management systems. Uncontrolled and unscientific growth is evident around Pelling Gyalshing Bazaar area because of Tourism. Certain concrete buildings within the bazaar area and Pelling are at risk to itself and others. Last monsoon has destroyed most of the toe support around the location. There are a number of such cases in and around Gyalshing Sub-division needing geo-engineering and planning inputs.



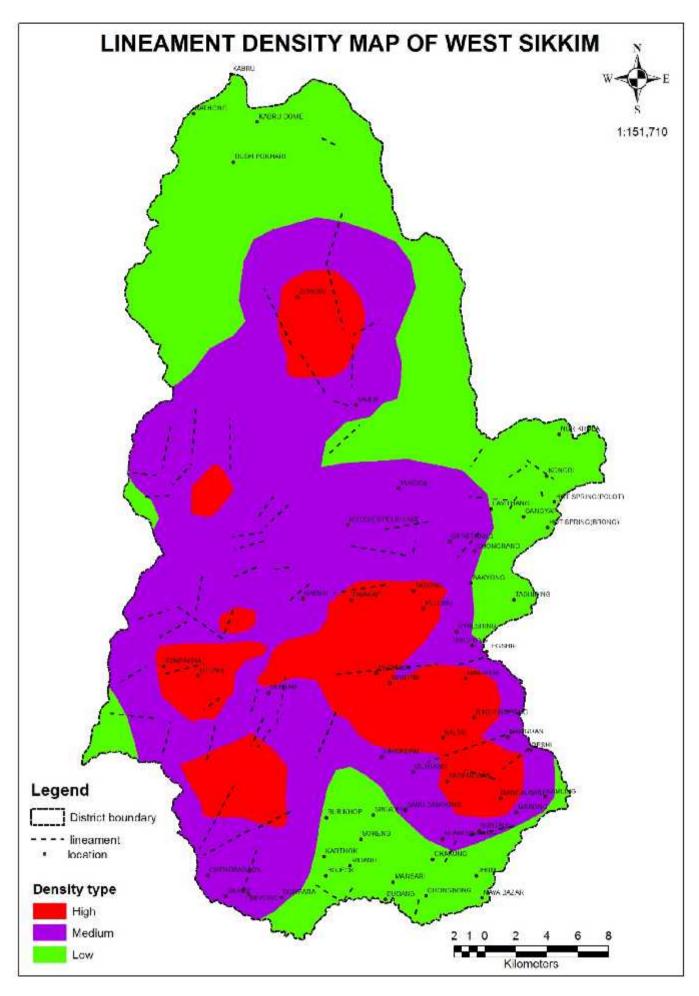


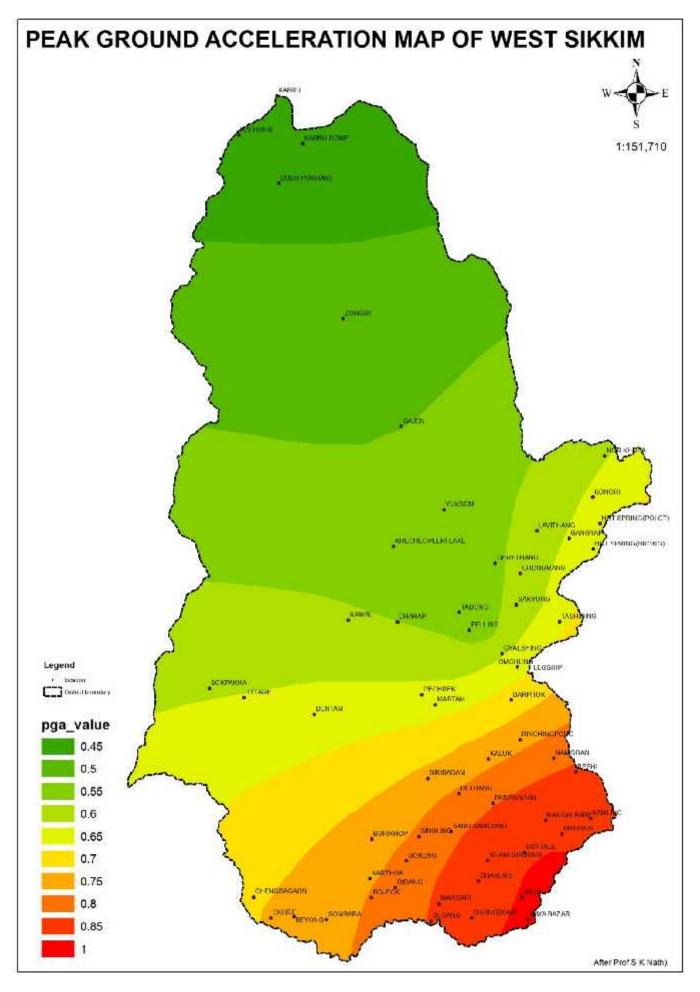
Landslide Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazards	1.97	0.89	Very High	
Medium High Hazards	26.09	10.02	High	
Medium Hazards	44.48	39.02	Medium	
Medium Low Hazards	26.78	45.38	Low	
Low Hazards	0.68	4.68	Low	

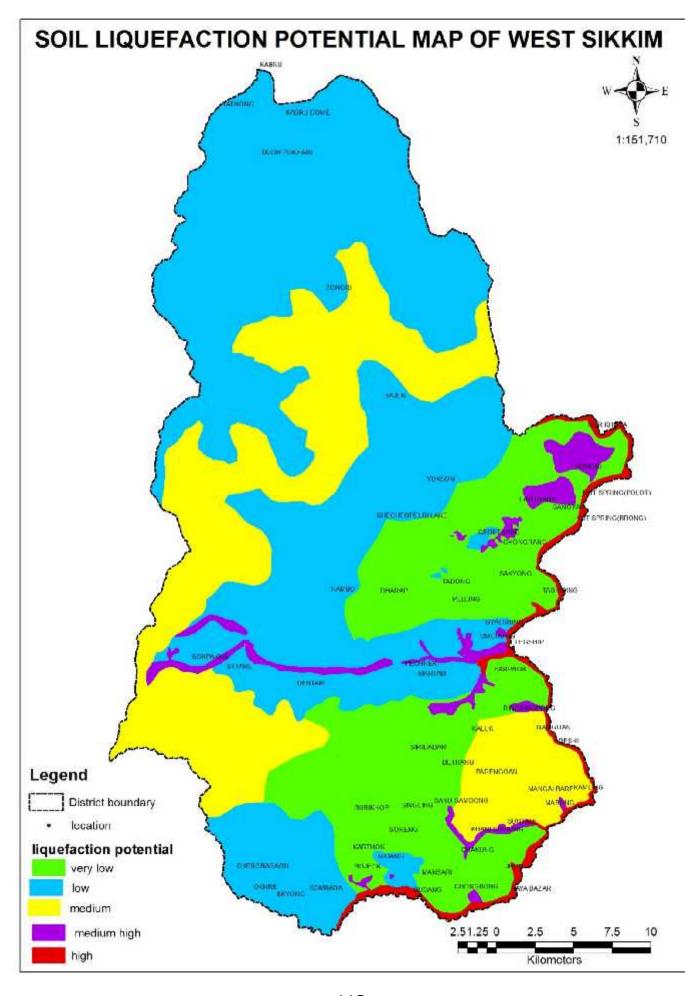


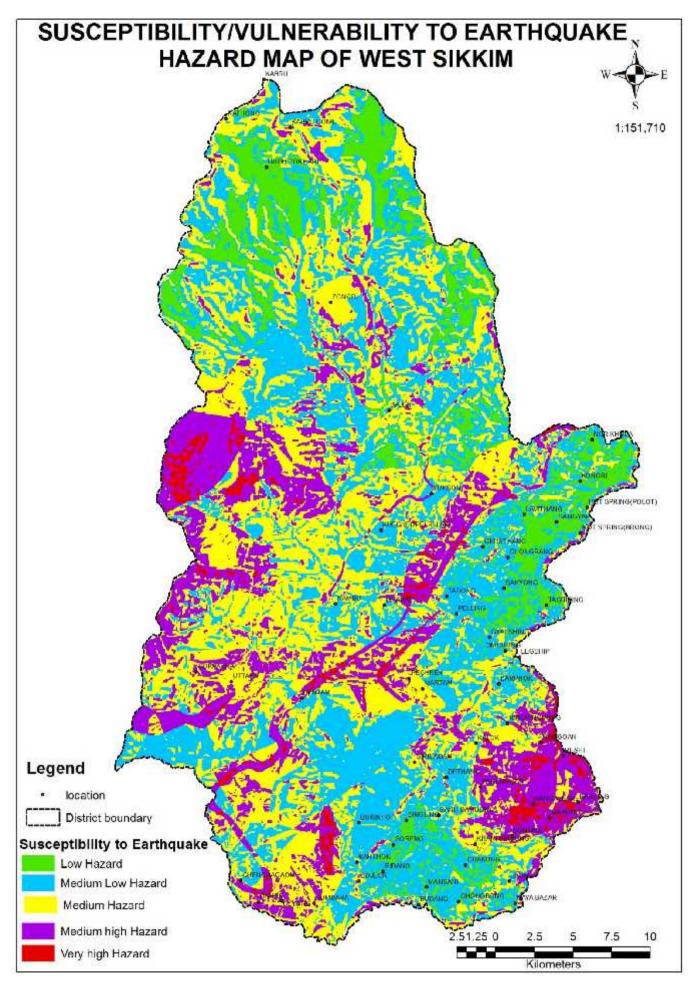
After extensive study and research of various maps and data it was possible to develop Landslide Hazard Risk and Vulnerability Map for the West District. The study leads to the following conclusions:

- 1.97% of the area fell in very high risk zone with 0.89% of the total settlement to be affected.
- 26.9% of the area fell in very medium high risk zone with 10.02% of the total settlement to be affected
- 44.8% of the area fell in very medium risk zone with 39.02% of the total settlement to be affected
- 26.78% of the area fell in very medium low zone with 45.38% of the total settlement to be affected.
- 0.68% of the area fell in very low risk zone with 4.68% of the total settlement to be affected.

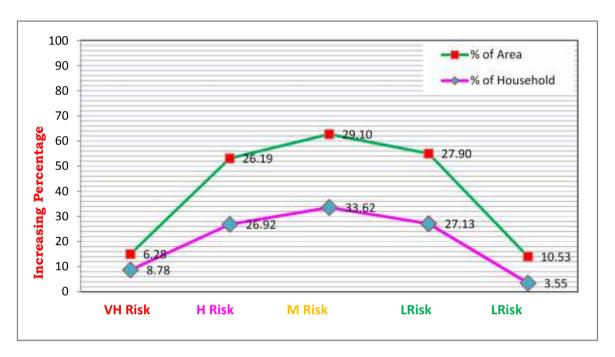






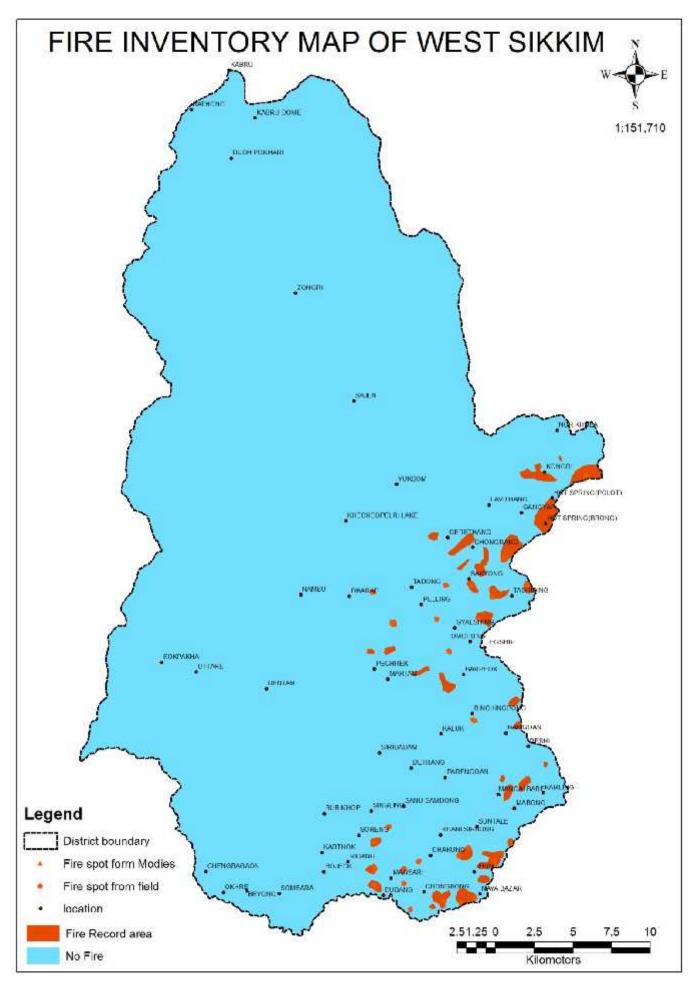


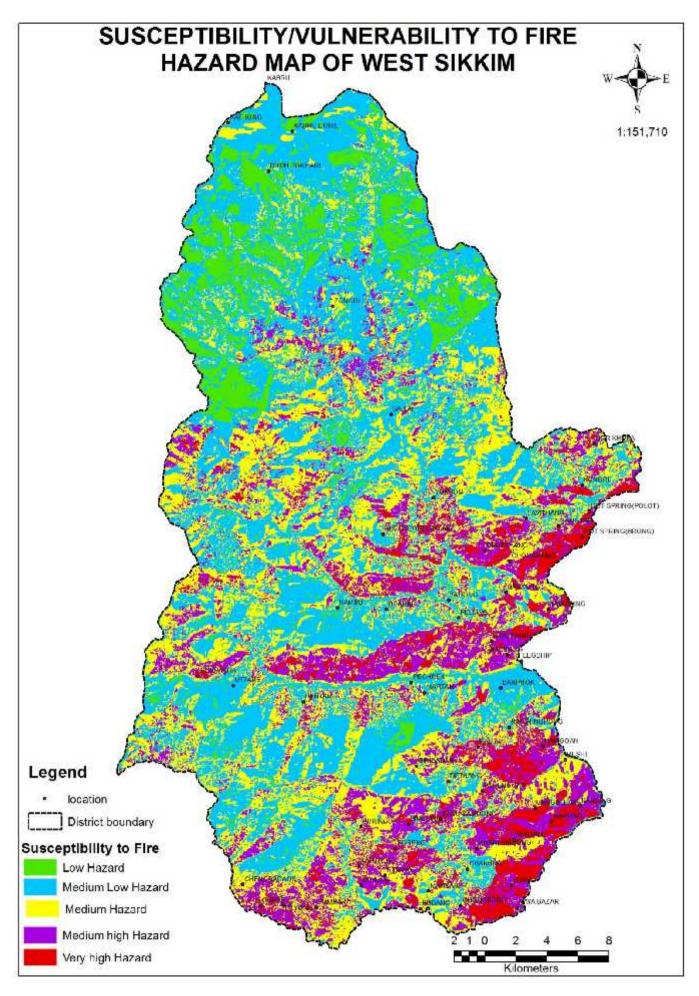
Earthquake Hazards						
Hazards Category						
Very High Hazards	6.28	8.78	Very High			
Medium High Hazards	26.19	26.92	High			
Medium Hazards	29.10	33.62	Medium			
Medium Low Hazards	27.90	27.13	Low			
Low Hazards	10.53	3.55	Low			



After extensive study and research of various maps and data, develop Earthquake Hazard Risk and Vulnerability Map for the West Sikkim. The study leads us to the following conclusions:

- 6.28% of the area fell in very high risk zone with 8.78% of the total settlement to be affected
- 26.19% of the area fell in very medium high risk zone with 26.92% of the total settlement to be affected
- 29.10% of the area fell in very medium risk zone with 33.62% of the total settlement to be affected
- 27.90% of the area fell in very medium low zone with 27.13% of the total settlement to be affected
- 10.53% of the area fell in very low risk zone with 3.55% of the total settlement to be affected



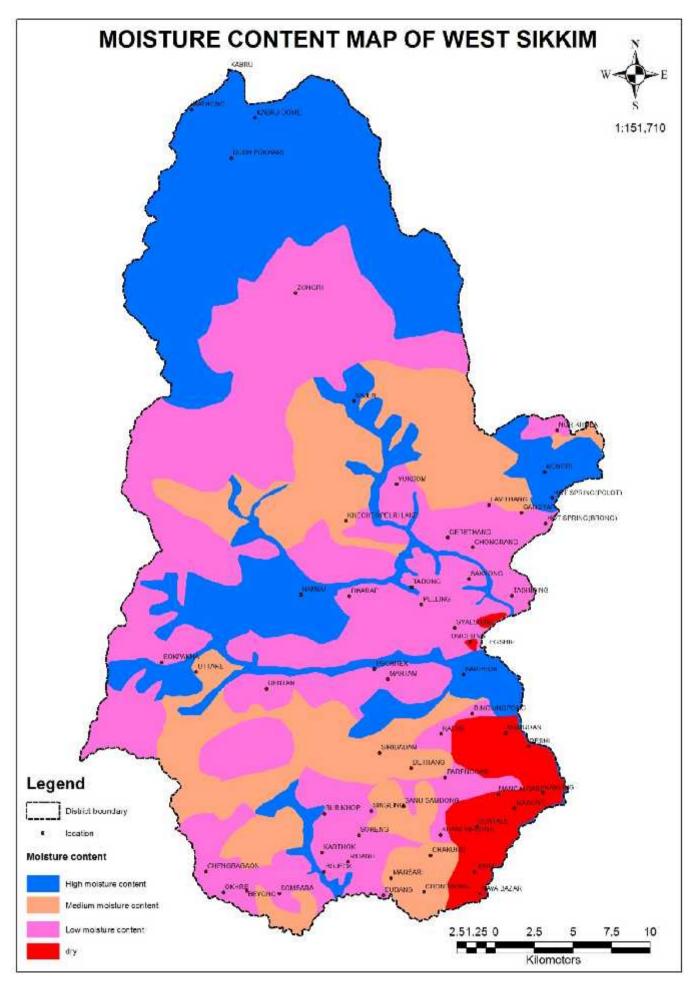


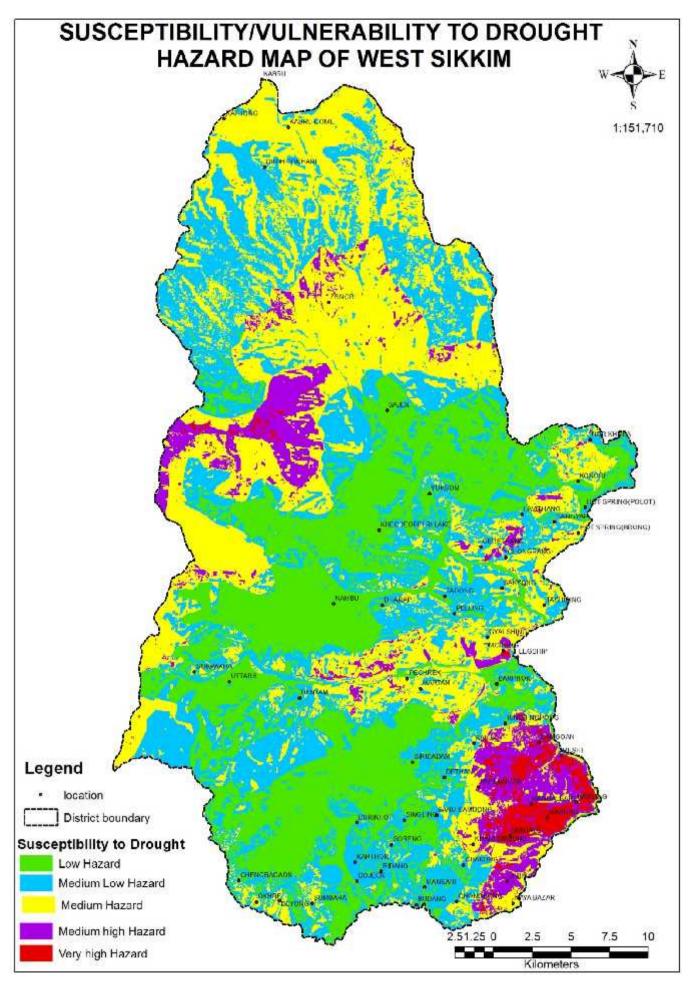
Fire Hazards				
Hazards Category	Risk type			
Very High Hazards	4.92	11.01	Very High	
Medium High Hazards	15.86	32.60	High	
Medium Hazards	30.68	37.71	Medium	
Medium Low Hazards	40.11	18.43	Low	
Low Hazards	8.43	0.24	Low	



After extensive study and research of various maps and data, develop Fire Hazard Risk and Vulnerability Map for the West District of Sikkim. The study leads us to the following conclusions:

- 4.92% of the area fell in very high risk zone with 11.01% of the total settlement to be affected
- 15.86% of the area fell in very medium high risk zone with 32.60% of the total settlement to be affected
- 30.68% of the area fell in very medium risk zone with 37.71% of the total settlement to be affected
- 40.11% of the area fell in very medium low zone with 18.43% of the total settlement to be affected
- 8.83% of the area fell in very low risk zone with .24% of the total settlement to be affected



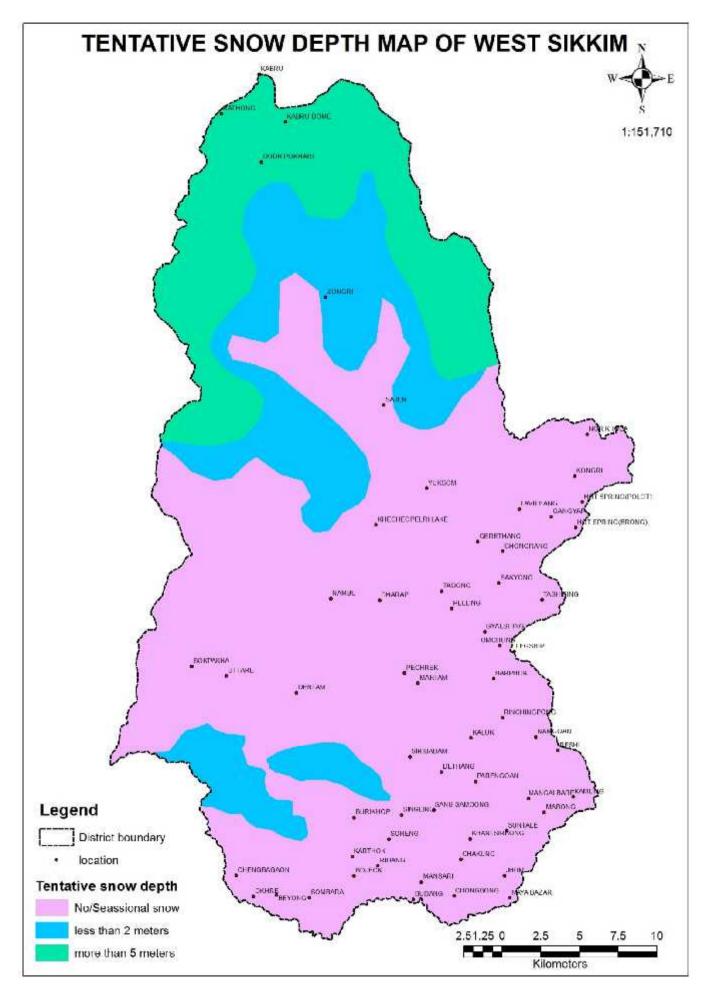


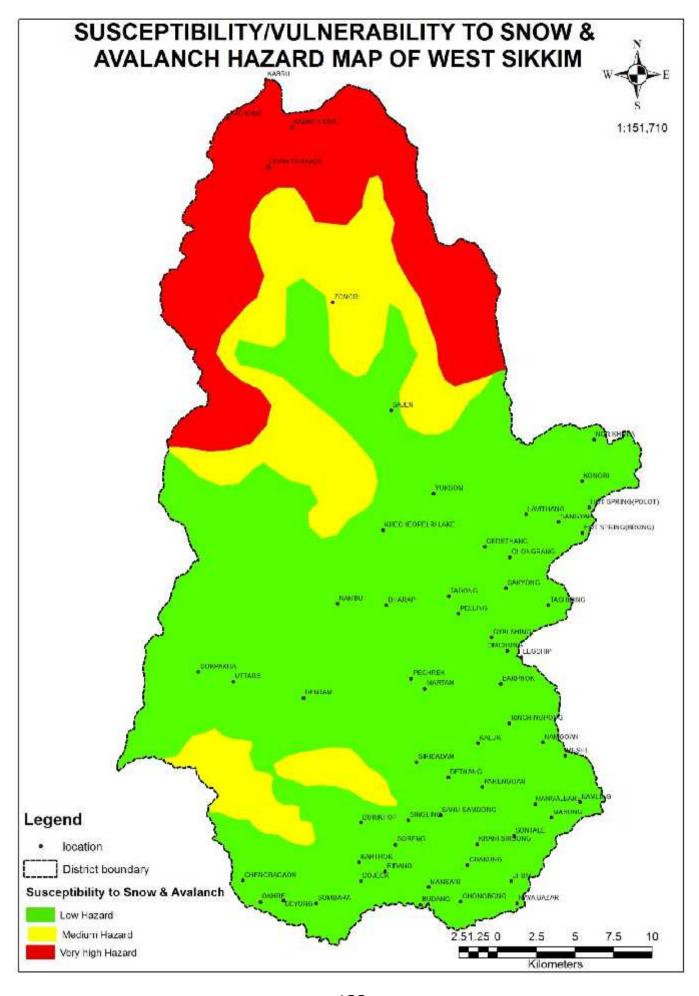
Drought Hazards					
Hazards Category	ards Category % of Area % of Household Risk type				
Very High Hazards	1.61	4.03	Very High		
Medium High Hazards	7.06	9.86	High		
Medium Hazards	32.24	27.35	Medium		
Medium Low Hazards	31.47	37.93	Low		
Low Hazards	27.61	20.83	Low		



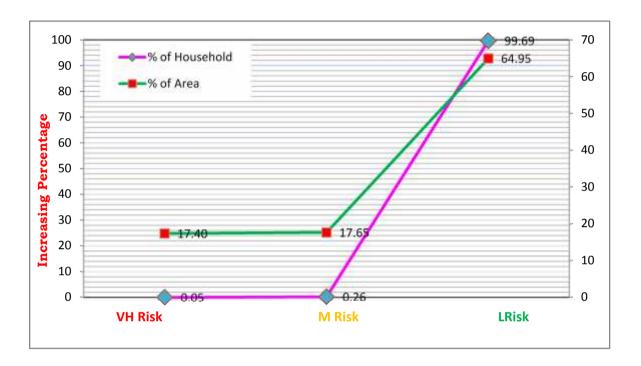
After extensive study and research of various maps and data, develop Drought Hazard Risk and Vulnerability Map for the West district of Sikkim. The study leads us to the following conclusions:

- 1.61% of the area fell in very high risk zone with 4.03% of the total settlement to be affected
- 7.06% of the area fell in high risk zone with 9.86% of the total settlement to be affected
- 32.24% of the area fell in medium risk zone with 27.35% of the total settlement to be affected
- 31.47% of the area fell in very low risk zone with 37.93% of the total settlement to be affected
- 27.61% of the area fell in very low risk zone with 20.83% of the total settlement to be affected



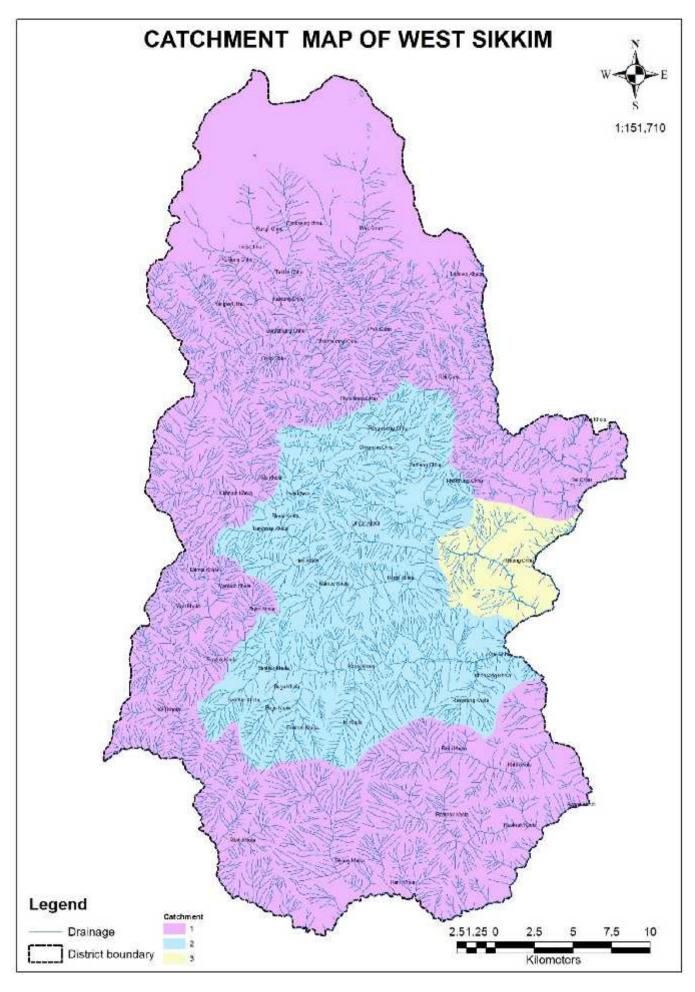


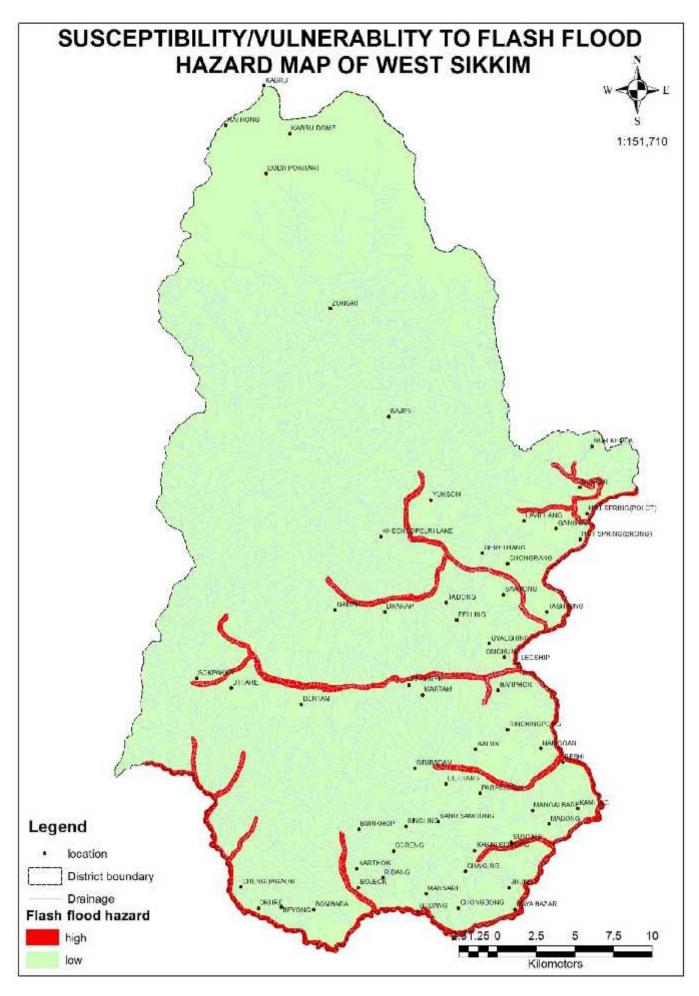
Snow and Avalanch Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazar	17.40	0.05	Very High	
Medium Hazards	17.65	0.26	Medium	
Low Hazards	64.95	99.69	Low	



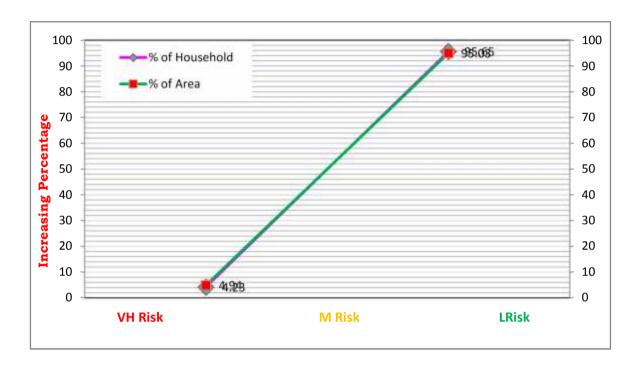
After extensive study and research of various maps and data, develop Snow and Avalanche Hazard Risk and Vulnerability Map for the West District of Sikkim. The study leads us to the following conclusions:

- 17.40% of the area fell in very high risk zone with 0 % of the total settlement to be affected
- 17.65% of the area fell in medium risk zone with .31% of the total settlement to be affected
- 64.95% of the area fell in very low risk zone with 99.69% of the total settlement are in this category.



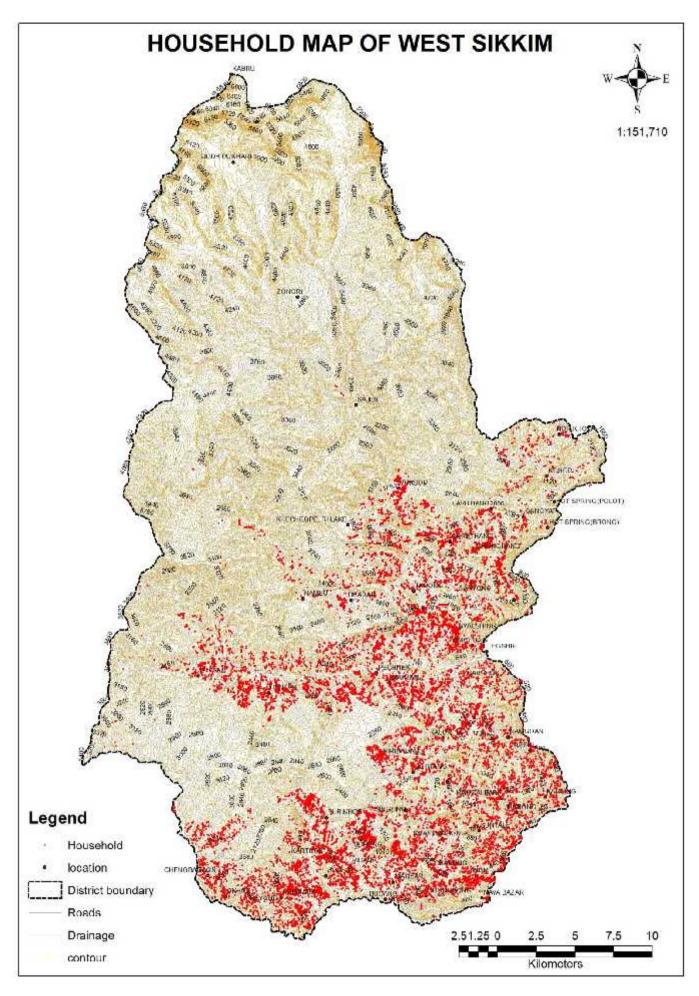


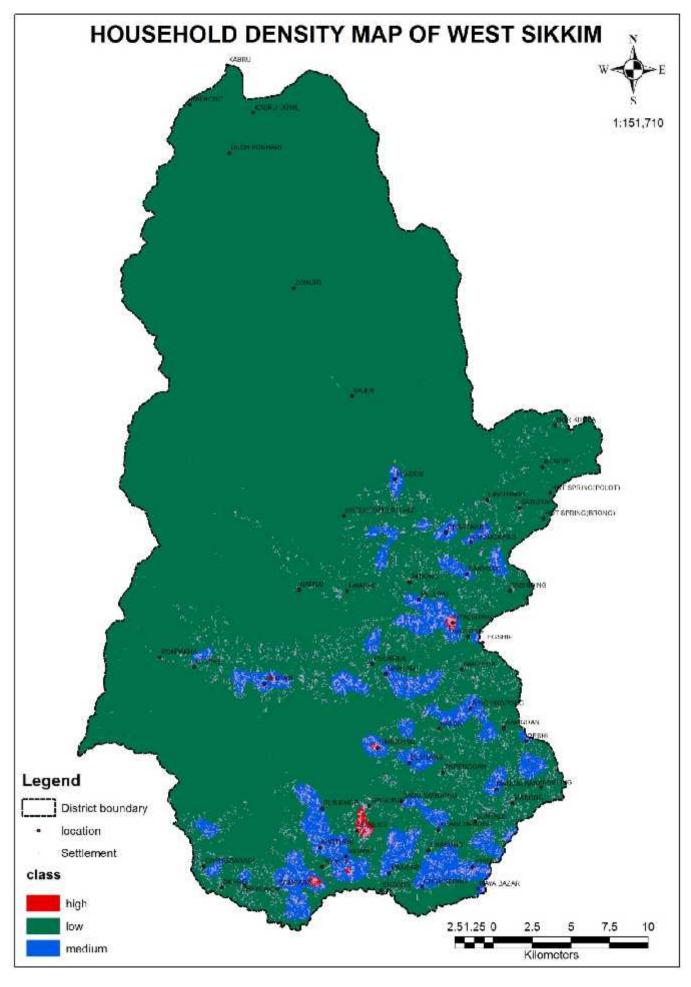
Flash flood Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazar	4.94	4.23	Very High	
Low Hazards	95.03	95.65	Low	

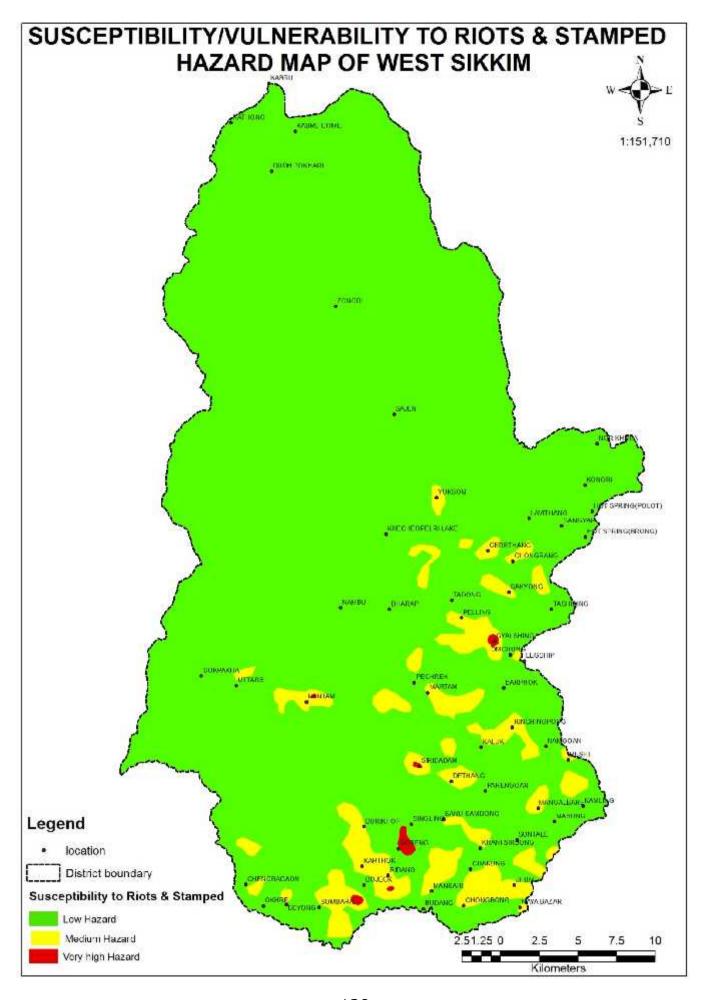


After extensive study and research of various maps and data, develop Flash flood Hazard Risk and Vulnerability Map for the West District of Sikkim. The study leads us to the following conclusions:

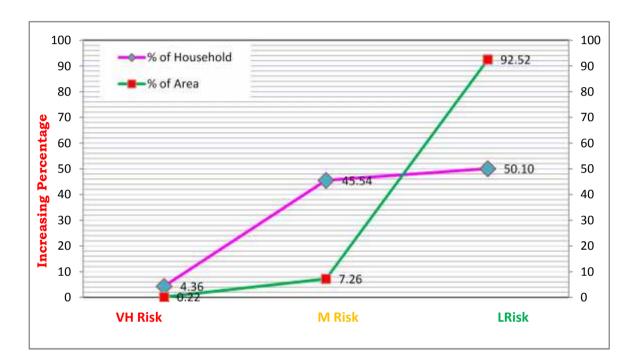
- 4.94% of the area fell in very high risk zone with 4.23% of the total settlement to be affected.
- 95.03% of the area fell in very low risk zone with 95.65% of the total settlement to be affected.







Riots/Stamped Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazar	0.22	4.36	Very High	
Medium Hazards	7.26	45.54	Medium	
Low Hazards	92.52	50.10	Low	



After extensive study and research of various maps and data, develop Riot Hazard Risk and Vulnerability Map for the West District of Sikkim. The study leads us to the following conclusions:

- 0.22% of the area fell in very high risk zone with 4.36% of the total settlement to be affected
- 7.26% of the area fell in high risk zone with 45.54% of the total settlement to be affected
- 92.52% of the area fell in very low risk zone with 50.10% of the total settlement to be affected.

Multi-hazards:

Taking into account the different Hazards that may affect the region of West District of Sikkim, developed a multi hazard map and a Risk Matrix Chart to assess the impact of each hazard in the respective WEST DISTRICT.

			respective WDS	Risk Matrix				
5	þ	EVERY YEAR		RIOTS			LANDSLIDE	Ď.
4	/Likelihood	2-10 YRS				FIRE		Likelihood
3	Like	11-20 YRS					EARTHQUAKE	Like
2	-	21-30 YRS		DROUGHT		FLASH FLOOD		1cy/
1	Frequency	31-50 YRS	HAILSTROMS, SNOW & AVALANCHES					Frequency/
Score Of likely- hood	<u>a</u>	Score of Impact	1 TO 7	8 TO 14	15 TO 21	22-28	29-35	Ē
Severity/ magnitude of damage								

RELATIVELY INCREASING RISK

MEDIUM	
LOW LOW MEDIUM HIGH VERY HIGH	

Methodology

In this analysis extensive background check was done with extensive historical research, as well as observational data. Different kinds of maps were created so as to assess the risk and vulnerability of the region. This information was then considered in the context of the seven impact criteria, which are outlined in Table 1 below. The impact criteria were individually ranked on an ascending scale from one to five, one being the least severe and five being the most severe. The sum of these scores was taken to create an overall consequence score, the score was then contrasted against a likelihood rating of one to six, one being the least likely and six being most likely. Details regarding the measure of likelihood are seen in Table 2. The aggregate score of each hazard, combined with the hazard impact consequence and likelihood provide the basis for a risk ranking of *low*, *medium low*, *medium high* and *very high*.

Table 1 – Seven Categories of Impact		
Categories of Impact	Score	
Fatality	1 TO 5	
Injury	1 TO 5	
Critical Facilities (Hospitals, Fire/Police Services etc.)	1 TO 5	
Lifelines (Water, Gas, Power, etc.)	1 TO 5	
Property Damage	1 TO 5	
Environmental Impact	1 TO 5	

Economic and Social Impact	1 TO 5	
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Table 2 - Measure of Likelihood		
Measure of Likelihood	Return Period (yrs)	Score
Frequent or Very Likely Every	EVERY YEAR	5
Moderate or Likely Every	2-10 YRS	4
Occasional, Slight Chance Every	11-20 YRS	3
Unlikely, Improbable Every	21-30 YRS	2
Highly Unlikely, Rare Event Every	31-50 YRS	1

RISK RATING INTERPRETATION

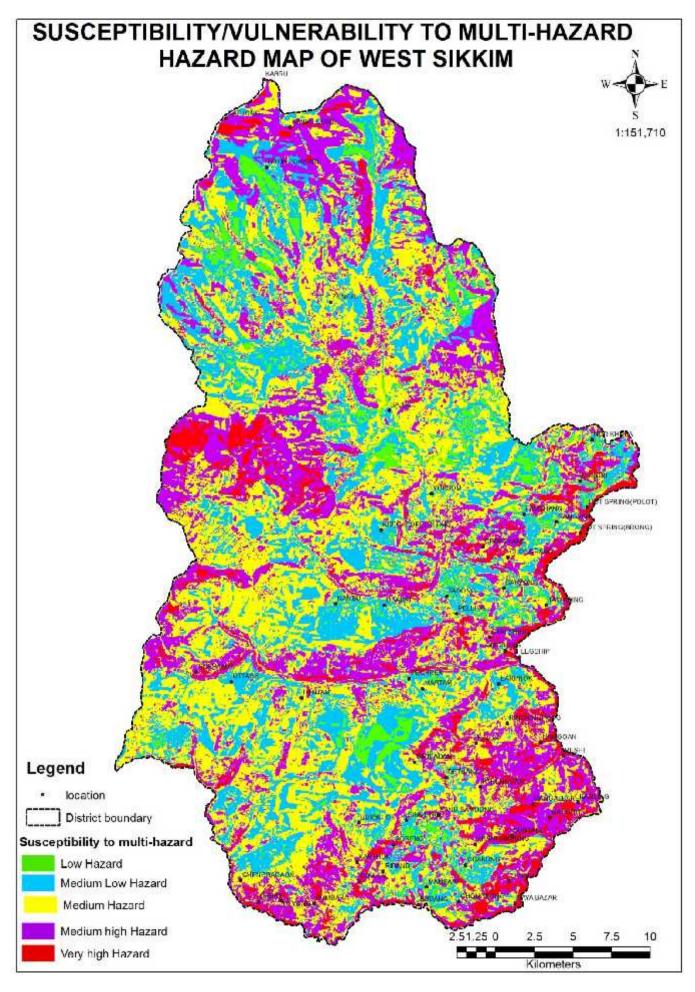
These risks are *low*. Implementation of mitigation measures will enhance emergency preparedness, but it is of less urgency and highly unlikely to occur in that area than the following hazards.

These risks are **medium low**. Implementation of mitigation measures will enhance emergency preparedness, Hazards is highly unlikely to occur in that area, but is of more urgency than low

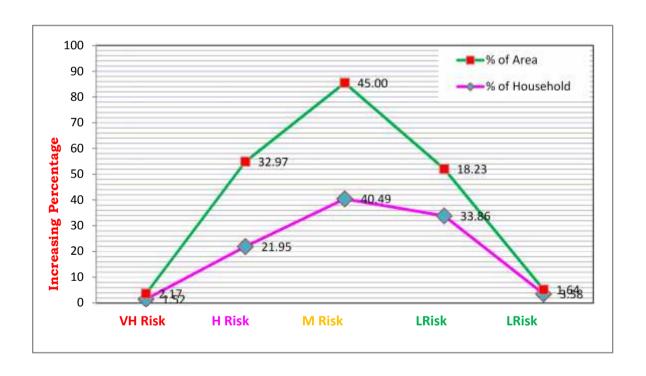
These risks are **medium**. These hazards have intermediate levels of frequency and severity. Hazards classified as moderate are more urgent than medium low hazards and are often common place concerns. Given this, moderate level hazards should be addressed with an appropriate level of urgency.

These risks are **medium high**. These hazards warrant review and development of mitigation actions to reduce the risk to an acceptable level. But these hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

These risks are **very high**. These hazards are both frequent and are of high severity. These hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

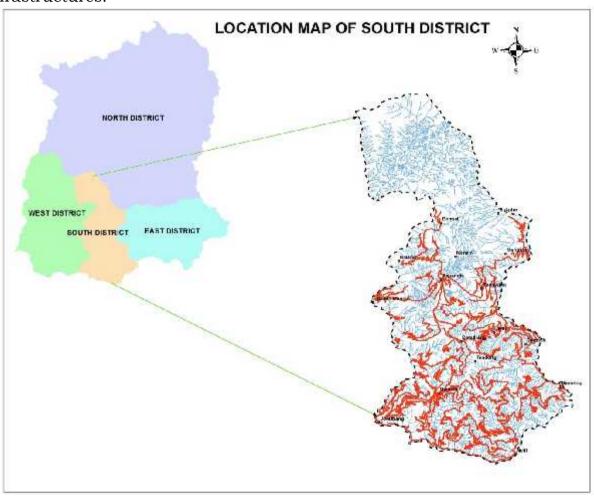


Multi- Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazar	2.17	1.52	Very High	
Medium High Hazards	32.97	21.95	High	
Medium Hazards	45.00	40.49	Medium	
Medium Low Hazards	18.23	33.86	Low	
Low Hazards	1.64	3.58	Low	



SOUTH SIKKIM

The South District of Sikkim has its headquarter at Namchi and it is bound by Tista river in the East, Rangit river in the west and South and Dzongu area of north district in the North. The district of South Sikkim has a total area of 750 sq.km and the population of 1, 31,525 persons (2001 census). Namchi is becoming a fast growing tourist destination basically due to its Bio-diversity, Natural beauty and in development of religious and other tourist attractive infrastructures.



GEOLOGY

The area under investigation covers South District of Sikkim; Parts of South Sikkim has been mapped geologically by a number of researchers from time to time. At each stage of mapping, additional details were added. In Sikkim Himalaya trouble begins when the question of stratigraphy comes up. Each researcher, over a period of time brings out their own stratigraphic classifications. They are yet to arrive at a commonly agreeable consensus because of lack of well documented markers such as fossils, horizons or features characteristic of these areas generally tolerated stratigraphic succession for 'Rangit Window Zone' is as under:-

Gondwana: Pebble slate, calcareous phyllite, fossil and non-fossiliferrous carbonaceous shale, coal and sandstone etc.

Buxa: Phyllites, slates, calc-phyllite/slate, dolomite/limestone, pink dolomite and purple phyllite etc.

Dalings: Phyllites, Barbed phyllite, quartzite, sericitic and chloritic phyllite, massive and flaggy quartzite, quartz veins, milky quartzite(marker horizon) etc.

Darjeeling and tsungthang formation: Quartzite, High grade Gneiss, Cal Gneiss, Granulite with bands of biotite/Graphite schist with pegmatite and aplite veins. Rangit valley has been seen as a place of profuse geologic features here the placement of lithounits in space, time and disparities between profusion of structural elements can lead a conscientious researcher to treasure house of new knowledge since the distribution of the lithounits are limited in space and mineral resource potentialities not yet estimated the area will receive only a cursory look each time for years to come within the Rangit valley area the stratigraphic sequences are invariably reversed. The younger sequences are always exposed in the 'windo zone' and the Dialing which are older form a sheet like structure enclosing the ypunger formations from all sides. The dalings are the low grade metamorphic sequence where the prominent lithounits are chlorite, sericitic phyllites and massive quartize. Flaggy types of quartzite within the daling are seen only near the contact zones invariably near the contact of Darjeeling and the Dalings. Basic intrusive has been noted within the Daling of Rangit area quite regularly their placement within the sequences in space and time is not yet interoperated the quartz in intrusives, rampant in dalings seem to receive much attention from different geologists working in these areas. Their distribution and age in relation to the daling has been stipulated these intrusives are profuse throughout but as the dalings approach contact between the Daling and Darjeeling, their number decrease appreciably these intrusives are much latter than the dalings. In most cases they are the suited for base metal occurrences though they are profuse their distribution in space is limited. The Daling on the whole are barren save for occasional basemental occurrences of limited dimensions. The Daling sequence along the north part of areas is overlain by higher grade metamorphic rocks that belong to Darjeeling and Tsungthang sequence of rocks. The rock types present in these areas are high grade gneiss(Augen and Banded Gneiss), Sillimanite and Kyanite bearing schist or Gneiss, Quartzites, Calcerous Gneiss, Granulites and associated band of Biotite schists and Pegmetite veins

Buxa formation: The main rock types in this formation are Dolomites, Purple Quartizites and variegated Phyllite, Pink and Buff colored Dolomite and Stromatolite bearing Dolomites which belong to the upper most sequence of this formation. Grey to pink Dolomites are exposed along Phalidara, Bagdara, Salibong, Mamley, Pabong and Wok areas. Stromatalite Bearing Dolomites occur along Mamley area.

Gondwana formatio: The basal portion of the Gondwana is represented by Peddle bed sequence. The pebbles are mainly of Quartize, Dolomite, Granite and Phyllite and show sub-angular to rounded shape. The pebble-bed is mainly overlain by course to medium grained Sandstone with intercalation of Shales with occasional coal seams. The Sandstones are massive and well bedded and highly jointed, plant fossils are also found in the shales of Gondwana sequence. Geomorphologically, the area consists of structural-cum-denudation and glacial land form units. Extensive sculpturing of the landscape by glacial agencies has been observed in the area with subsequent

modification by glacis-fluvial and fluvial agencies. Imprints of at least three deformational phases have been observed in the area. The genisses show compatible deformational structures with the associated Metasedimentaries. Field and Petrographic studies indicate a main phase of regional prograde Metamorphism associated with the earliest deformation producing a dominant and pervasive planar fabric through Metamorphic reconstitution. The second phase of Metamorphism is accompanied by very little Metamorphic reconstitution and is mainly retrogressive in nature.

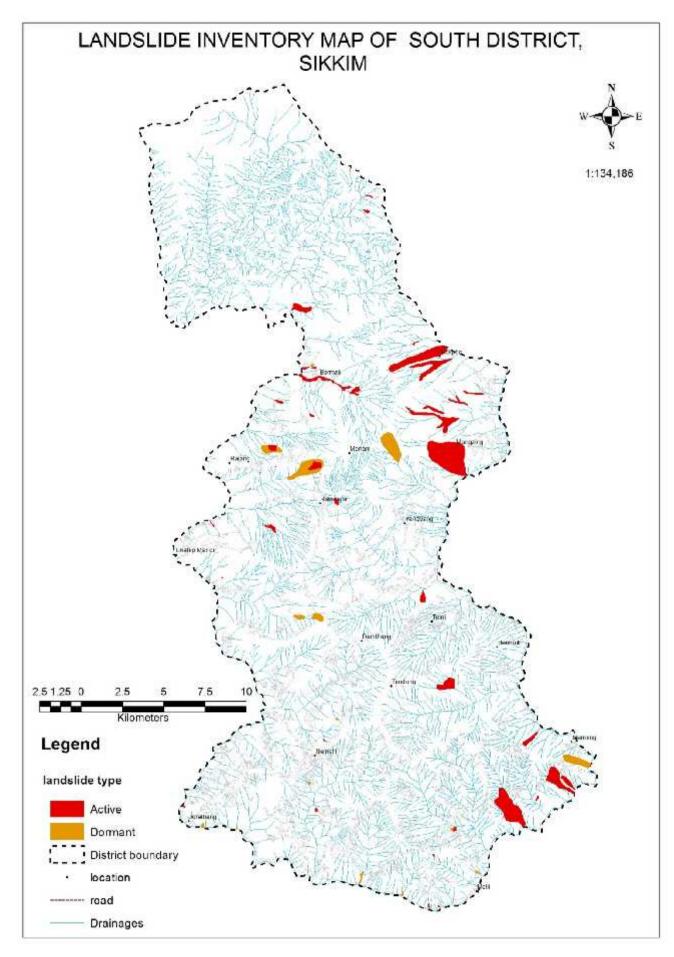
The similarity in the imprints of the deformational fabrics of the high grade gneisses and the associated Metasedimentaries point to a possible common mode of evolution through granitisation in response to the main phase of deformation and metamorphism.

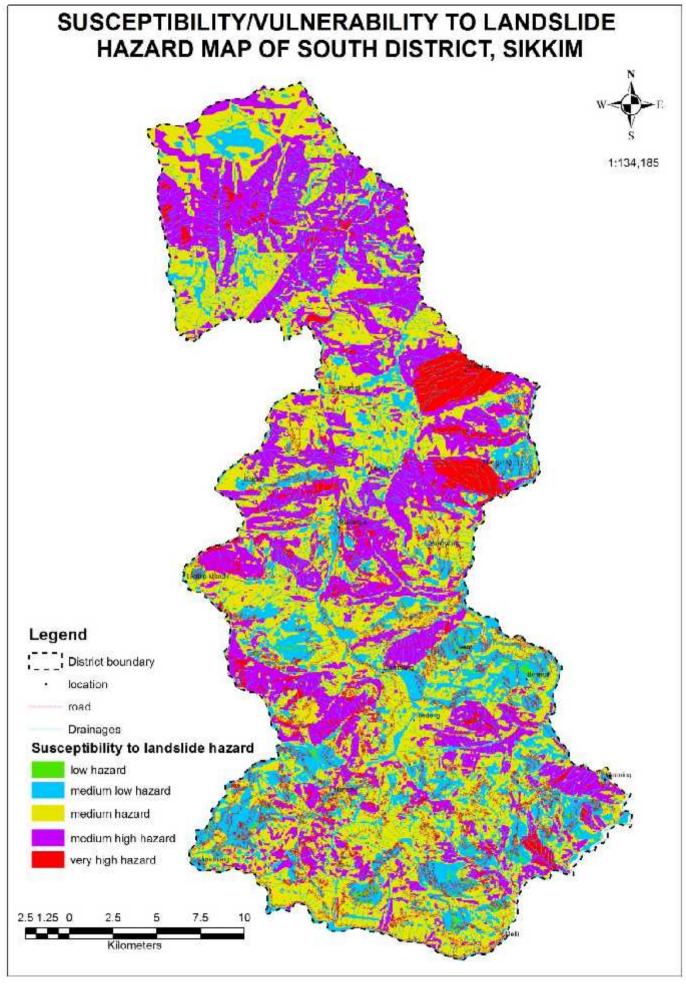
HYDROGEOLOGY AND DRAINAGE

The Tista River, running almost N-S in the Eastern part of the area, and Rangit along Western and Southern part of the area, is the major drainage channel, to which there are numerous tributaries of various orders. The main tributaries are the Bermali Chu, Rishi Chu, Rangpo Chu, Bhaga khola etc. The major rivers and tributaries are characterized by arid meanders with welldeveloped meander – scrolls and terraces of at least three levels. The hill slopes are covered with veneers of rock and soil debris, which are potential sources of landslide materials. The slopes are highly unstable, due to high slope angles, fairly heavy rainfall and significant toe-erosion by the rivers and streams, which are characterized by high discharge, particularly during the monsoons. The average yearly rainfall in the area varies from 160 to 320cms. The heaviest rainfall takes place generally during the period from July to September. Winter in higher altitude is quite severe, but the temperature records generally well over 0° c. In the summer, these places are very pleasant; whereas in lower altitudes, e.g., in Jorethang, Melli, etc., in the vicinity of river beds, the summer is quite hot and sultry.

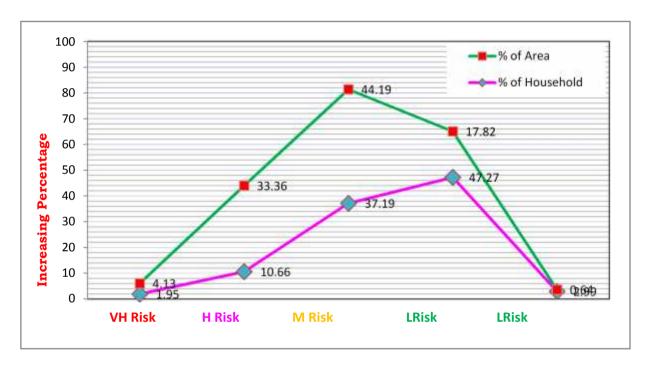
LAND-USE AND LAND-COVER

Gently sloping and flat areas throughout the eastern hill slopes are extensively used for paddy cultivation by bundh irrigation system and steeper slopes with perennial source of water are being used for cardamom cultivations. The practice has lead to excessive seepage within the unconsolidated mass leading to worsening stability condition of the already fragile landscape. Deforestation both within private & forest area has lead to silt load in water bodies. Further the disturbance along the toe regions has jeopardized maintenance of the road which runs over subsidence zone. The alignment of the damaged road in the area seems to be contributing factor for initiation of destabilization of fragile landscape to lesser scale by disrupting natural water courses and concentration of surface run-off to a particular place.



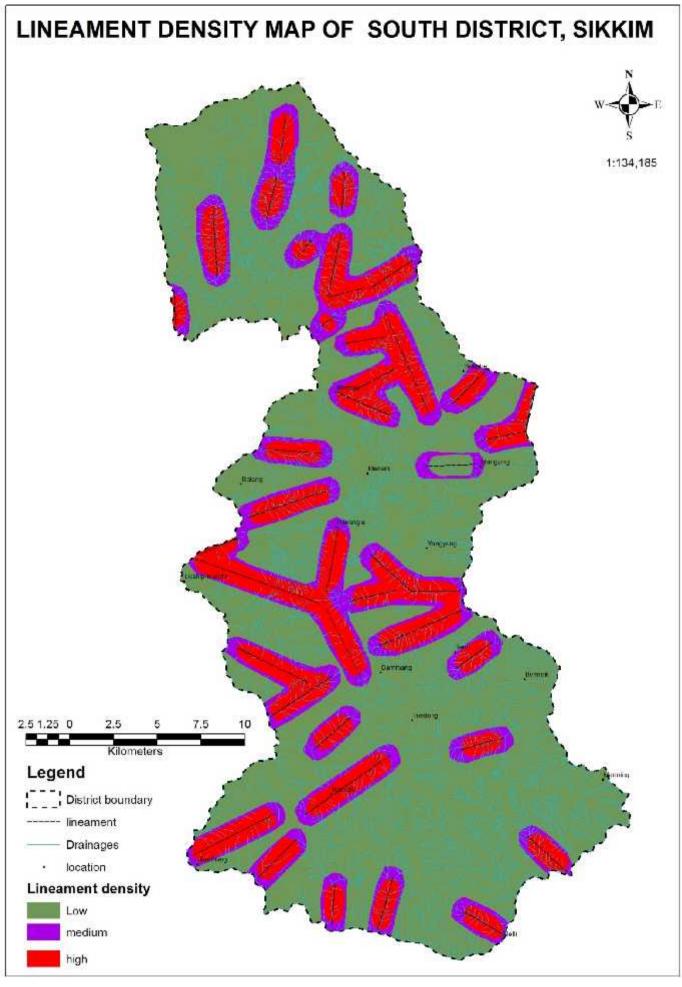


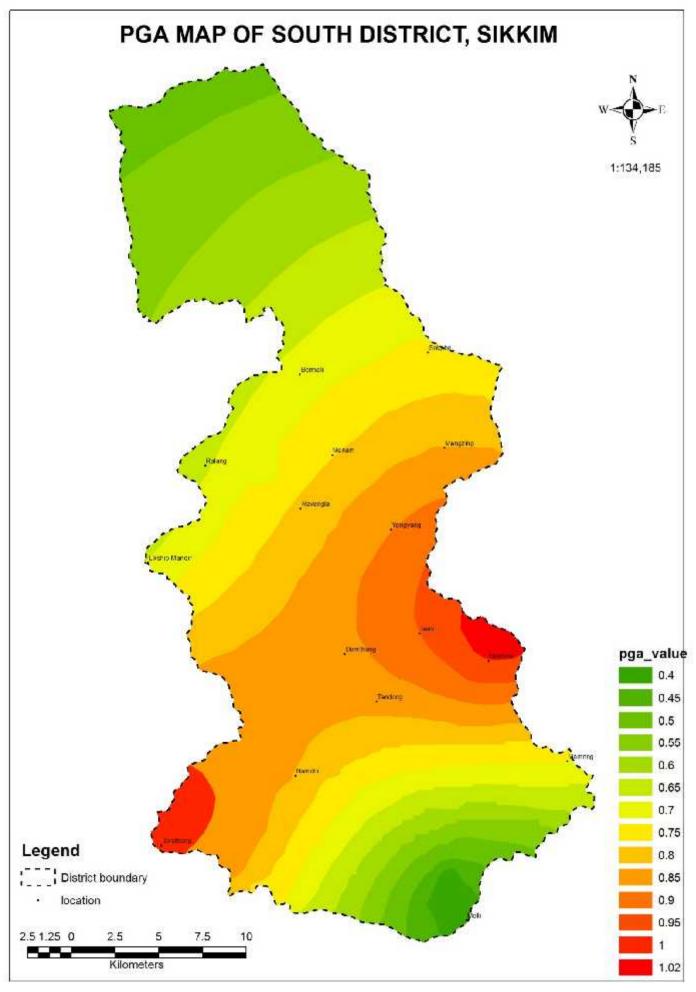
Landslide Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazar	4.13	1.95	Very High	
Medium High Hazards	33.36	10.66	High	
Medium Hazards	44.19	37.19	Medium	
Medium Low Hazards	17.82	47.27	Low	
Low Hazards	0.64	2.99	Low	

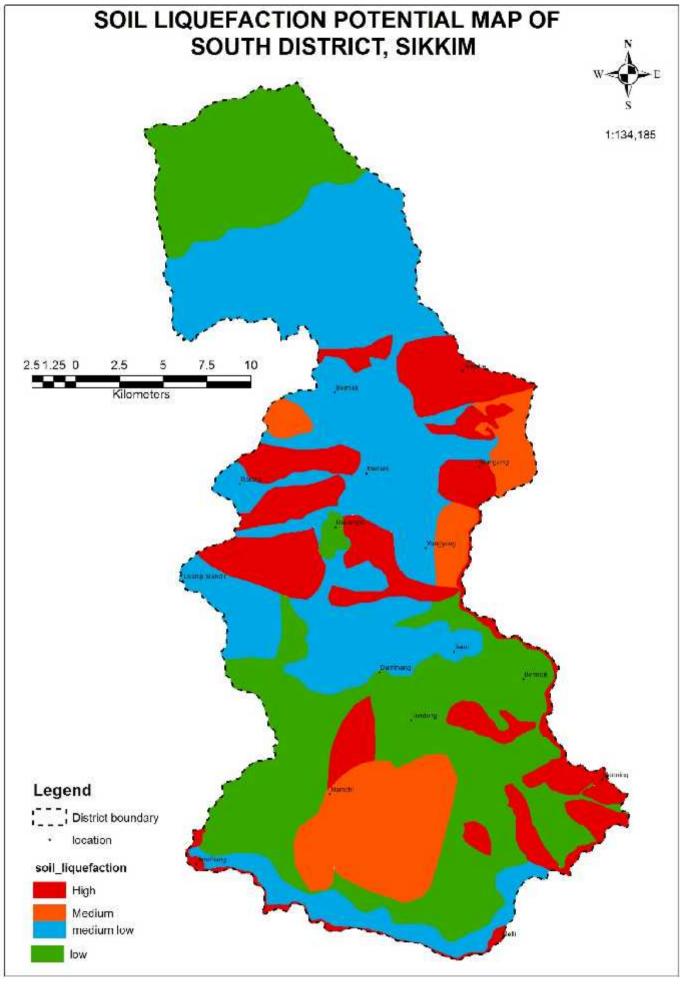


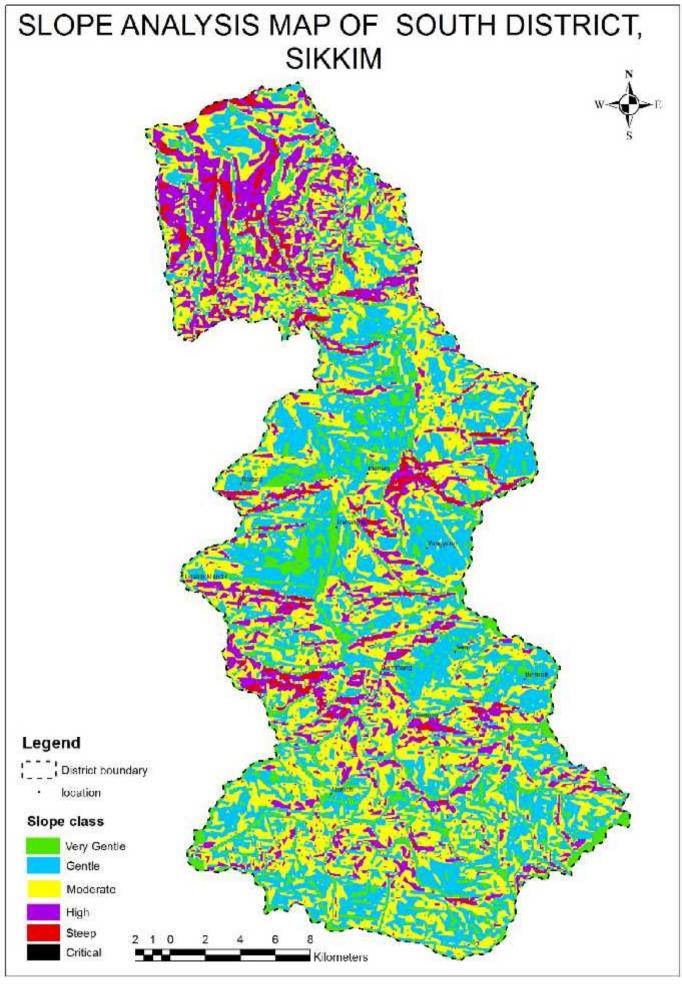
After extensive study and research of various maps and data it was possible to develop Landslide Hazard Risk and Vulnerability Map for the South District. The study leads to the following conclusions:

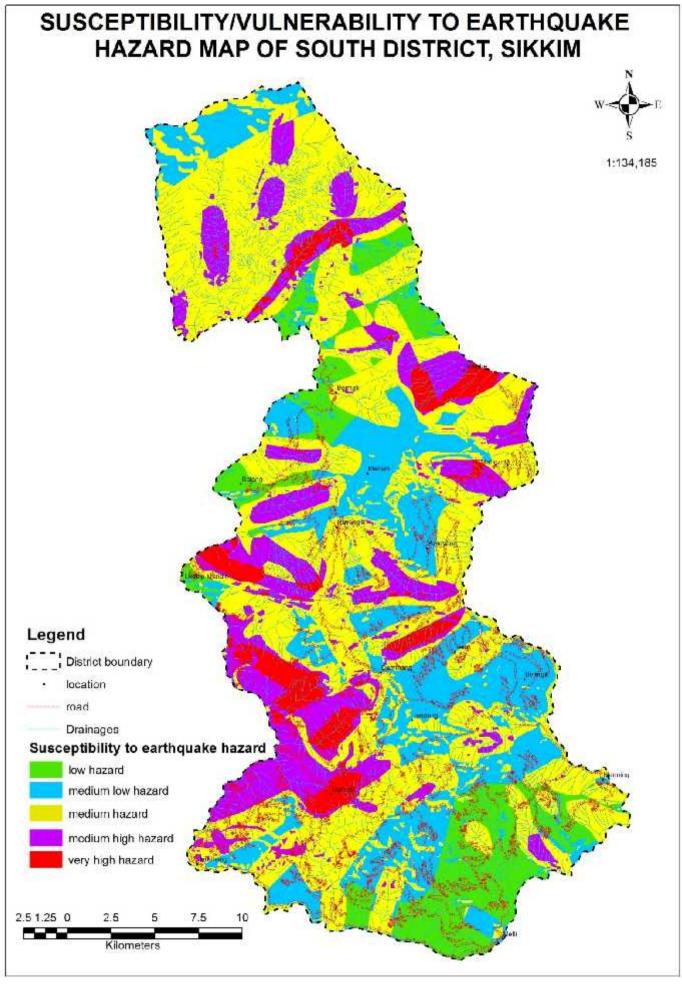
- 4.13% of the area fell in very high risk zone with 1.95% of the total settlement to be affected.
- 33.36% of the area fell in very medium high risk zone with 10.66% of the total settlement to be affected.
- 44.19% of the area fell in very medium risk zone with 37.19% of the total settlement to be affected.
- 17.82% of the area fell in very medium low zone with 47.27% of the total settlement to be affected.
- 0.64% of the area fell in very low risk zone with 2.99% of the total settlement to be affected.



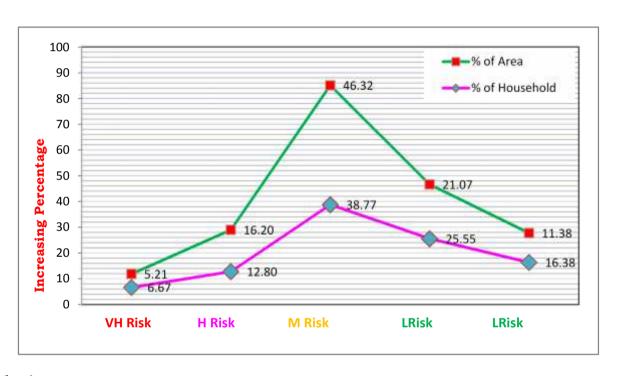






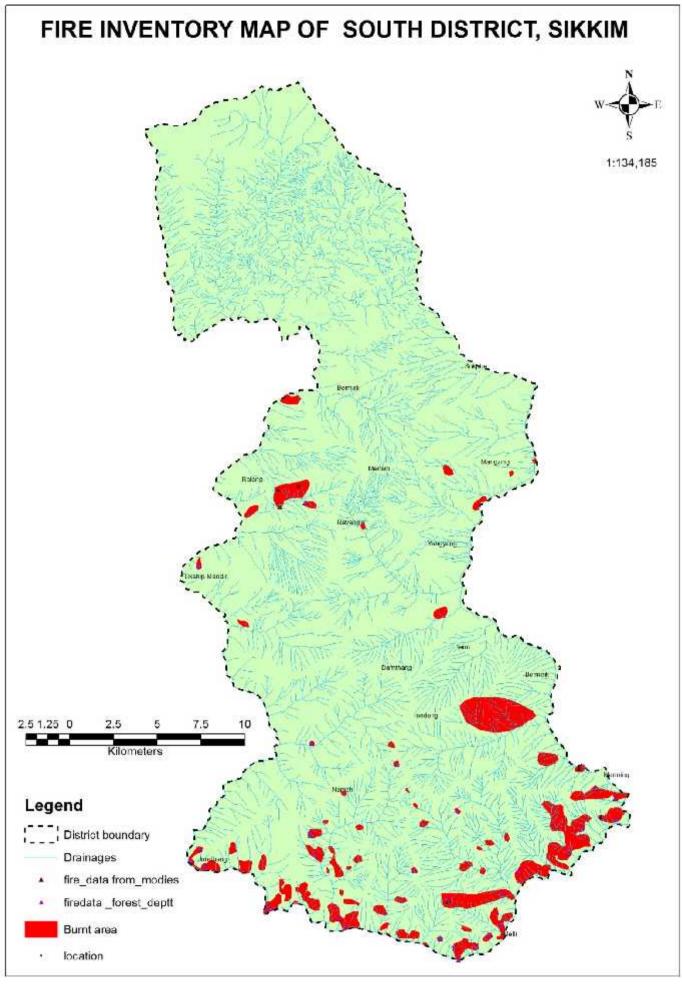


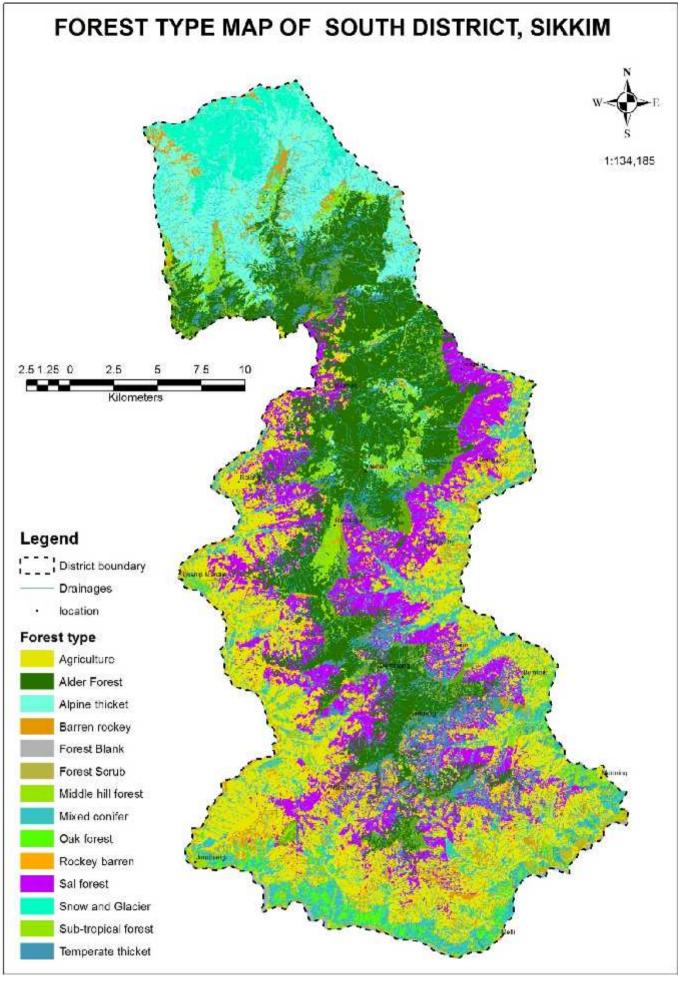
Earthquake Hazards						
Hazards Category	% of Area	% of Area % of Household Risk type				
Very High Hazar	5.21	6.67	Very High			
Medium High Hazards	16.20	12.80	High			
Medium Hazards	46.32	38.77	Medium			
Medium Low Hazards	21.07	25.55	Low			
Low Hazards	11.38	16.38	Low			

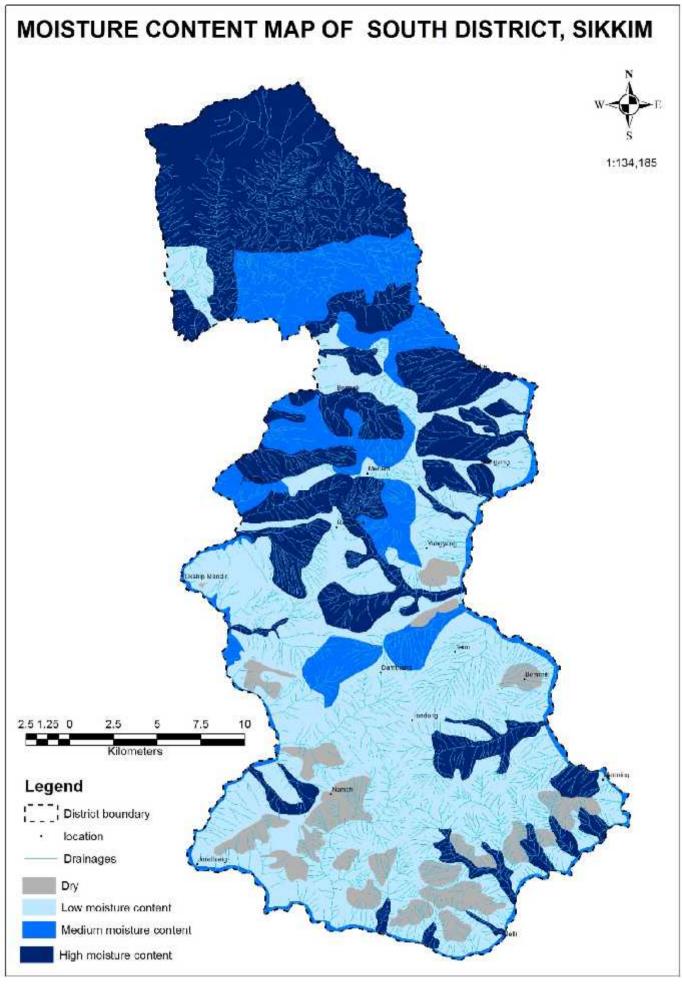


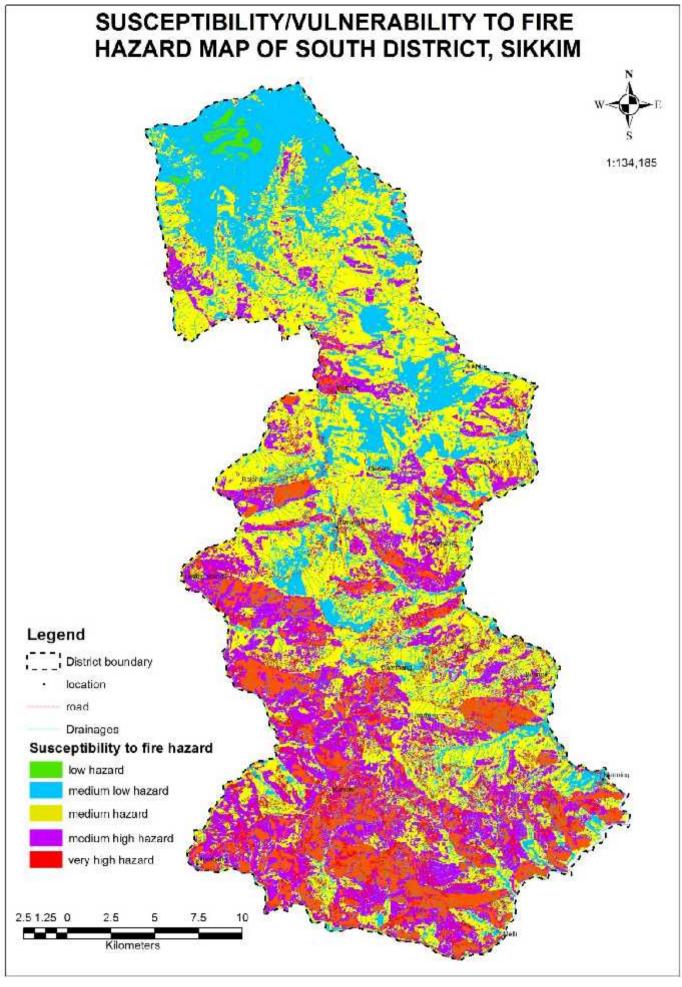
After extensive study and research of various maps and data, develop Earthquake Hazard Risk and Vulnerability Map for the South Sikkim. The study leads us to the following conclusions:

- 5.21% of the area fell in very high risk zone with 6.67% of the total settlement to be affected.
- 16.20% of the area fell in very medium high risk zone with 12.80% of the total settlement to be affected.
- 46.32% of the area fell in very medium risk zone with 37.77% of the total settlement to be affected.
- 21.07% of the area fell in very medium low zone with 25.55% of the total settlement to be affected.
- 11.38% of the area fell in very low risk zone with 16.38% of the total settlement to be affected.

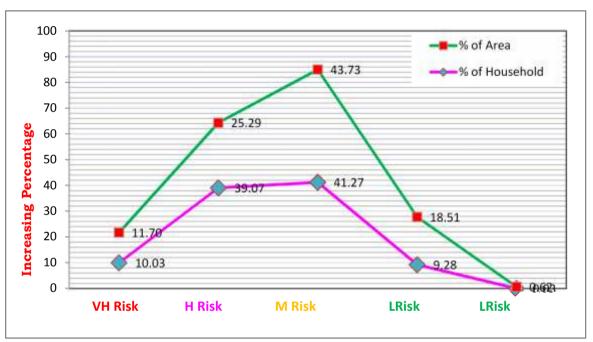






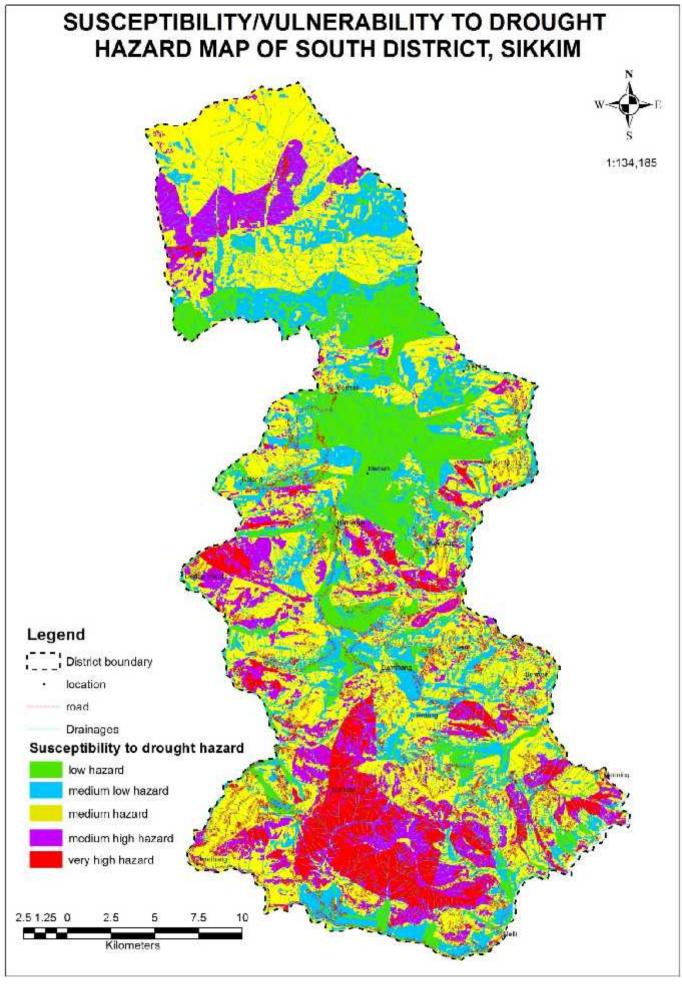


Fire Hazards					
Hazards Category	% of Area	% of Household	Risk type		
Very High Hazar	11.70	10.03	Very High		
Medium High Hazards	25.29	39.07	High		
Medium Hazards	43.73	41.27	Medium		
Medium Low Hazards	18.51	9.28	Low		
Low Hazards	0.62	0.03	Low		

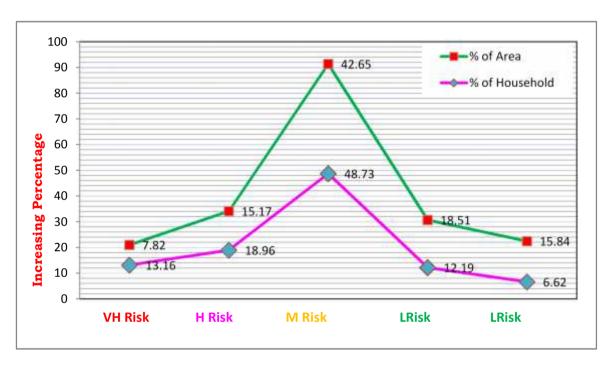


After extensive study and research of various maps and data, develop Fire Hazard Risk and Vulnerability Map for the South District of Sikkim. The study leads us to the following conclusions:

- 11.70% of the area fell in very high risk zone with 10.03% of the total settlement to be affected.
- 25.29% of the area fell in very medium high risk zone with 39.07% of the total settlement to be affected.
- 43.73% of the area fell in very medium risk zone with 41.27% of the total settlement to be affected.
- 18.51% of the area fell in very medium low zone with 9.28% of the total settlement to be affected.
- 0.62% of the area fell in very low risk zone with 0.03% of the total settlement to be affected.

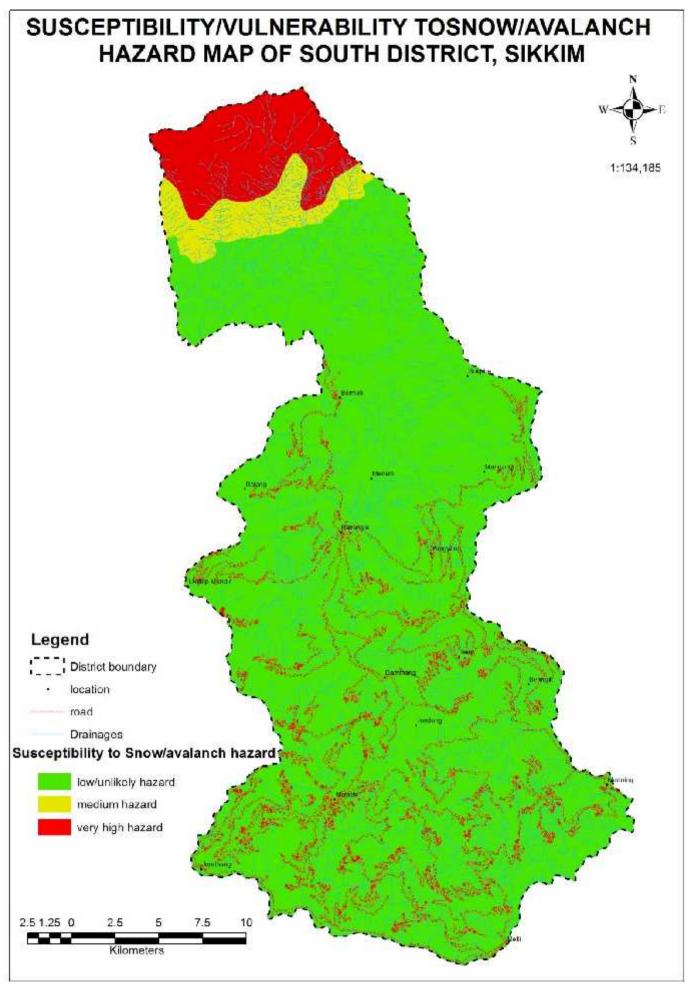


Drought Hazards					
Hazards Category	% of Area % of Household Risk type				
Very High Hazar	7.82	13.16	Very High		
Medium High Hazards	15.17	18.96	High		
Medium Hazards	42.65	48.73	Medium		
Medium Low Hazards	18.51	12.19	Low		
Low Hazards	15.84	6.62	Low		

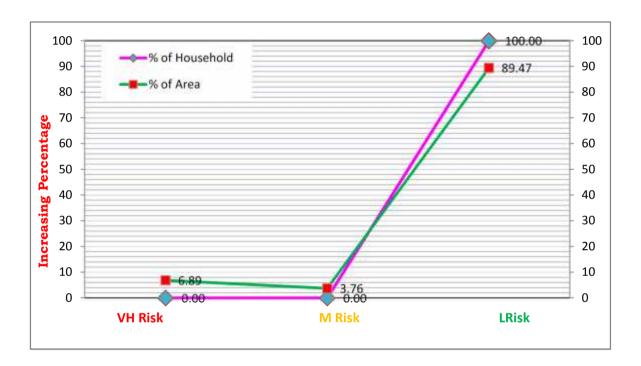


After extensive study and research of various maps and data, develop Drought Hazard Risk and Vulnerability Map for the South district of Sikkim. The study leads us to the following conclusions:

- 7.82% of the area fell in very high risk zone with 13.16% of the total settlement to be affected
- 15.17% of the area fell in high risk zone with 18.96% of the total settlement to be affected
- 42.65% of the area fell in medium risk zone with 48.73% of the total settlement to be affected
- 18.51% of the area fell in very low risk zone with 12.19% of the total settlement to be affected
- 15.84% of the area fell in very low risk zone with 6.62% of the total settlement to be affected

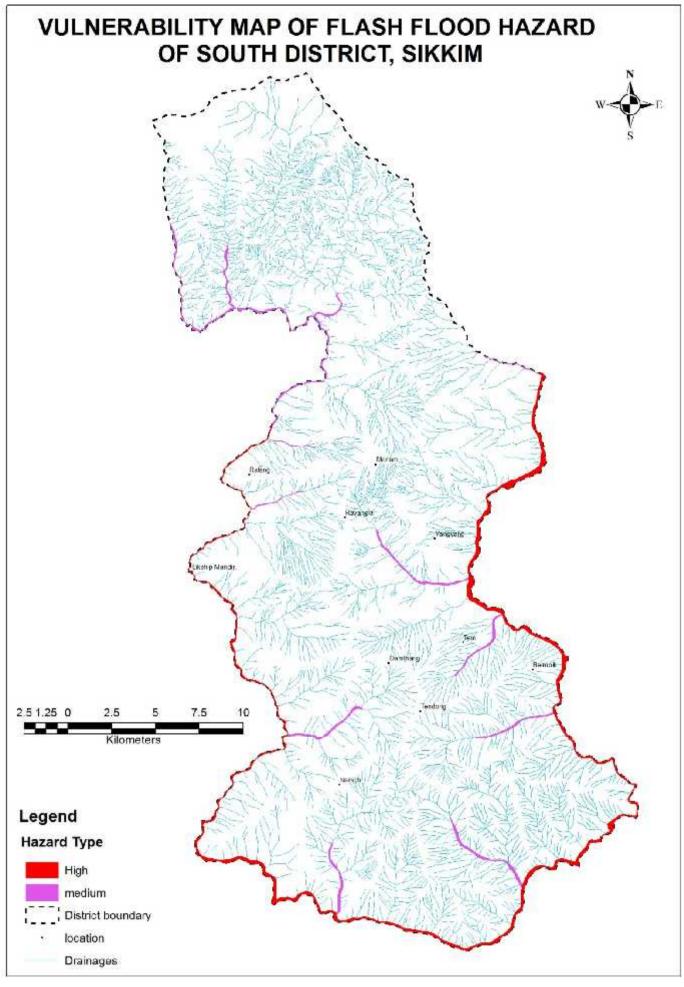


Snow and Avalanche Hazards					
Hazards Category	% of Area	% of Household	Risk type		
Very High Hazar	6.89	0.00	Very High		
Medium Hazards	3.76	0.00	Medium		
Low Hazards	89.47	100.00	Low		

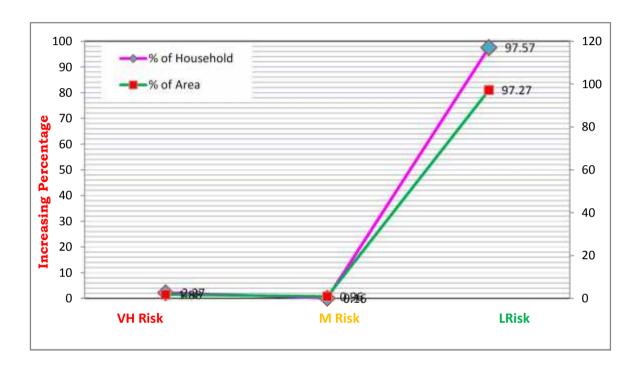


After extensive study and research of various maps and data, develop Snow and Avalanche Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

- 6.89% of the area fell in very high risk zone with 0 % of the total settlement to be affected.
- 3.76% of the area fell in medium risk zone with 0% of the total settlement to be affected.
- 89.47% of the area fell in very low risk zone with 100% of the total settlement are in this category.

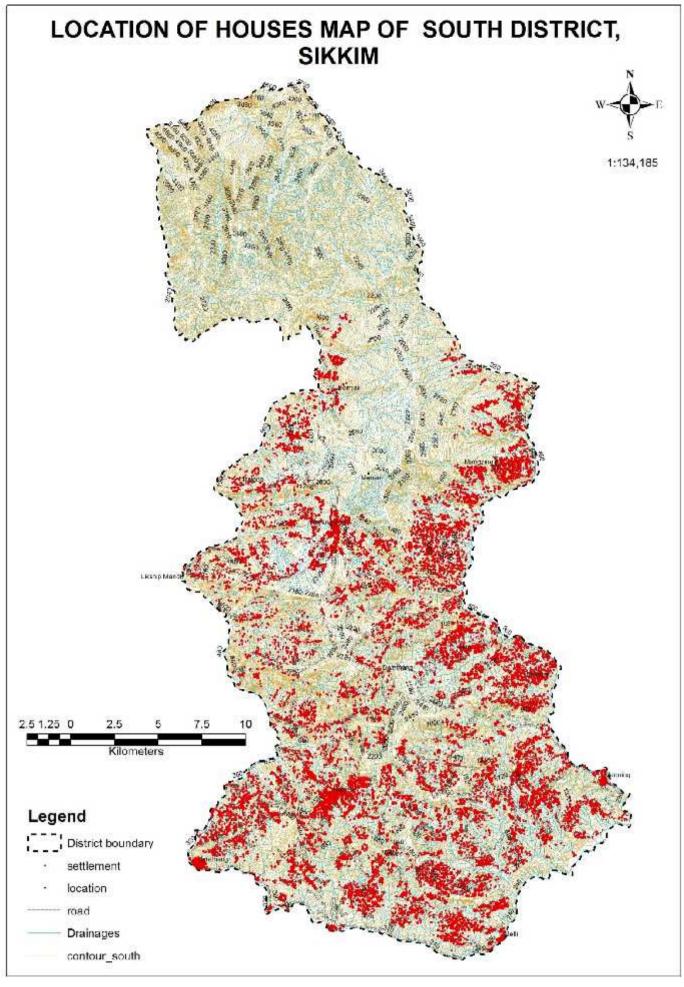


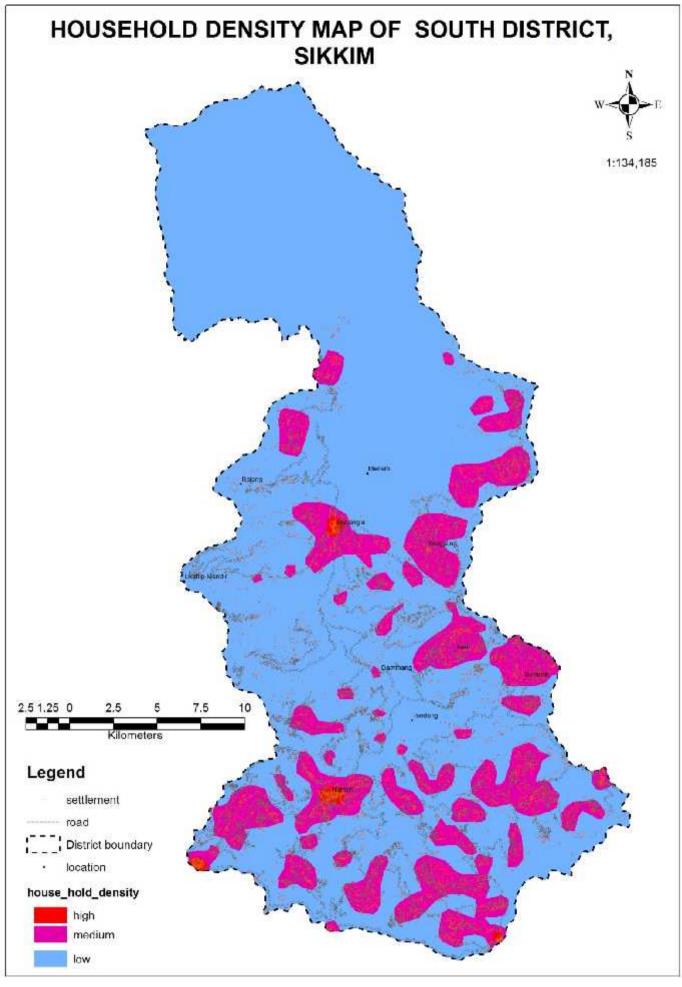
Flashflood Hazards					
Hazards Category	% of Area	% of Household	Risk type		
Very High Hazar	1.88	2.27	Very High		
Medium Hazards	0.96	0.16	Medium		
Low Hazards	97.27	97.57	Low		

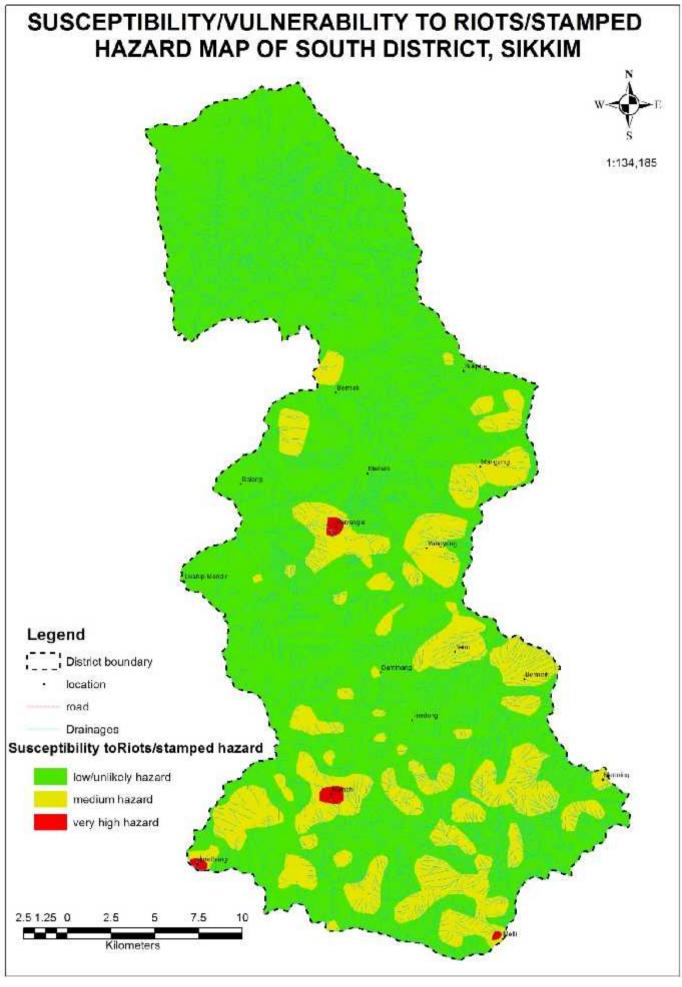


After extensive study and research of various maps and data, develop Flashflood Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

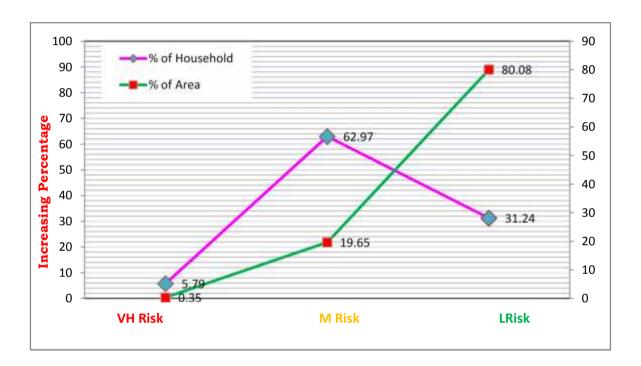
- 1.88% of the area fell in very high risk zone with 2.27% of the total settlement to be affected.
- 0.96% of the area fell in medium risk zone with 0.16% of the total settlement to be affected.
- 97.27% of the area fell in very low risk zone with 97.57% of the total settlement to be affected.







Riots/Stamped Hazards					
Hazards Category	% of Area	% of Household	Risk type		
Very High Hazar	0.35	5.79	Very High		
Medium Hazards	19.65	62.97	Medium		
Low Hazards	80.08	31.24	Low		



After extensive study and research of various maps and data, develop Riot Hazard Risk and Vulnerability Map for the East District of Sikkim. The study leads us to the following conclusions:

- 5.79% of the area fell in very high risk zone with 0.35% of the total settlement to be affected.
- 62.97% of the area fell in high risk zone with 19.65% of the total settlement to be affected.
- 31.24% of the area fell in very low risk zone with 80.08% of the total settlement to be affected.

Multi-hazards:

Taking into account the different Hazards that may affect the region of Gangtok Municipal Corporation, developed a multi hazard map and a Risk Matrix Chart to assess the impact of each hazard in the respective SOUTH SIKKIM.

	Risk Matrix Chart							
5		EVERY YEAR		DROUGHT		FIRE	LAND SLIDE	
4		2-10 YRS						
3	pool	11-20 YRS					EARTHQUAKE	poor
2	/Likelihood	21-30 YRS		RIOTS		FLASHFLOOD		Likelihood
1	-	31-50 YRS	HILLSTROMS, SNOW AND AVALANCHES					
Score Of likely- hood	Frequency	Score of Impact	1 TO 7	8 TO 14	15 TO 21	22-28	29-35	Frequency/
Severity/ magnitude of damage								

RELATIVELY	INCREASING	RISK
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LOW	MEDIUM LOW	MEDIUM	HIGH	VERY HIGH

Methodology

In this analysis extensive background check was done with extensive historical research, as well as observational data. Different kinds of maps were created so as to assess the risk and vulnerability of the region. This information was then considered in the context of the seven impact criteria, which are outlined in Table 1 below. The impact criteria were individually ranked on an ascending scale from one to five, one being the least severe and five being the most severe. The sum of these scores was taken to create an overall consequence score, the score was then contrasted against a likelihood rating of one to six, one being the least likely and six being most likely. Details regarding the measure of likelihood are seen in Table 2. The aggregate score of each hazard, combined with the hazard impact consequence and likelihood provide the basis for a risk ranking of *low, medium low, medium, medium high* and *very high*.

Table 1 - Seven Categories of Impact	
Categories of Impact	Score
Fatality	1 TO 5
Injury	1 TO 5
Critical Facilities (Hospitals, Fire/Police	
Services etc.)	1 TO 5
Lifelines (Water, Gas, Power, etc.)	1 TO 5
Property Damage	1 TO 5
Environmental Impact	1 TO 5
Economic and Social Impact	1 TO 5

Table 2 - Measure of Likelihood		
	Return Period	
Measure of Likelihood	(yrs)	Score
Frequent or Very Likely Every	EVERY YEAR	5
Moderate or Likely Every	2-10 YRS	4
Occasional, Slight Chance Every	11-20 YRS	3
Unlikely, Improbable Every	21-30 YRS	2
Highly Unlikely, Rare Event Every	31-50 YRS	1

RISK RATING INTERPRETATION

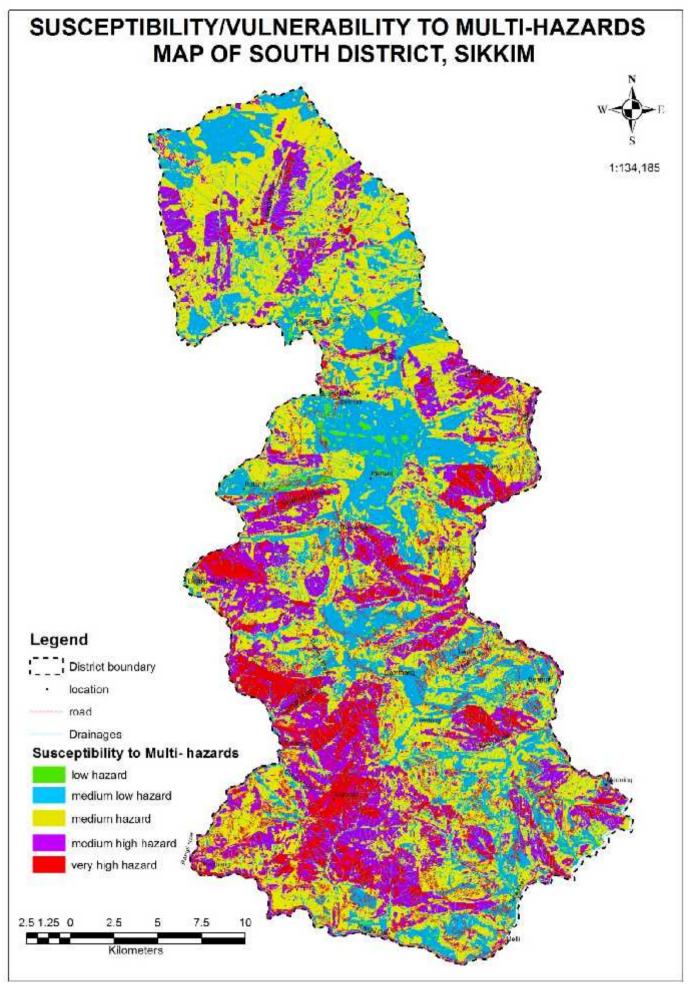
These risks are **low**. Implementation of mitigation measures will enhance emergency preparedness, but it is of less urgency and highly unlikely to occur in that area than the following hazards.

These risks are medium low. Implementation of mitigation measures will enhance emergency preparedness, Hazards is highly unlikely to occur in that area, but is of more urgency than low

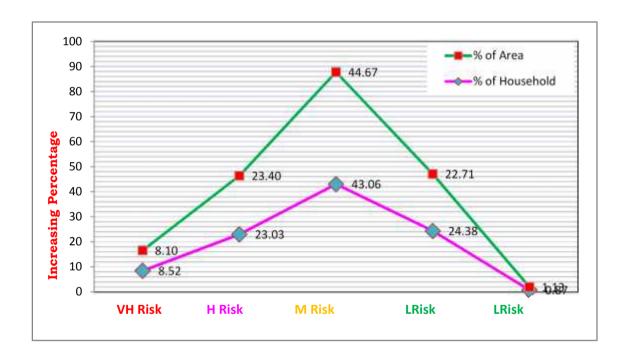
These risks are **medium**. These hazards have intermediate levels of frequency and severity. Hazards classified as moderate are more urgent than medium low hazards and are often common place concerns. Given this, moderate level hazards should be addressed with an appropriate level of urgency.

These risks are **medium high**. These hazards warrant review and development of mitigation actions to reduce the risk to an acceptable level. But these hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.

These risks are **very high**. These hazards are both frequent and are of high severity. These hazards require immediate examination and mitigation measures to reduce the risk to an acceptable level.



Multi- Hazards				
Hazards Category	% of Area	% of Household	Risk type	
Very High Hazar	8.10	8.52	Very High	
Medium High Hazards	23.40	23.03	High	
Medium Hazards	44.67	43.06	Medium	
Medium Low Hazards	22.71	24.38	Low	
Low Hazards	1.13	0.87	Low	

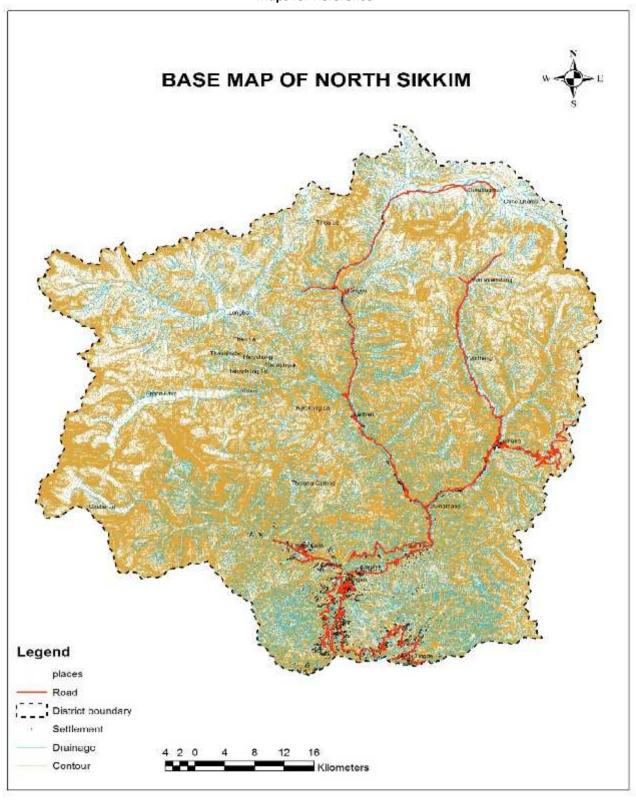


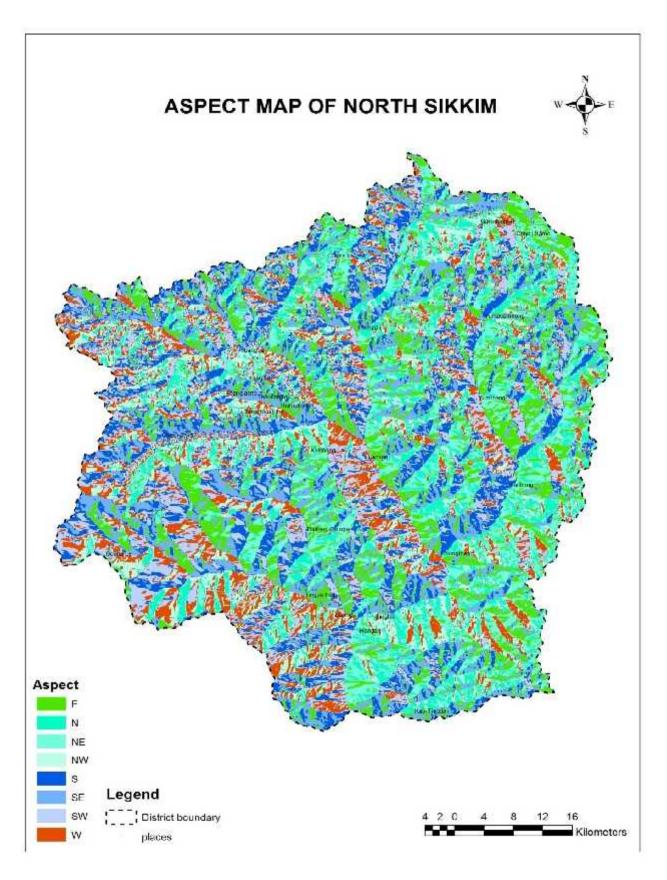
Conclusion and Recommendation

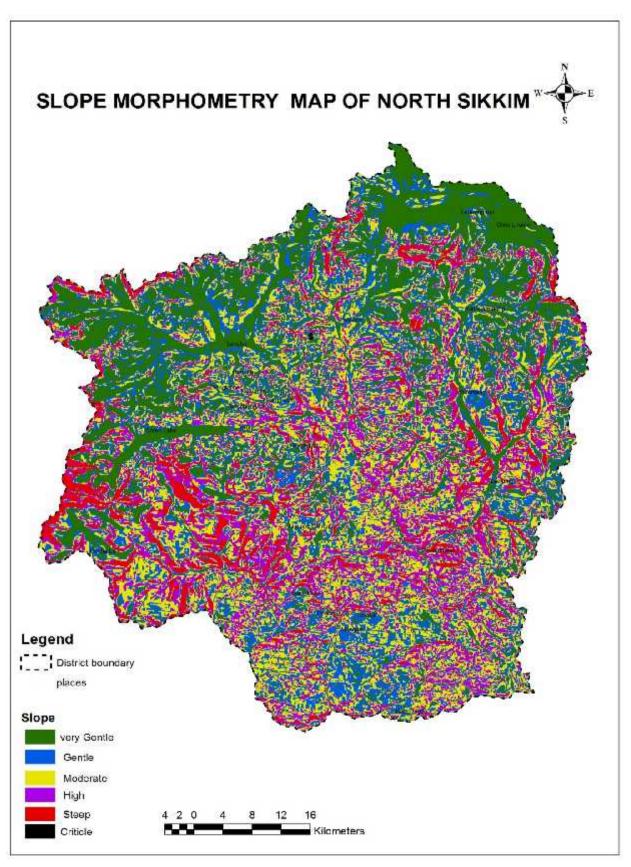
The Multi Hazard Risk Vulnerability Assessment (MHRVA) for North East West South District of Sikkim was carried out in 1:50000 Scale using the GIS Platform. The different Hazard components taken into consideration are Landslides, Earthquake, Fire, Draught, Snow Avalanches, Flash Flood, and Riots. For every component the factors that are liable to cause the particular Hazard type were taken up into consideration and studied in detail and analysed. All the vulnerable areas that poise threat and to turn into disaster and risk the life and property of people are mapped. The Hazard mapping of the areas has been carried out with individual Hazard components. The MHRVA map combines all the hazard maps and the area is rated in terms of severity and frequency.

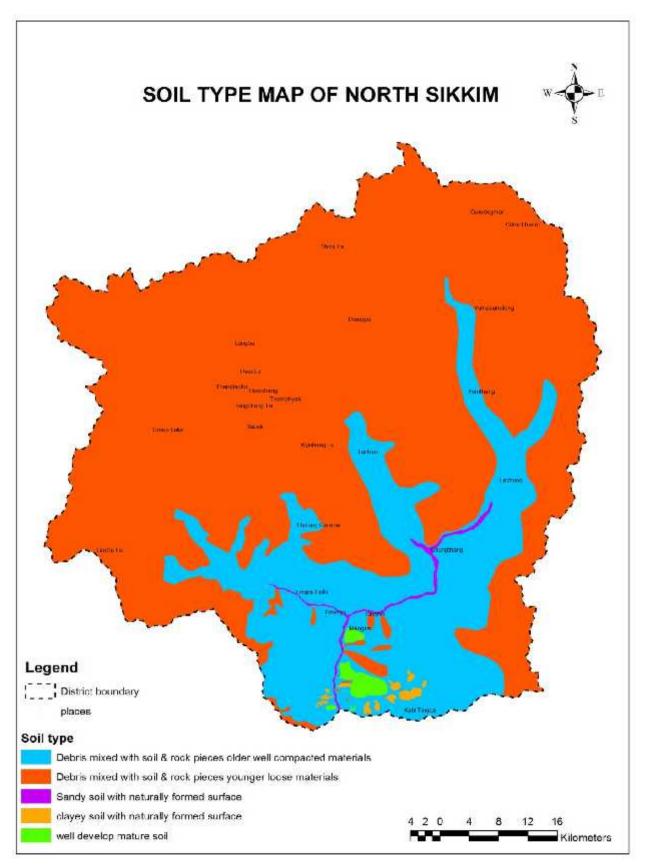
East District of Sikkim being the most populous district has largely populated towns and villages. The capital Gangtok falling in this district has also been mapped under MHRVA in 1: 15000 scales the present assessment of the area gives general idea about the condition of the land in regional sense where in the less vulnerable area to disasters can be selected for infrastructural development programmes and the vulnerable areas to hazards can be mitigated and can be used accordingly furthermore, the limitation to this study is that no detailed analysis of soil and rock by drillings and test in geo technical laboratory were carried out due to limitation of funds etc. Accordingly it is advised to take up rock and soil tests in geo-technical laboratory of the particular site proposed to bring about infrastructural development.

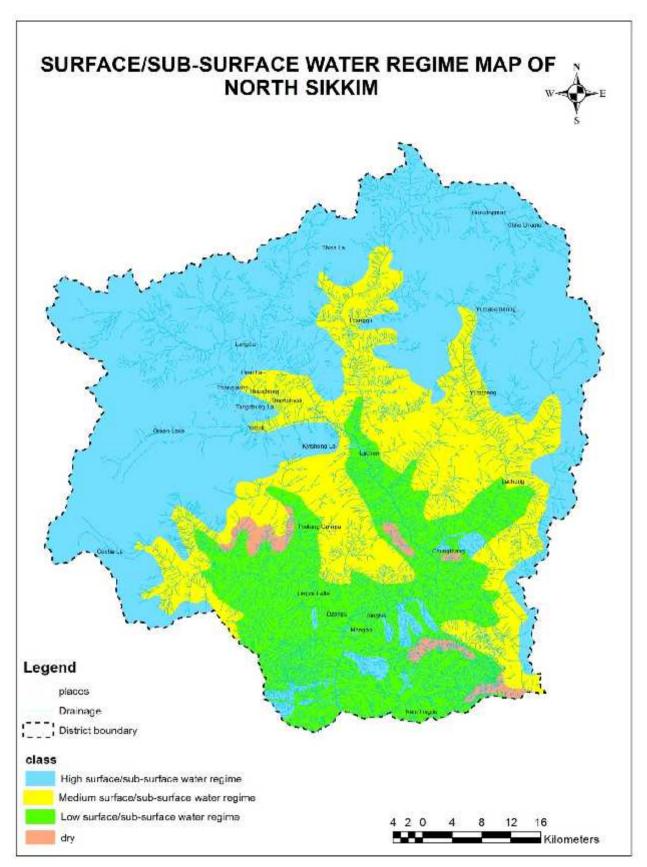
Sikkim State Disaster Management Authority has initiated and carried the Multi Hazard Risk Vulnerability Assessment for city of Gangtok in 1: 2000 Scale this type of assessment needs to be carried out in other major towns or fast growing towns like Singtam, Rangpo, Pakyong and in 1: 5000 Scale in other old and populated towns & villages etc.

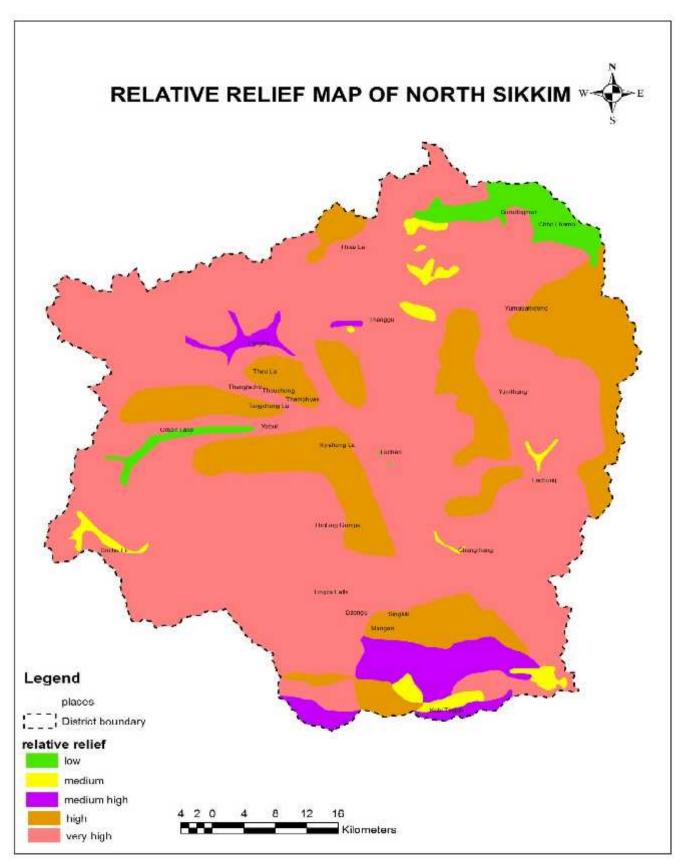


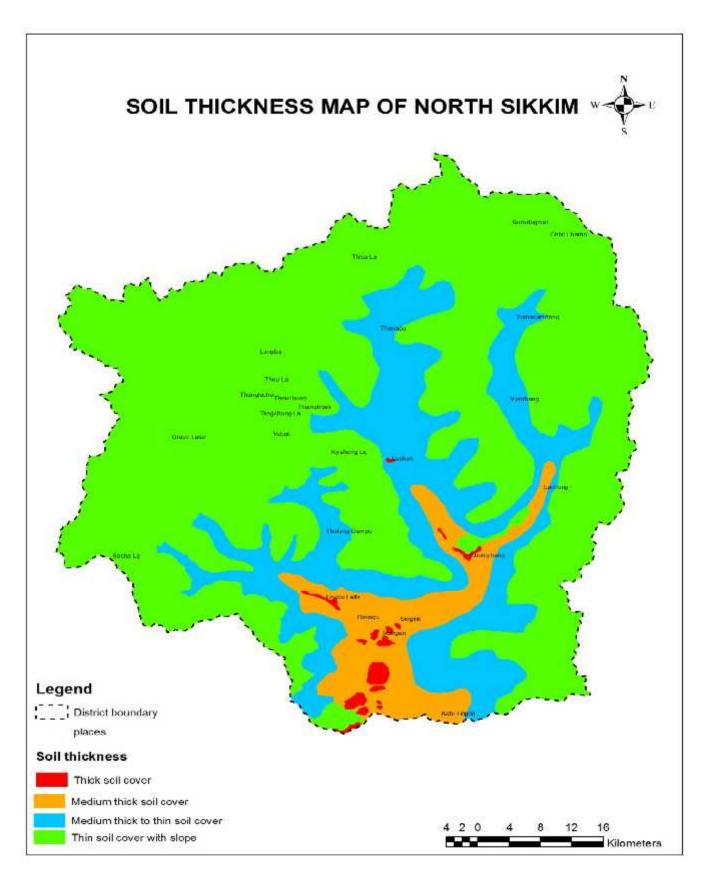




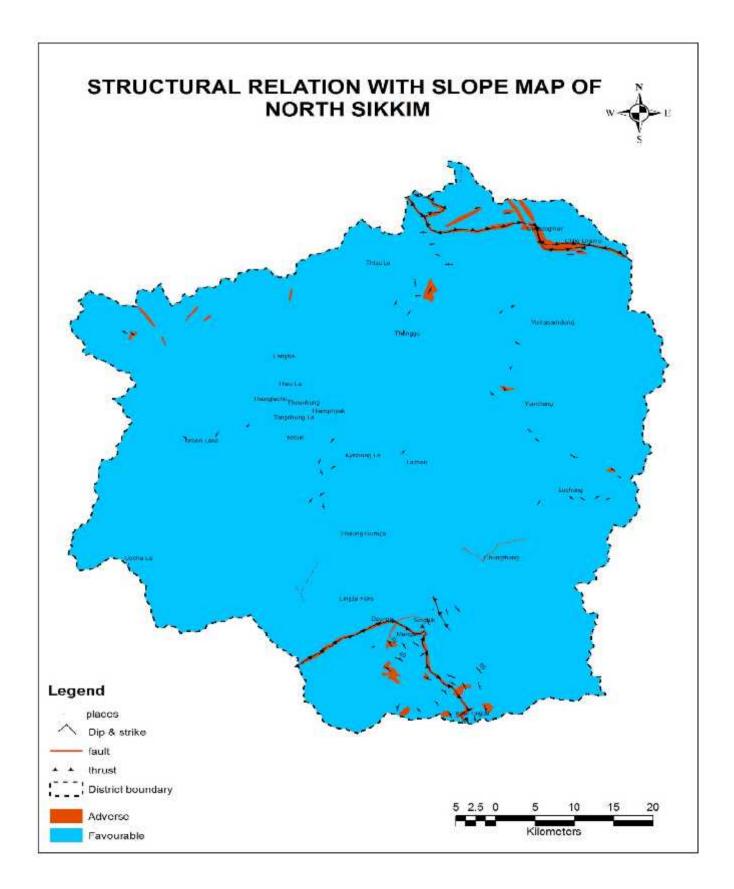


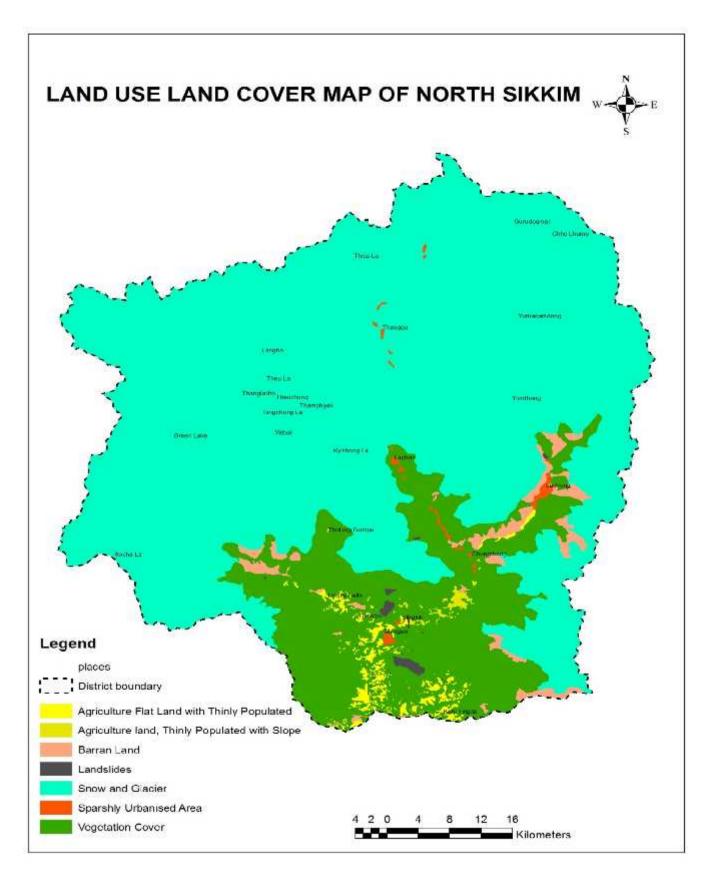


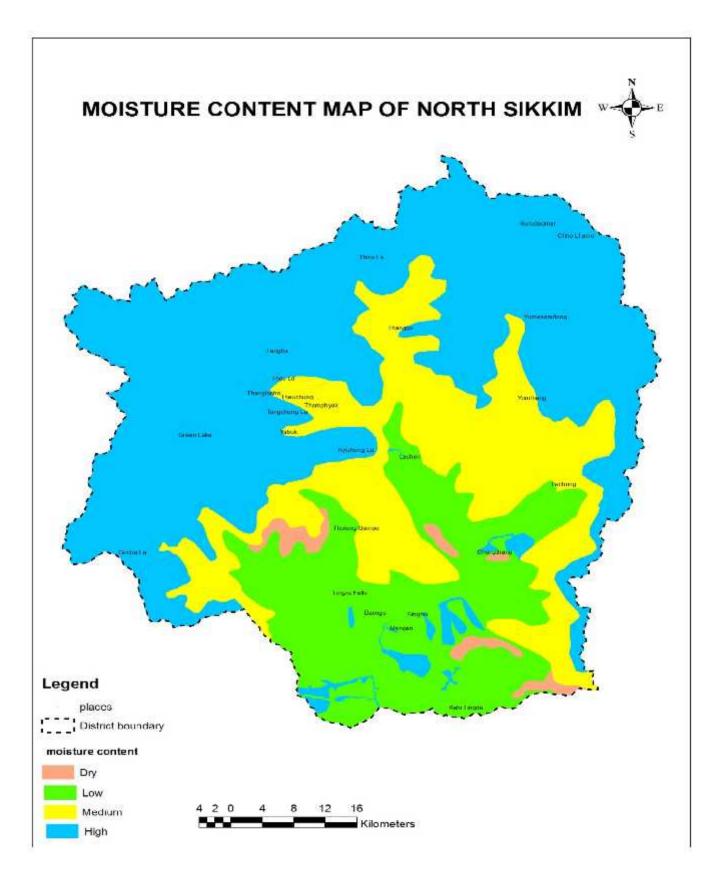


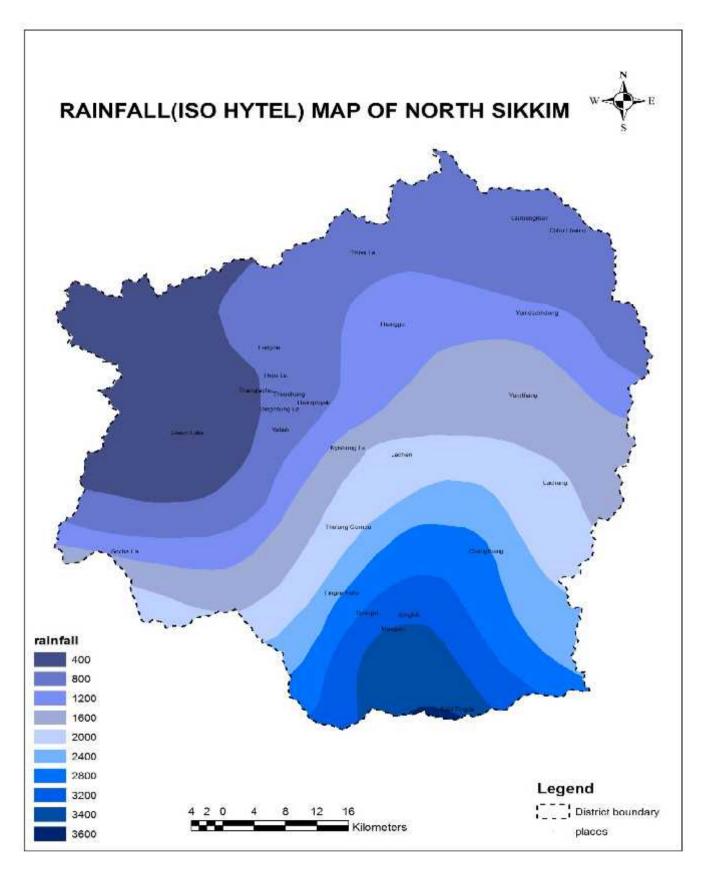


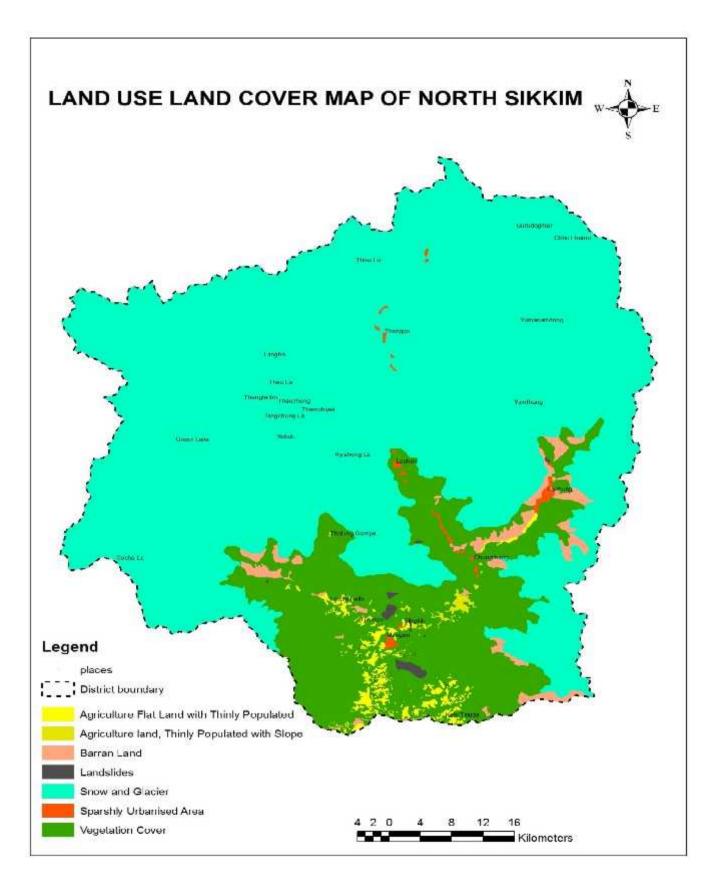


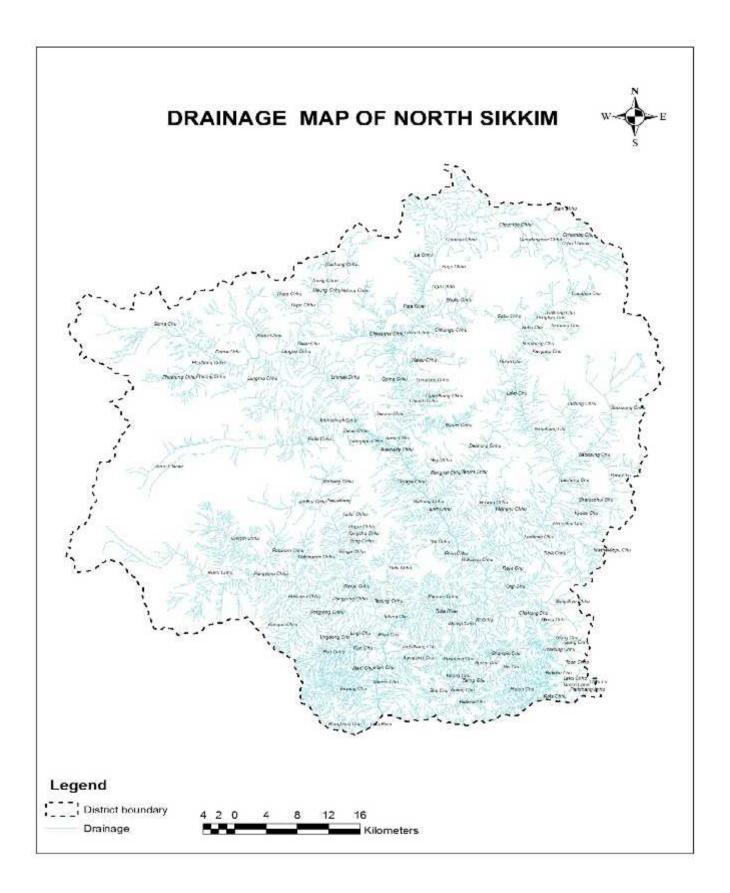


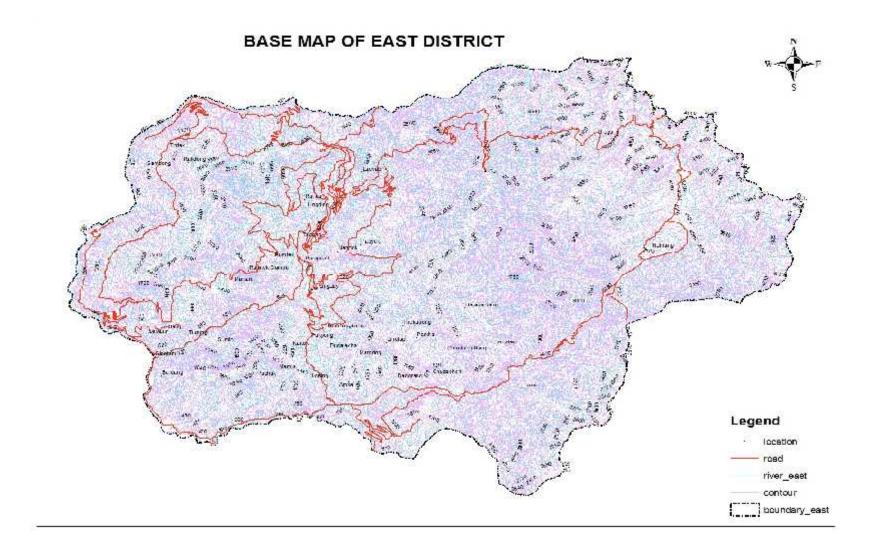


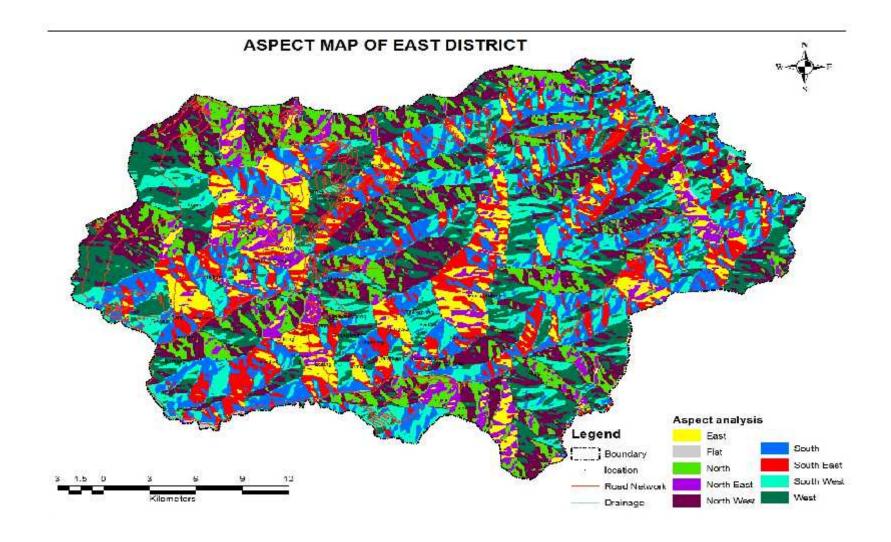


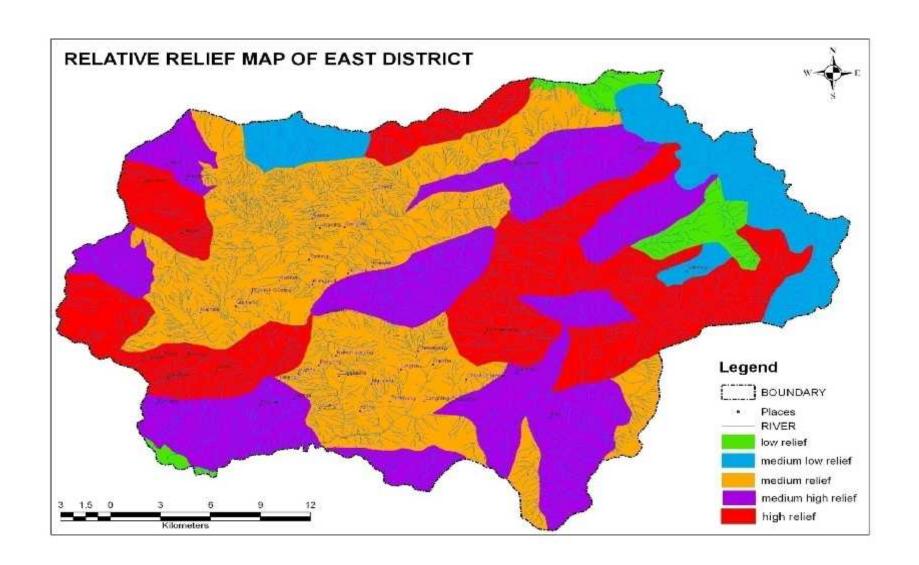


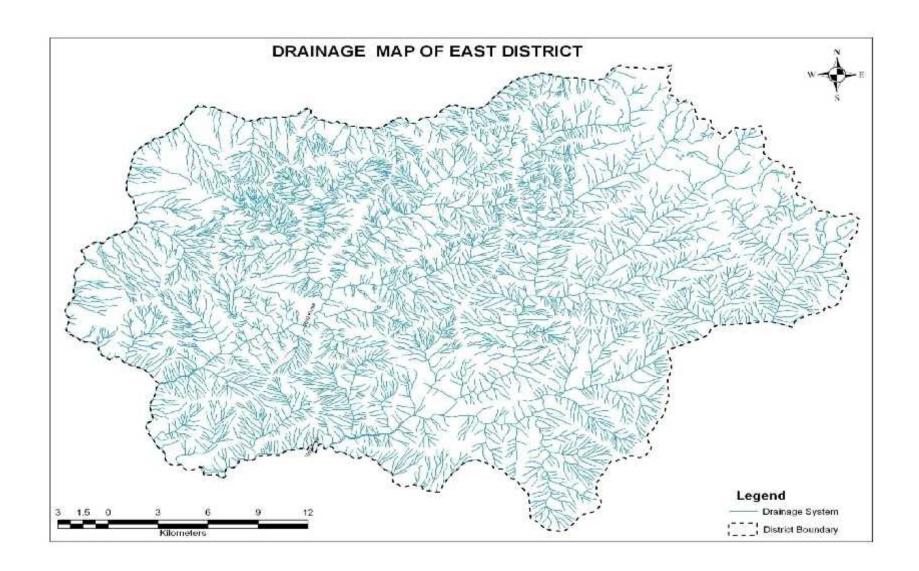


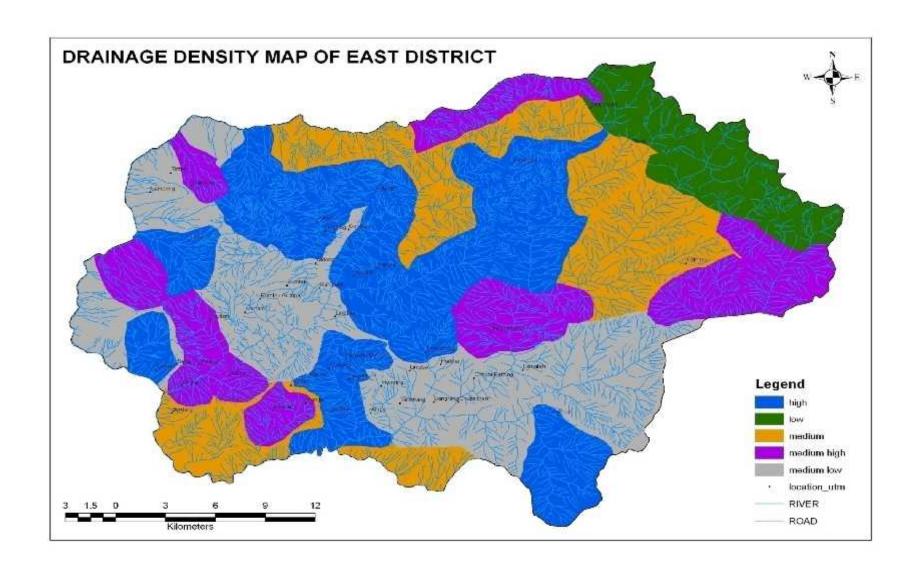


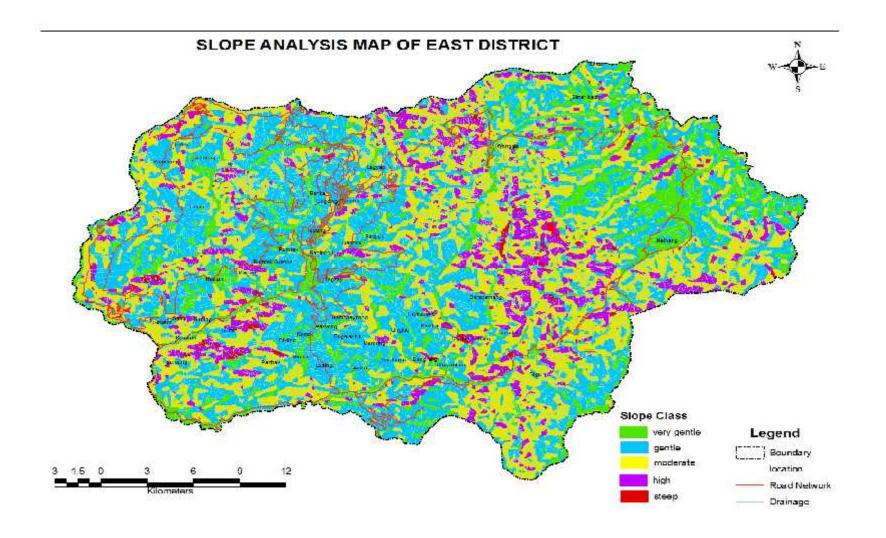


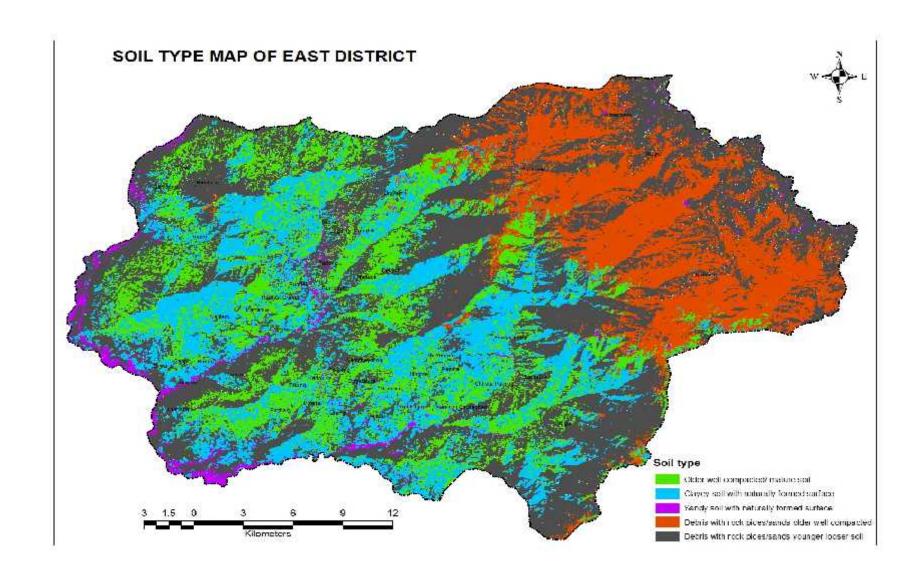


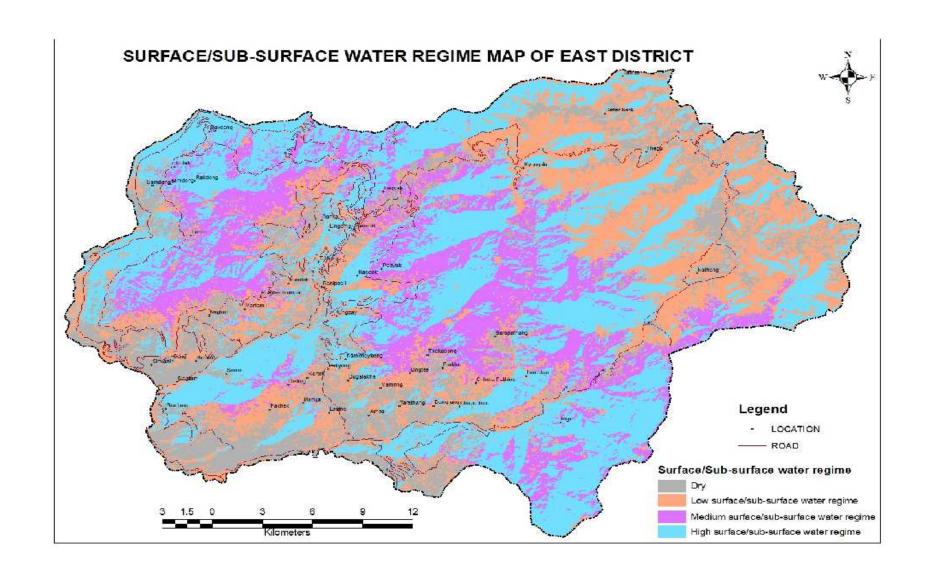


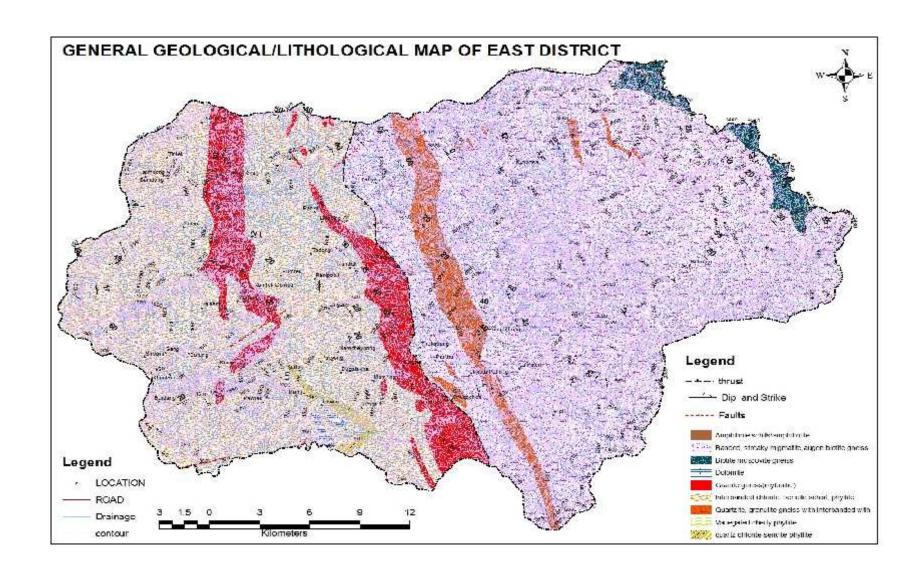


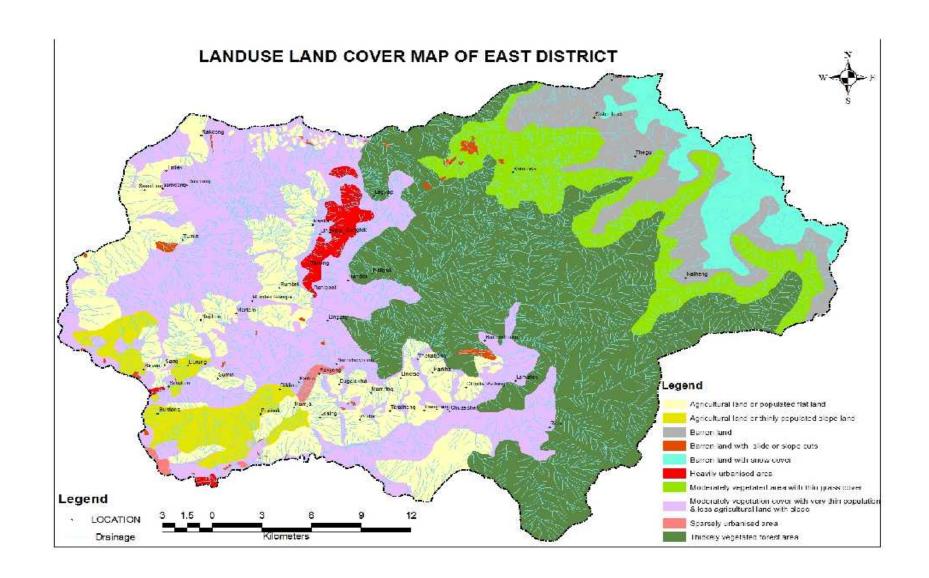


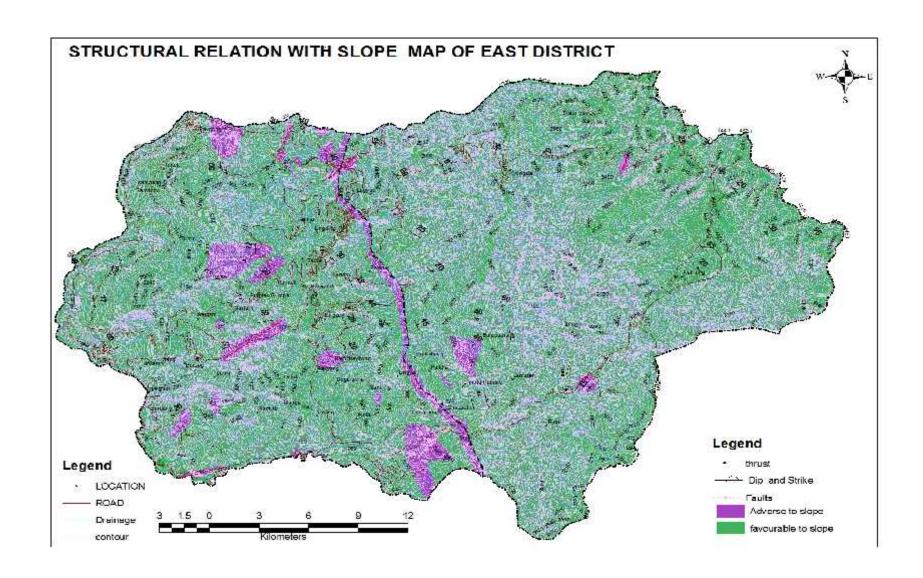


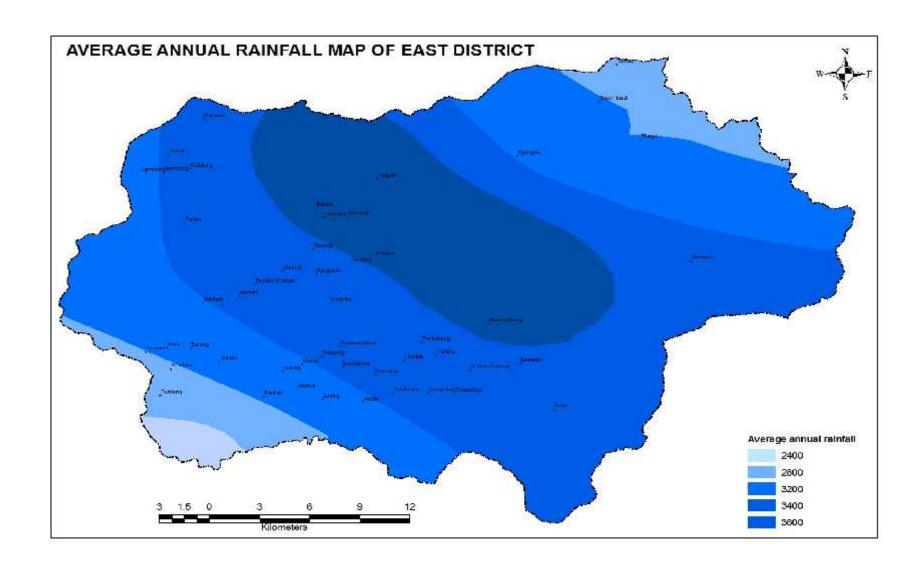


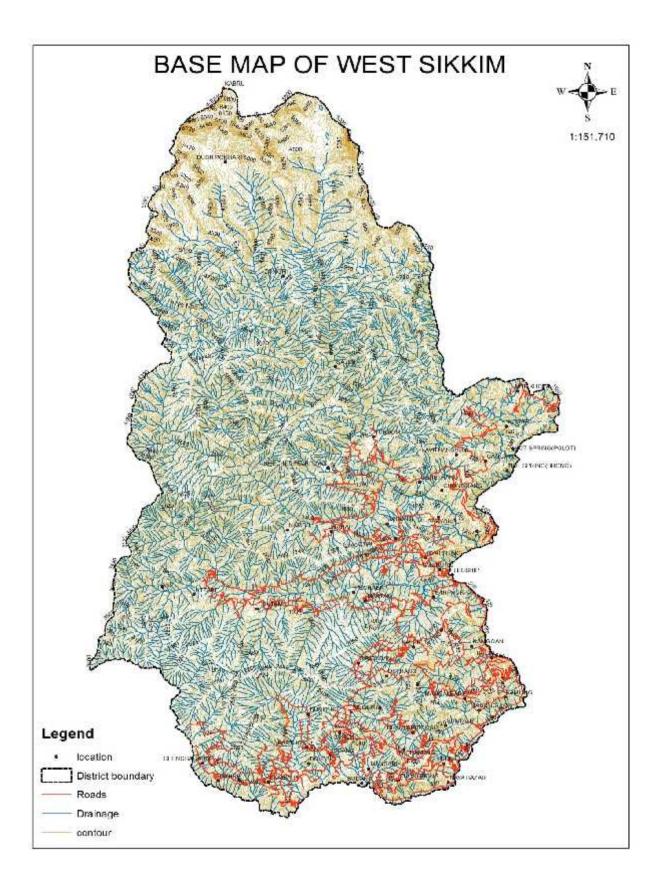


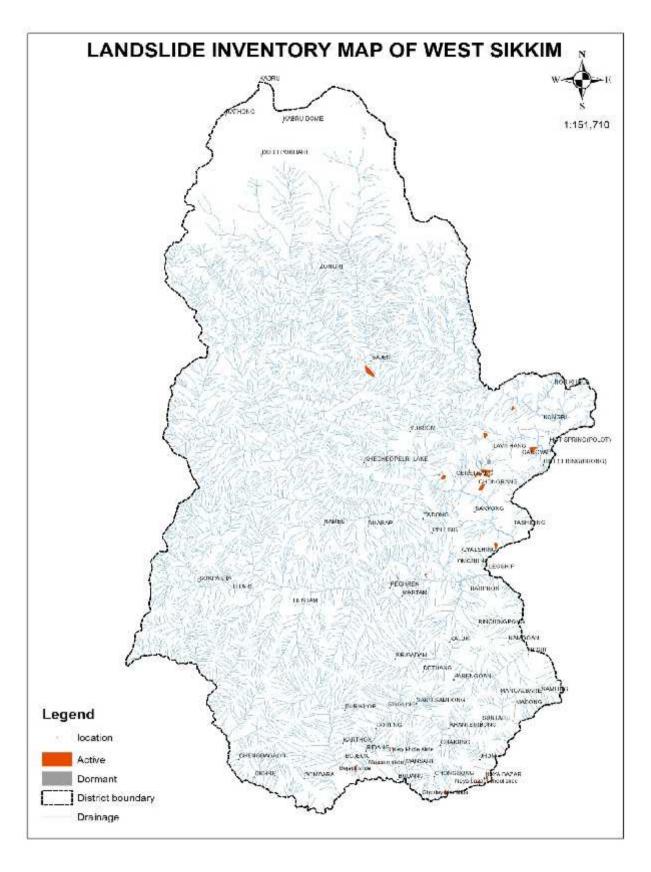


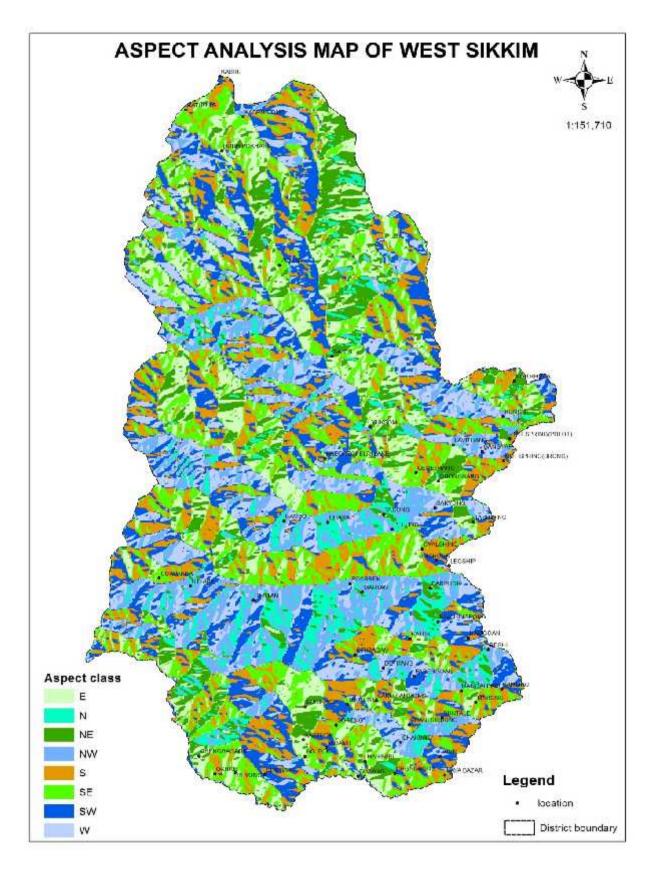


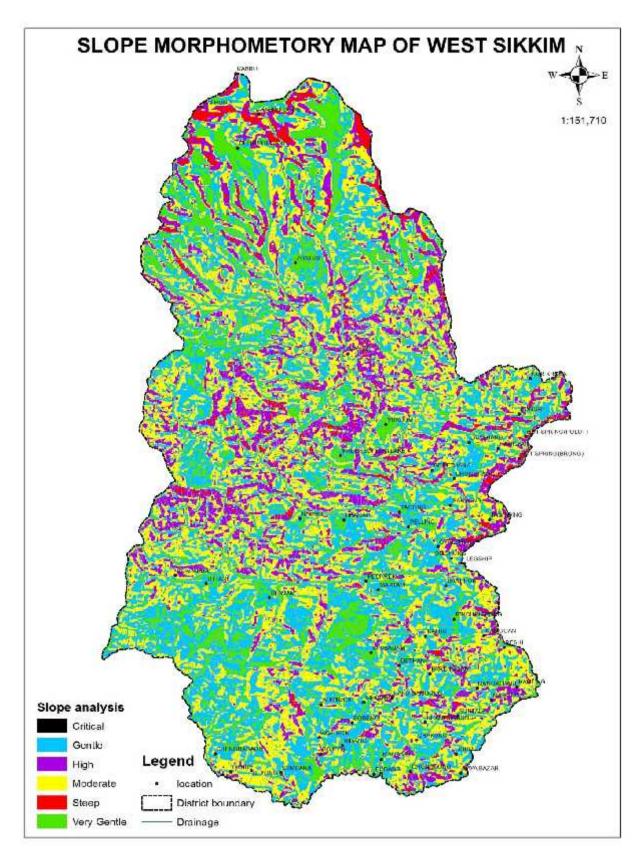


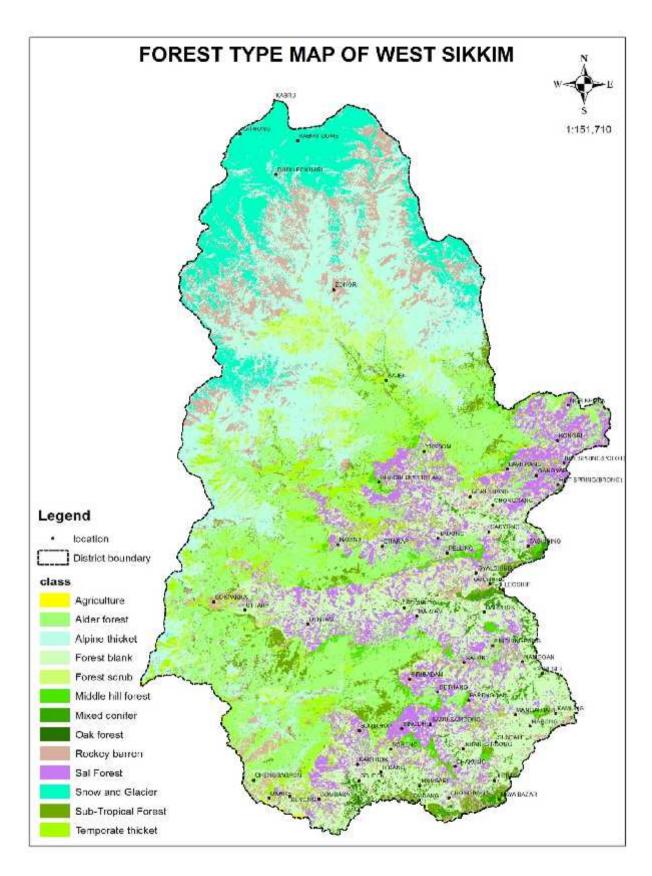


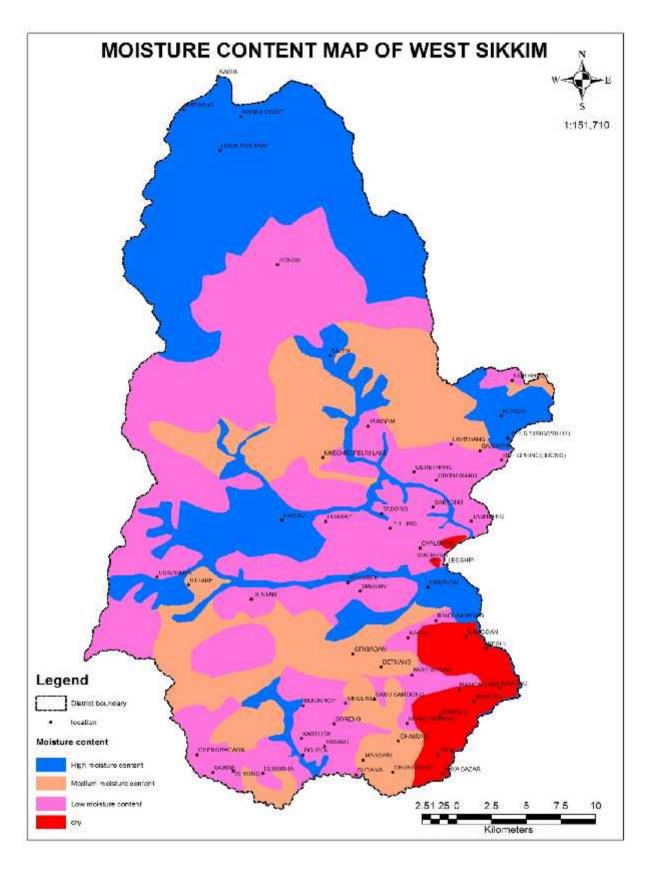


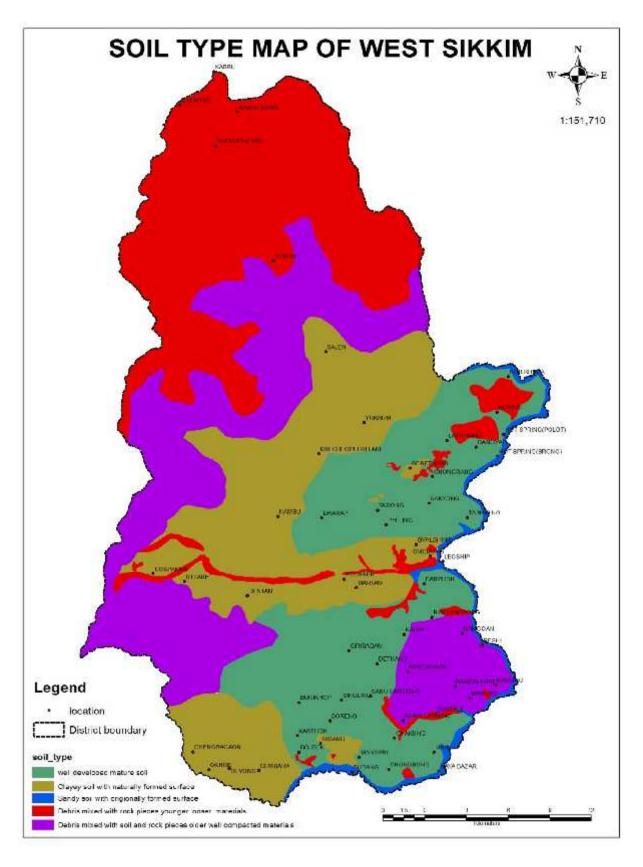


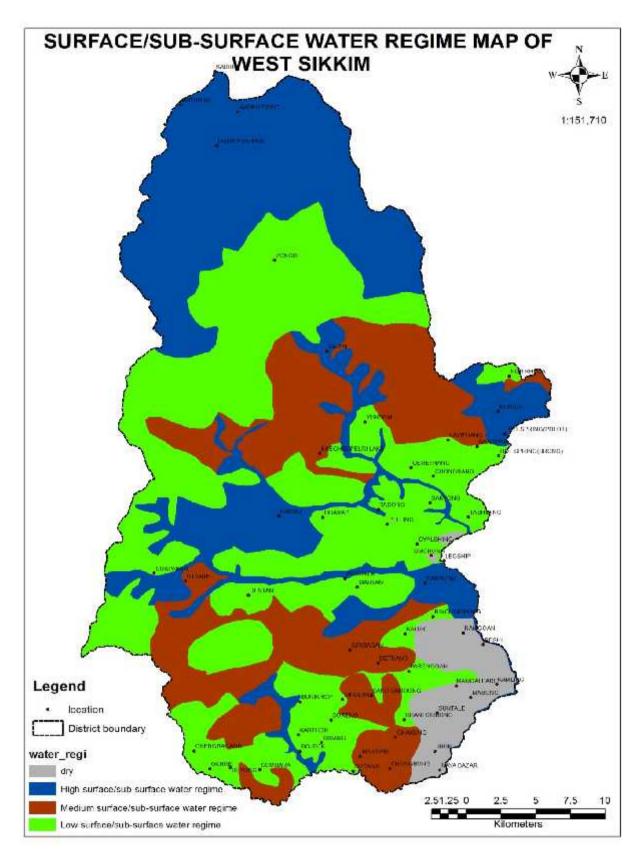


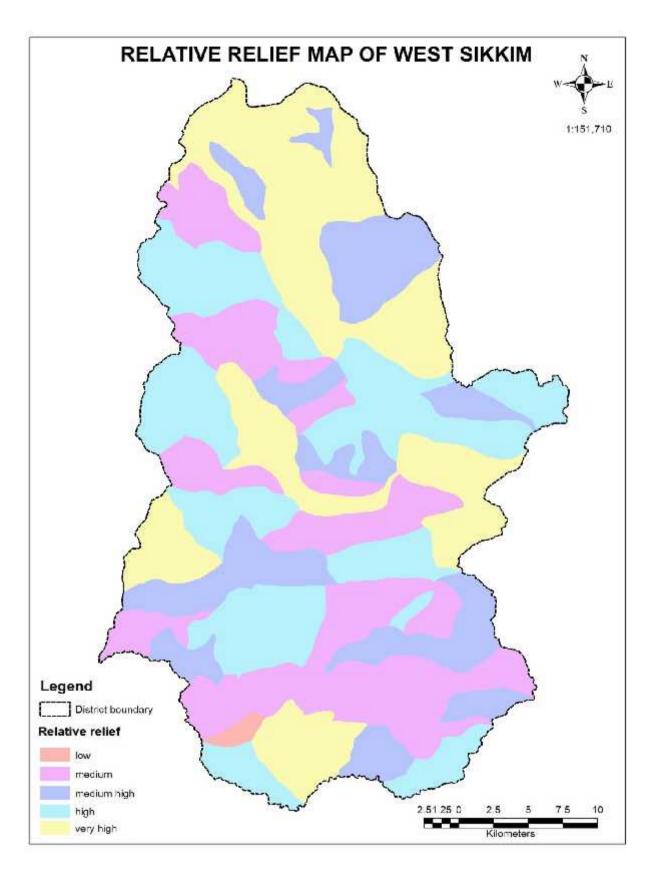


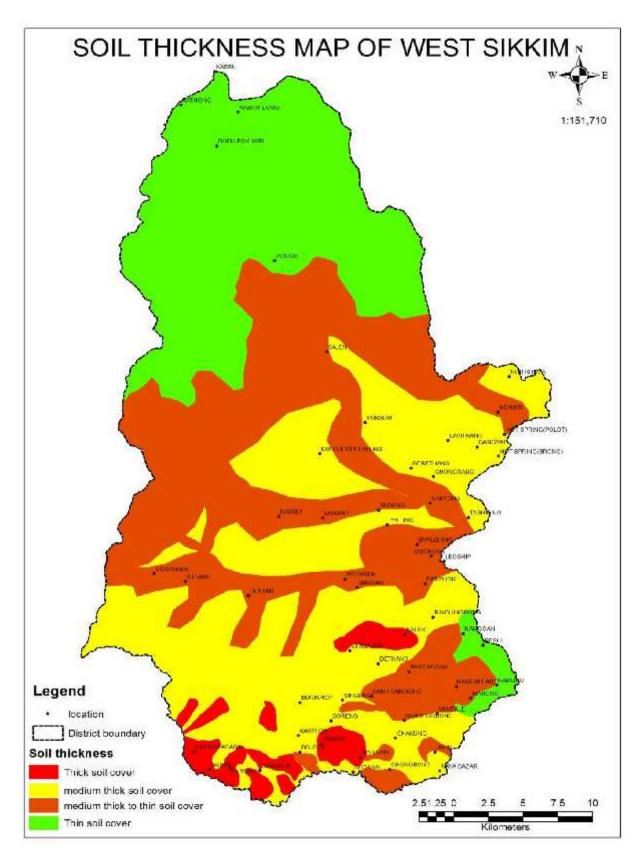


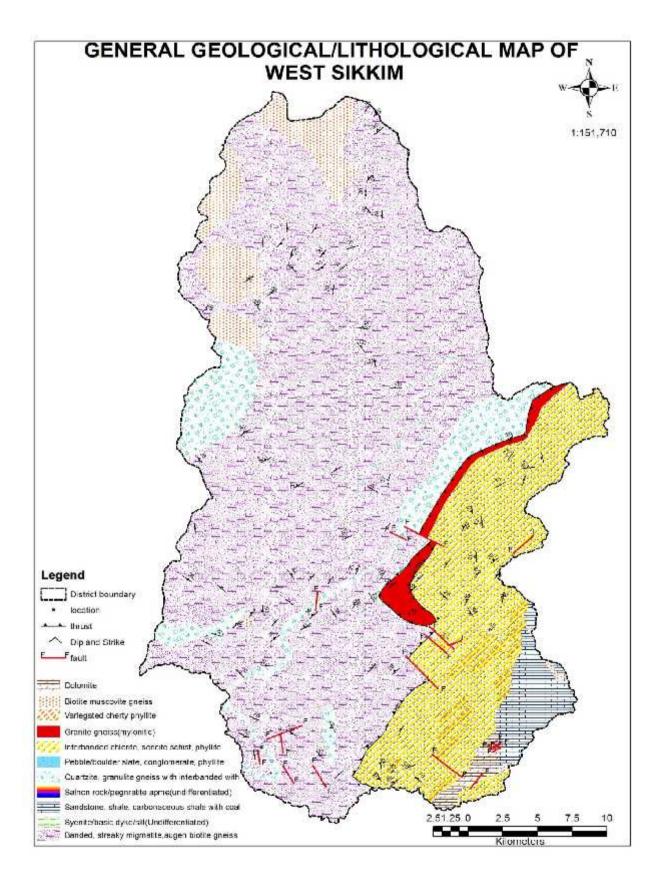


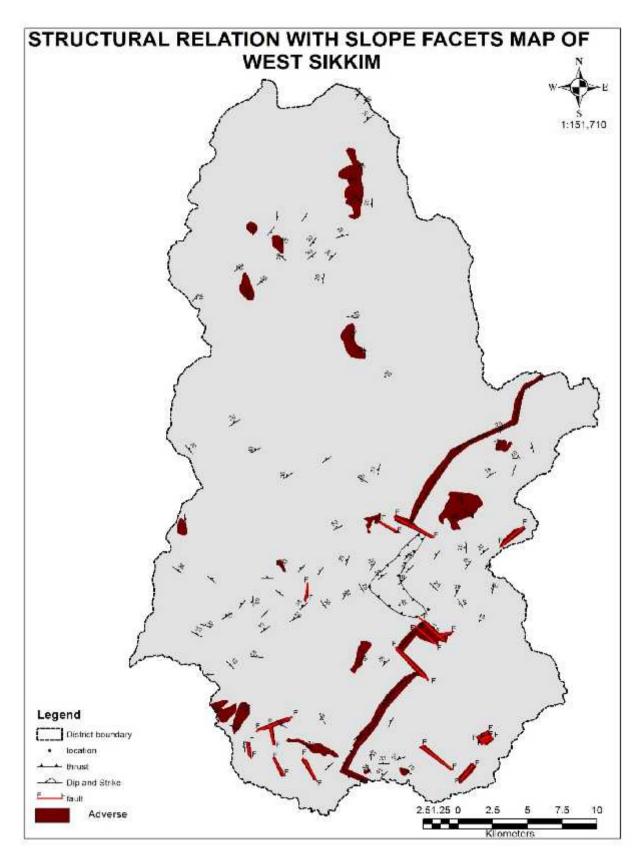


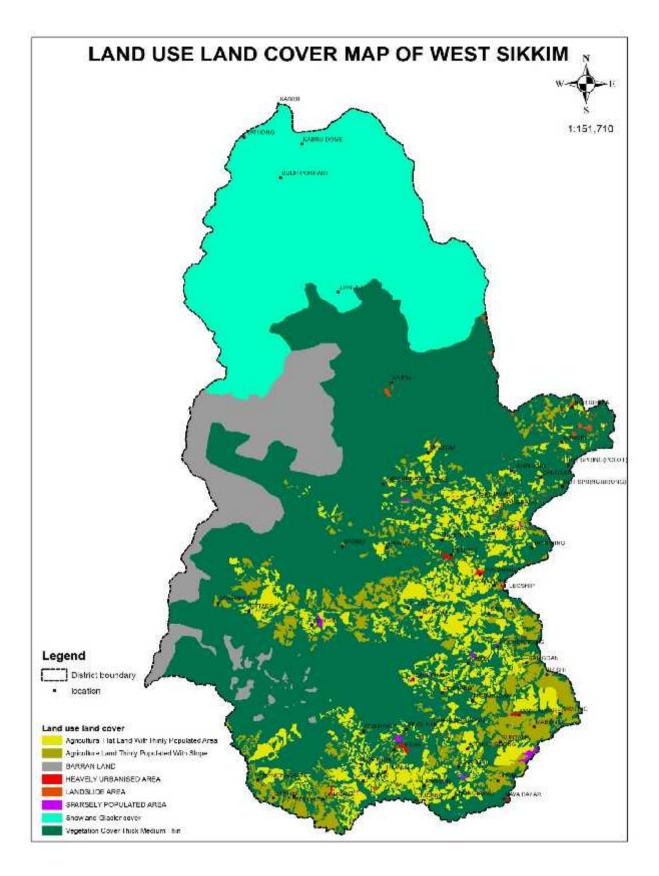


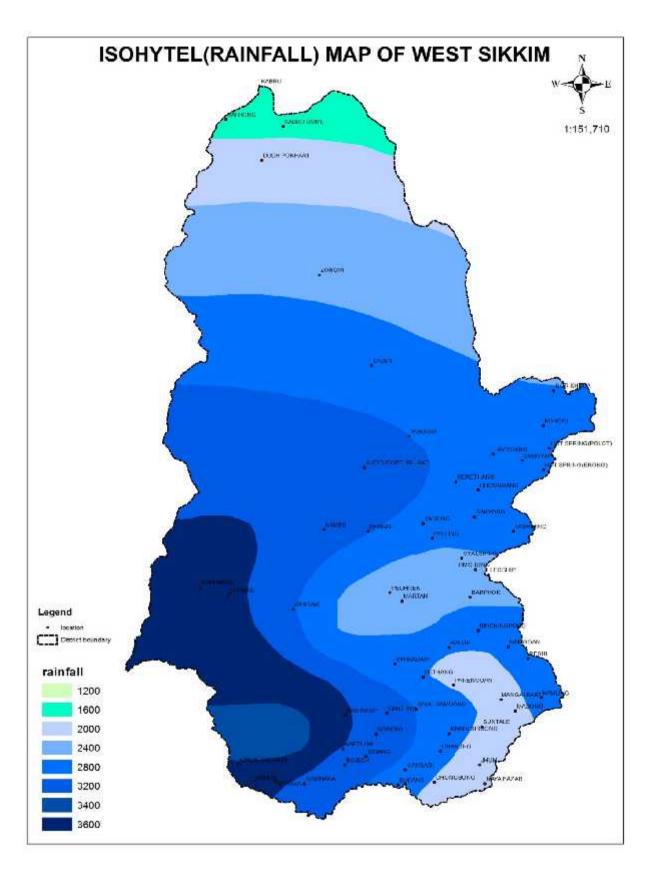


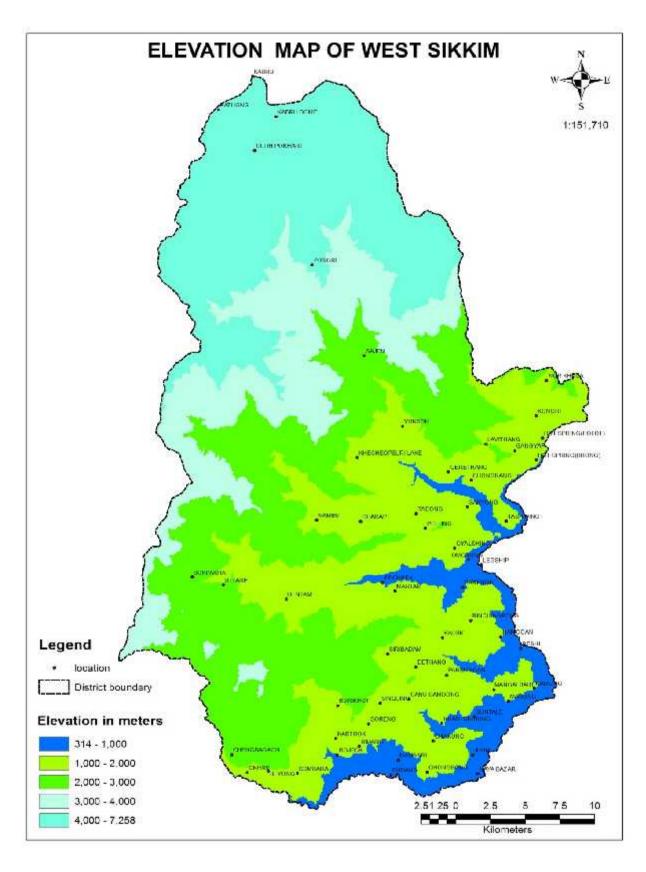


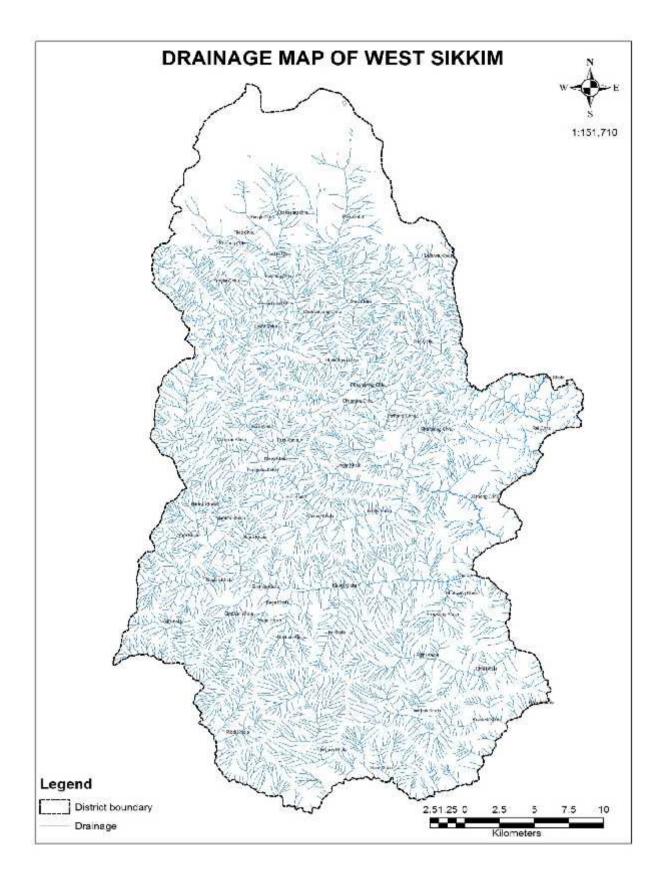


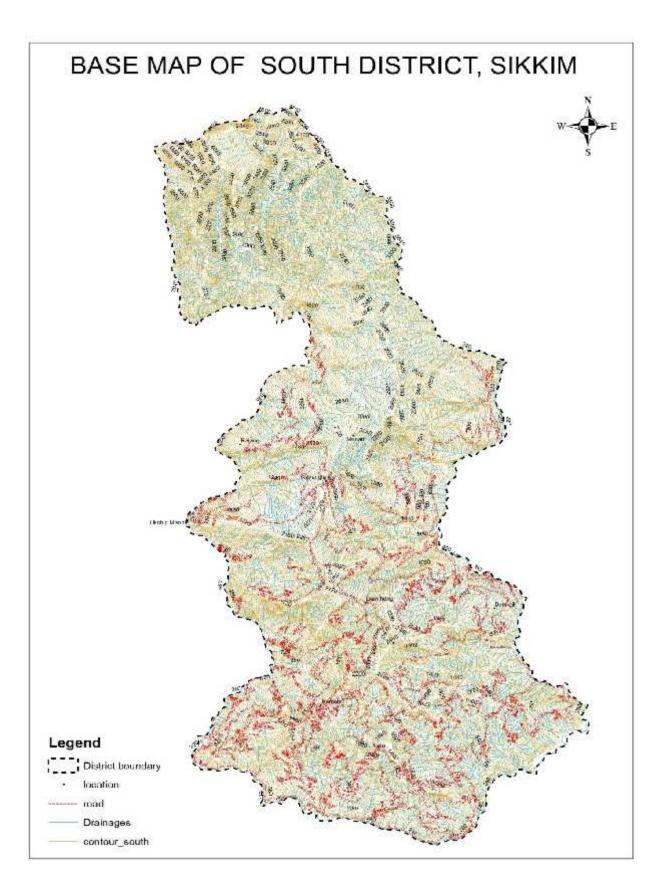


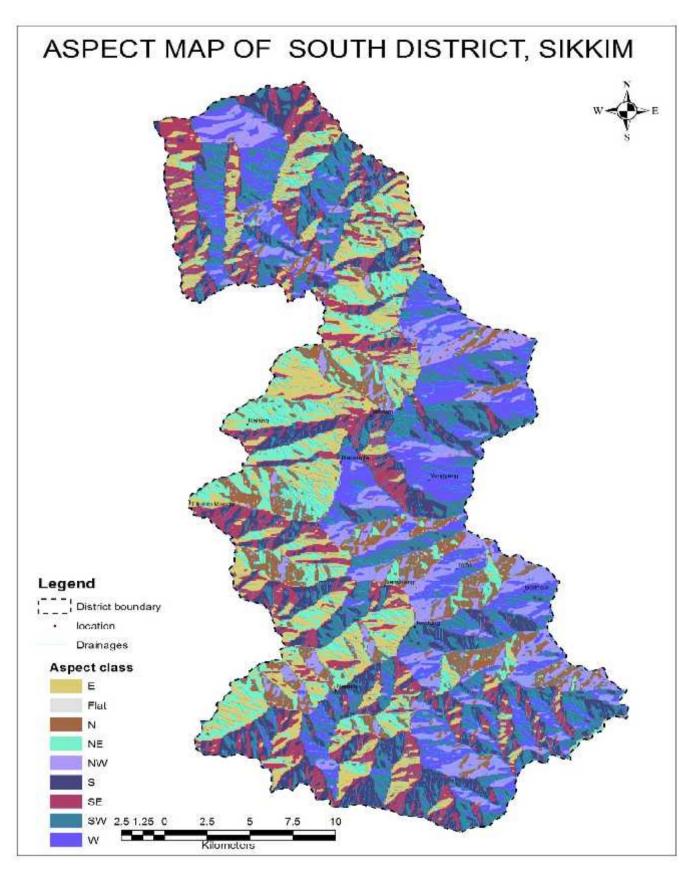


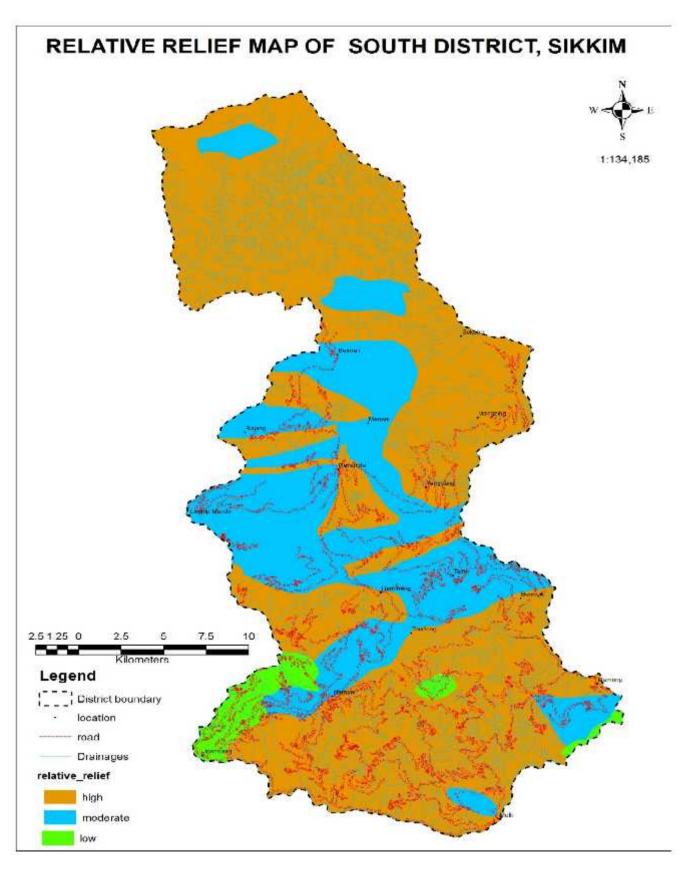


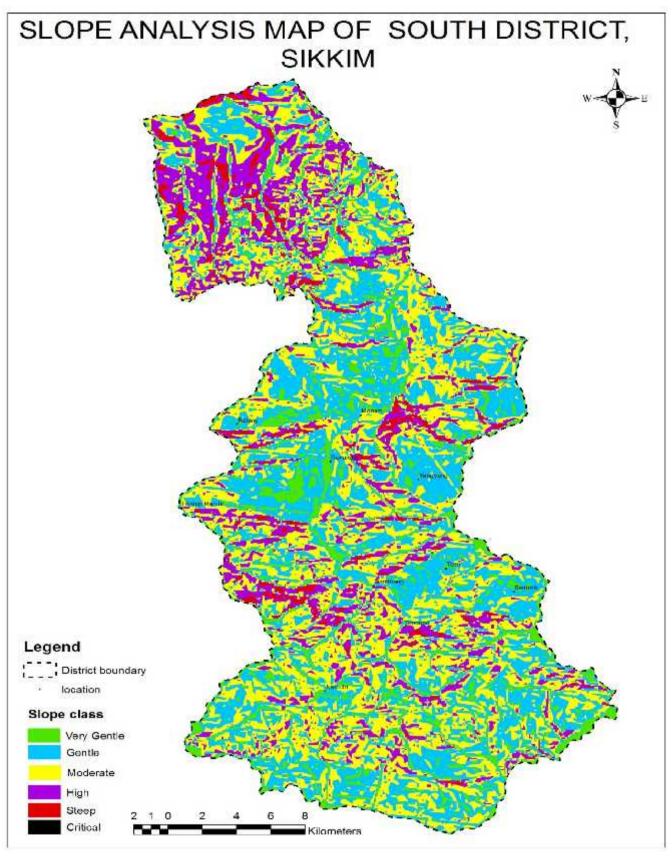


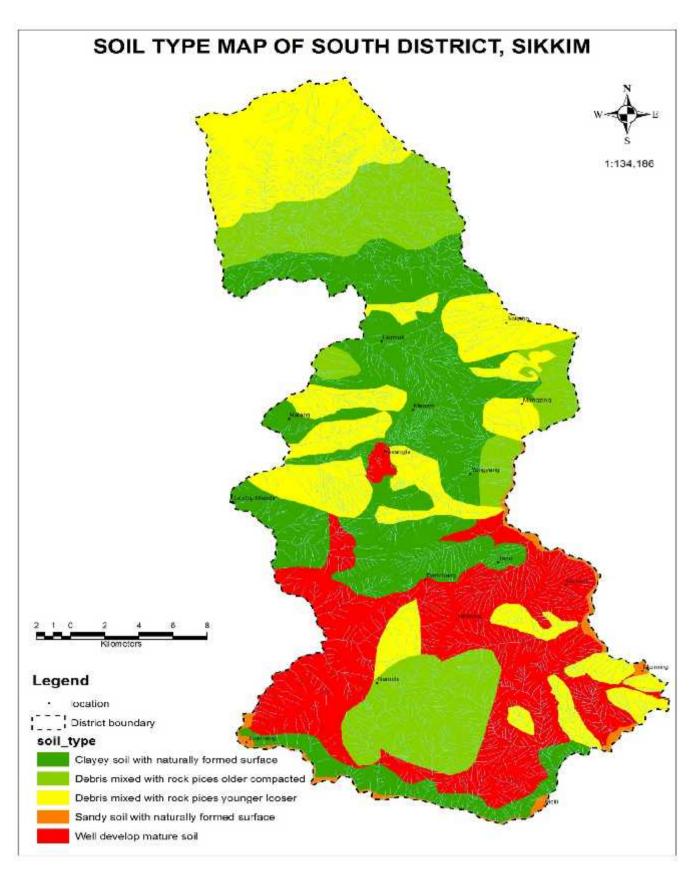


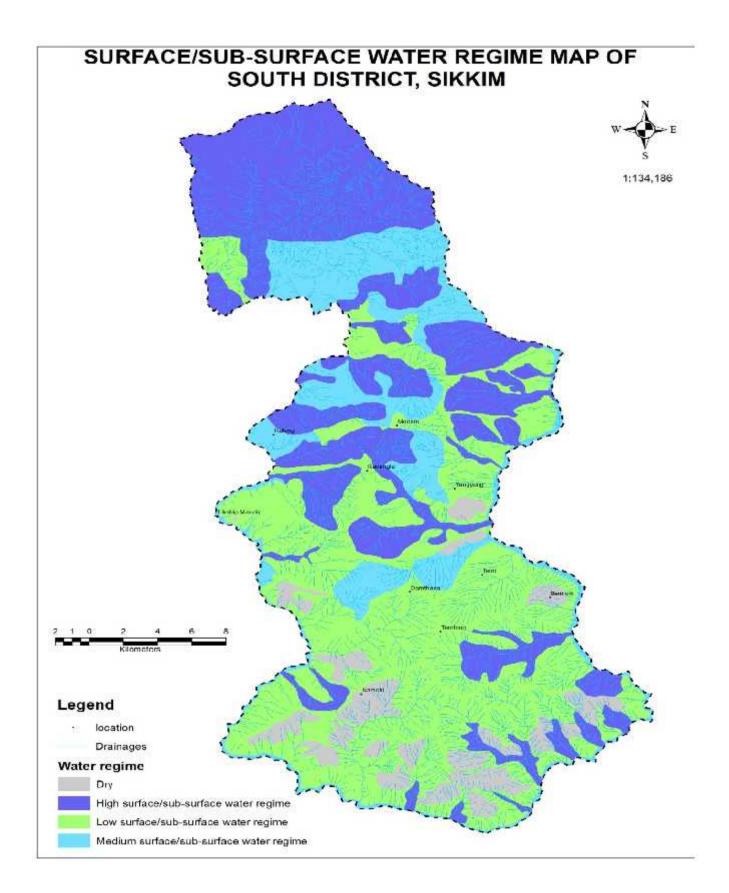


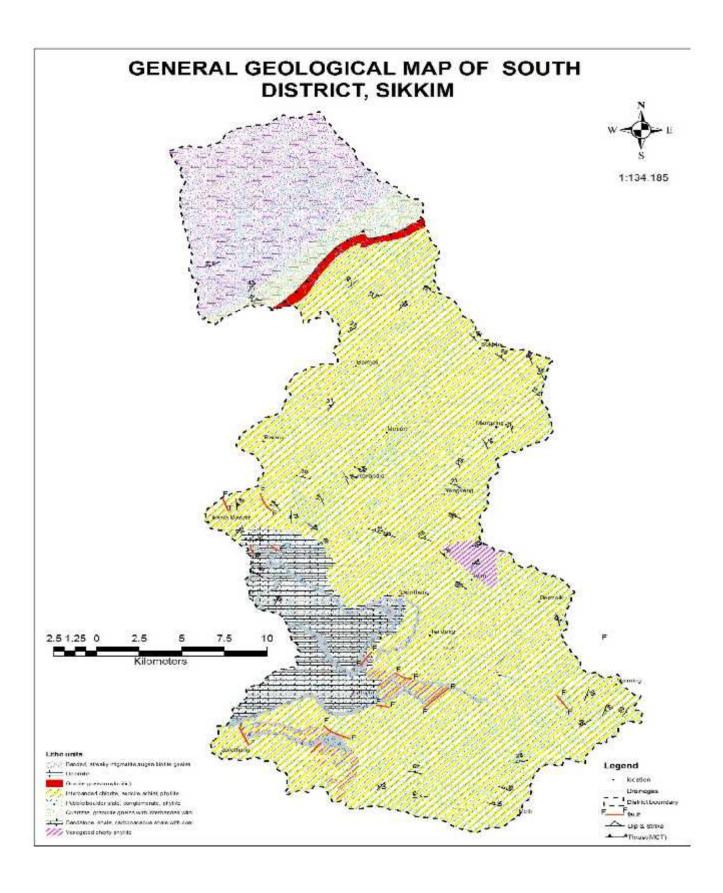


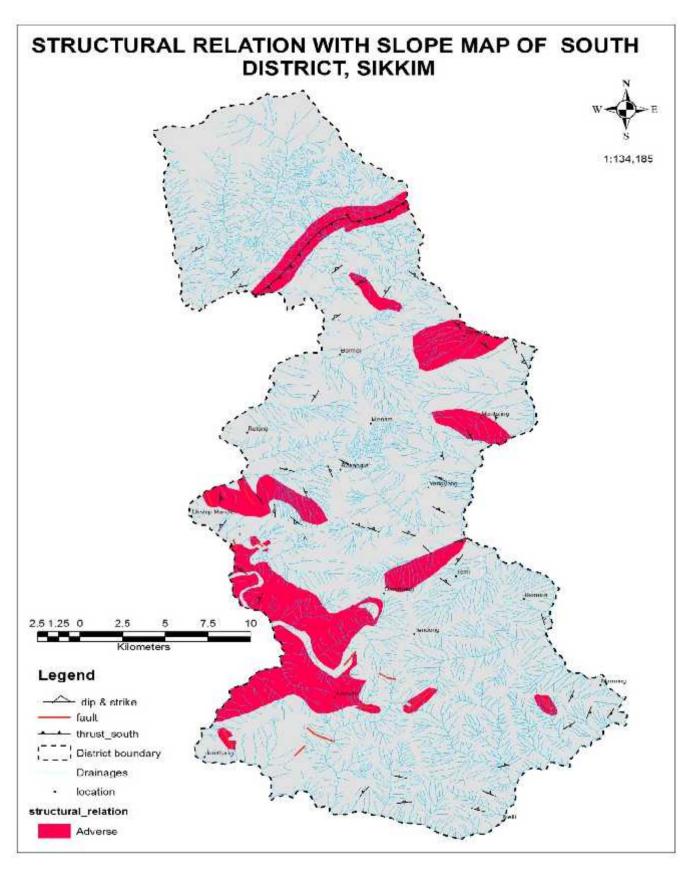


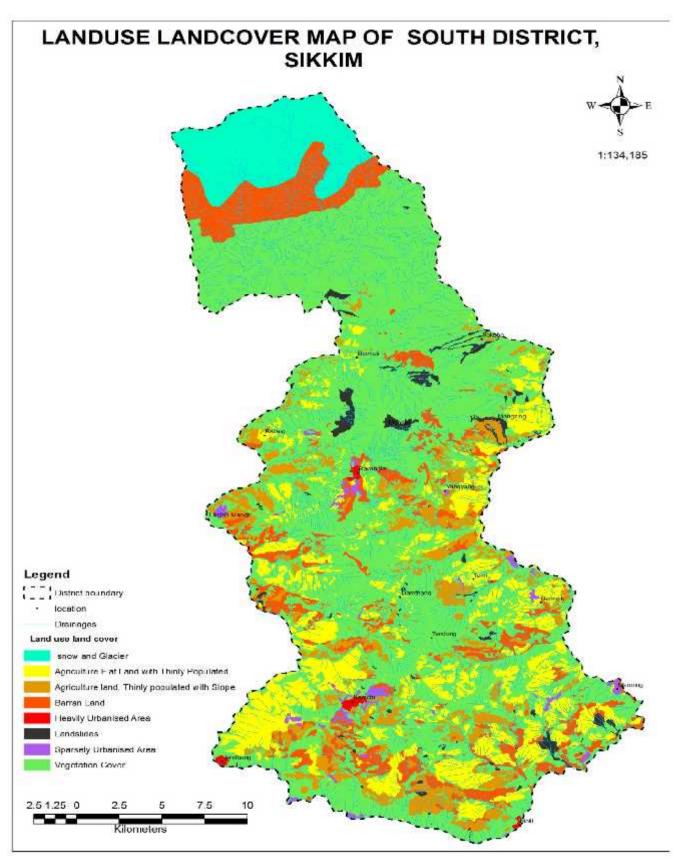


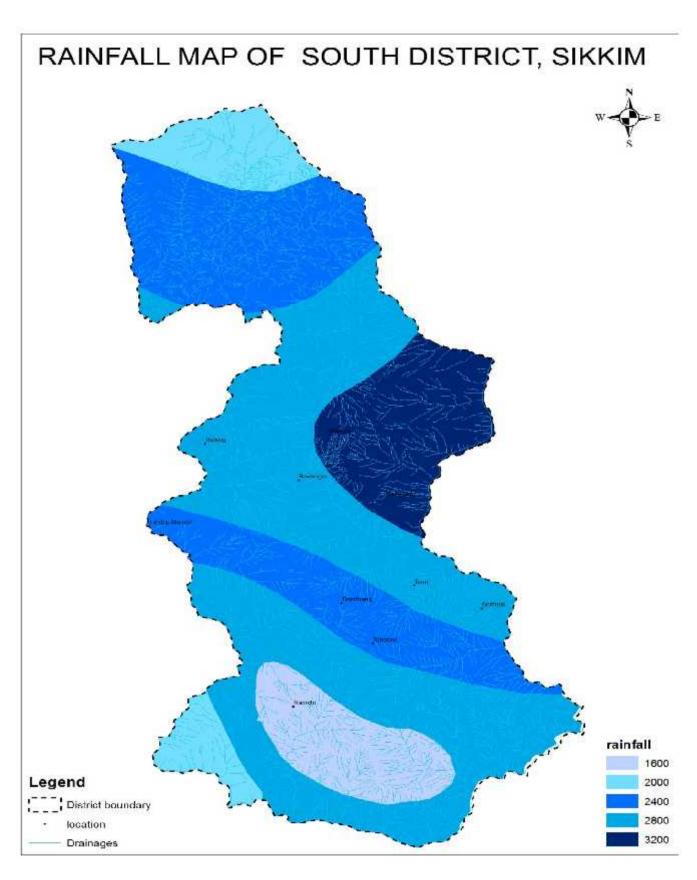


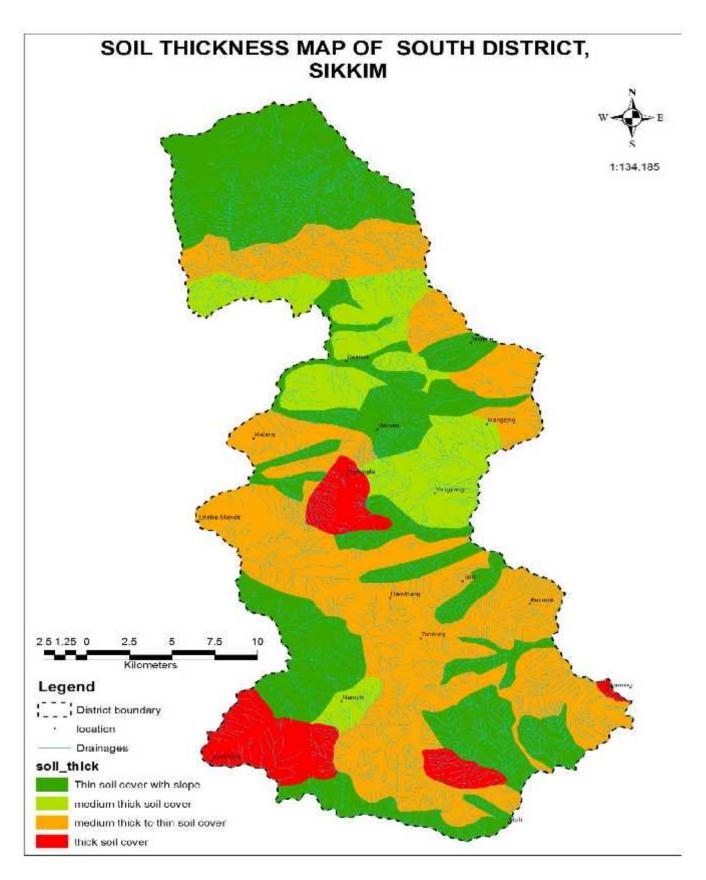


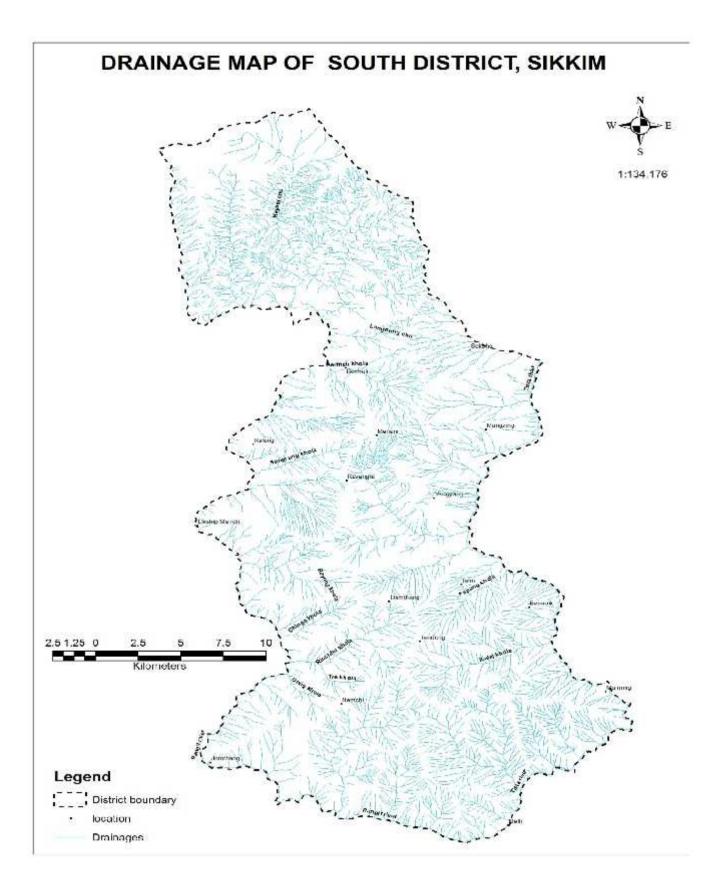












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