CONTENTS

PART FIVE

GIS MAPPING OF LANDSLIDE VULNERABLE AREAS OF EAST SIKKIM

PART SIX

PART SEVEN

PART ONE

Abstract

In the quest for better living, man has been for decades exploiting the non-renewable resources, which many a times is synonymous with the developmental activity. This pursuit is ever increasing with the development of mankind, industrialization, globalization and technological revolutions etc., and the gap between the supply and demand has not been bridged. This development has been at the cost of disturbing the ecosystems of the planet Earth. Certain terrains of the land are highly vulnerable to natural disasters. If we add to natural hazards, the increasing vulnerability caused by human activity, such as industrialization, uncontrolled urbanization, and the deterioration of the environment, we see a dramatic increase in frequency and effects of disasters. Disasters follow a cycle that includes the stage prior to impact, response to the disaster, and reconstruction and rehabilitation activities. The costs of reconstruction consume a major portion of available assets, reduce the resources for new investment, and can delay the development process.

The Himalayas, where we live in, are young lofty mountain chains and is believed to have originated by the continent-to-continent collision in the late Miocene period and the process is still continuing. The architecture of this episodic uplift is known as thrusting. Himalayas are sources of natural resources most important being the renewable hydro power resource. The Himalayas are further the origin of major river systems, which are mainly snow fed. Now, with global warming and with many other reasons, the glaciers, which are the sources of rivers, are retreating. Also a point is to be noted here that the Himalayas are rated to fall under higher zonation on seismicity and landslides. Hence, earthquakes are to make an impact to the environment if it is to strike with higher magnitude.

Therefore, with resources provided by the Himalayas, the natural hazards associated with the mountain chain has to be contended with while initiating developmental activities. For sustainable development, a balance has to be maintained; otherwise, the environmental degradation brought about might outweigh the advantages of developmental activity. To understand about the balance between the development and environmental degradation, one has to understand the problems and hazards scientifically and adopt to manage and mitigate the effects of natural disasters. Sometimes, it is also seen that projects are environment friendly and has proved to be protecting the environment.

Landslide, constitute the major natural hazard which accounts for considerable loss of life, property and damage to communication networks, human settlements, agricultural and forest land in Sikkim. As yet, management of this type of hazard is confined to post disaster relief and rehabilitation and that

too on a temporarily basis. There is an urgent need to take up this hazard to be studied systematically and on priority basis at pre-hazard state.

Sikkim, as we all know, is situated in the Himalayan mountain system. She has been bestowed with natural resources and to take advantage of it depends upon how the human can balance the development and the environment as the development would cost a major stake if environment is not protected. We can tap these resources through proper planning with total scientific reasoning. Sikkim is plagued by various types of mass movement. The triggering factors are invariably excessive water, geological condition, earthquakes, etc. Hence, study and monitoring has become imperative to safeguard against the destruction of the failing slopes.

In brief, human society and the natural environment have become increasingly vulnerable to natural hazards such as earthquakes, landslides, hurricanes, droughts, and flash flooding, etc. The situation is particularly not always occurring in Sikkim, but it is situated in the very high zone in regard to earthquake and high zone with regards to landslides, which is one of the most disaster-prone regions of India according to multi hazard map of UNDP (Map no 03).

As Sikkim's population have been effected by many landslides and earthquakes in the past(Table No 07), this study particularly describes human vulnerability to natural disasters in Sikkim and the case study addresses one of the pioneering efforts of Geographic Information Systems (GIS) applications in human vulnerability due to Landslides. It is becoming increasingly recognized that computer methods such as models and GIS can be valuable tools for analyzing a geographical area in terms of its hazard vulnerability. Certainly, as long as society insists on occupying hazardous land, a good understanding of the risk involved makes sense. The introduction of computerized assessments (in this study using of GIS), which are designed to provide and analyse detailed information about natural disaster patterns and potential Landslides-related impacts and human vulnerability in Sikkim, have become a welcome addition to the State's long-standing battle against nature's fury.

INTRODUCTION

The Himalayas are known to be young-fold mountains, because these have been formed relatively recently in the earth's history, compared to the older mountain rangers like the Aravallis in India and the Appalachian in the USA. They are known as Fold Mountains because the mountains extend for 2500 km in length in a series of parallel ridges or folds.

The accepted theory about the formation of the Himalayas started to take shape in the year 1912 when German meteorologist Alfred Wegener developed his Theory of Continental Drift. The theory picks up the story about 250 million years ago, during which time, all the earth's land was a single super continent called Pangea surrounded by a large ocean.

Around 200 million years ago (also known as the Middle Permian Period), an extensive sea named Tethys stretched along the latitudinal area presently occupied by the Himalayas. Around this period, the super continent Pangea began to gradually split into different land masses and move apart in different directions. Resultantly, rivers from both the northern Eurasian land mass called Angara and the southern Indian land mass called Gondwana started depositing large amounts of sediments into the shallow sea i.e., Tethys. The two landmasses, the Eurasian and the Gondwana moved closer and closer and during the Upper Cretaceous period around 70 million years ago, these two land masses began to collide with each other. As a result, the already shallow Tethys seabed rapidly folded raised into longitudinal ridges and valleys.

During the Upper Eocene Period, about 65 million years ago, the bed of the Tethys started rising again, the sea retreated, and the seabed was elevated into high mountain ranges. This was the second phase of mountain building. Later, about 25 million years ago during the Middle Miocene period, another phase of mountain building took place, which led to the formation of the low Shivalik ranges.

The periodic process of mountain building is an ongoing-continuous process. Although the major upheaval of the Himalayas has passed, yet the Himalayas are still rising. The Indian plate is continuously moving north at the rate of about 2 cm/year, as a result the Himalayas are rising at the rate of 5 mm/year. This indicates that the Himalayas are still geologically active and structurally unstable characterized by the frequent occurrence of earthquakes in the entire Himalayan region. The detection of movement of the plates and uplifting of the Himalayas is, thus, explained by the Continental Drift Theory and is measured by the modern technology called Global Positioning System (GPS).

Due to such movements, various kinds of tectonic activities are ongoing processes. The Himalayan Stratigraphical Sequence is folded, faulted and thrusted due to which the normal stratigraphy is reversed. Himalayas are, thus, vulnerable to both natural and man-made processes. Apart from the natural processes, man has been responsible, to a large extent, for some of the environmental problems faced by the mountains. The strive for modernization, industrialization, globalization and the so-called higher standard of living, has distributed the fragile ecosystem of the Himalayas into many parts. Human exploration in terms of development of tourism, intricate network of roads, hydro power projects, urbanization, infrastructural development etc., needs to be executed in an environmental friendly and systemic manner.

Natural Disasters Overview in context to India and World

In the 1970s and the 80s, droughts and famines were the biggest killers in India, the situation stands altered today. It is probably a combination of factors like better reservoir management and food security measures that has greatly reduced the deaths caused by droughts and famines. Floods, high winds and earthquakes dominate (98%) the reported injuries, with ever increasing numbers in the last ten years. The period from 1973 to 1997 has been associated with a large number of earthquakes in Asia, which have a relatively high injury- to death ratio.

Floods, droughts, cyclones, earthquakes, landslides and avalanches are some of the major natural disasters that repeatedly and increasingly affect India. (World Disasters Report-1999, International Federation of Red Cross and Red Crescent Societies) in the last two decades, over 3 million people have been killed in natural disasters worldwide. According to statistical evidence, there have been three times as many losses resulting from disaster events in the past ten years than was the case in the 1960s. As a consequence, economic losses have been nine times greater during this decade, currently exceeding US $90 billion a year. In 1998 alone, natural calamities claimed the lives of more than 50,000 people worldwide (Extracted from CRED 2000). In many parts of the world, disasters caused by natural hazards such as earthquakes, floods, landslides, flash floods, drought, wildfires, tropical cyclones, tsunami and associated storm surges, and volcanic eruptions have exacted a heavy toll in terms of the loss of human lives and the destruction of economic and social infrastructure, not to mention their negative impact on already fragile ecosystems. Indeed, the period between 1960 and 2007, witnessed an exponential increase in the occurrence, severity and intensity of disasters, especially during the 1990s. This trend poses a major threat to the planet and therefore, needs to be addressed by the state, national, international community with a sense of urgency. While natural hazards will continue to occur, human action can either increase or reduce the vulnerability of societies to these hazards and related technological and environmental disasters by focusing on socio-economic factors determining such vulnerability. For example, population growth as well as changing demographic and economic patterns, which have led to uncontrolled urbanization, together with widespread poverty has forced large numbers of people to live in disaster-prone areas and sub-optimal shelters, thus increasing vulnerability. On the other hand, there is considerable scope for the reduction of risk through the application of disaster prevention and mitigation efforts based, for instance, on modern forecasting technology in terms of the development of early warning systems as well as improved land use settlements plans and building practices, provided that societies ensure the application of these practices in a manner consistent with the needs of sustainable development.

Sikkim is among the India's most vulnerable regions to both natural and human-made disasters since it is situated in the very high zone in regard to earthquake and high zone with regards to landslides, according to multi hazard map of UNDP (Map no 03) not only that Sikkim is one of the developing state. A tough mesh of rampant and unplanned urbanization is coming up in the state; unsafe buildings compound the risks. The four seasons arrive and depart in tandem with four major kinds of natural disasters: windstorm accompanied by heavy rainfall, earthquakes, landslides, flash floods and hailstorm. Other catastrophic events such as avalanches, blizzards, cold wave and fires occur less frequently and threaten fewer people. We know that human communities will always have to face natural hazards, whether windstorm, landslides, flash floods, hailstorms or earthquakes. But today's disasters owe as much too human activities as to the forces of nature. Indeed, the term natural is an increasingly misleading.

What we have witnessed over the past decades, however, is not nature's variation but a clear upward trend caused by human activities. There were three times as many great natural disasters in the 1990s as in the 1960s, while disaster costs increased more than nine fold in the same period. The facts are startling. The costs of weather-related disasters in 1998 exceeded the costs of all such disasters in the decade of the 1980s. Tens of thousands of mostly poor people died during the year, tens of millions have been temporarily or permanently displaced. We know why the trend is upward. Ninety per cent of disaster victims worldwide live in developing countries, where poverty and population pressures force growing numbers of poor people to live in harm's way- on flood plains, in earthquake-prone zones and on unstable hillsides. The vulnerability of those living in risk-prone areas is perhaps the single most important cause of disaster casualties and damage. We know that unsound development and environmental practices exacerbate the problem. Massive logging operations and the destruction of wetlands reduce the soils ability to absorb heavy rainfall, making erosion and flooding more likely. It is not just the costs of natural disasters that are exacerbated by human action. Many scientists believe that the recent upsurge of weather-related natural disasters is the product of increased global warming, much of which is probably caused by human activity. Given that the pressures of poverty and population growth continue to increase, the disaster trend is likely to worsen if we do not take disaster prevention more seriously (UNEP GEO 3 Report 2001).

Above all, we must never forget that it is poverty, not choice, that drives people to live in risk-prone areas. Equitable and sustainable economic development is not only a good in its own right, but also one of the best forms of disaster insurance.

Justification/rational of the study

In many areas, science can identify the physical hazards; it tells how many people are likely to be affected by each one, what are the various mitigations measures? One can rank risks and remedies and put things in perspective. But normally, policies are based more on fear rather than fact. By definition, fear is more emotional than rational. People have more fear about something emotional than rational. The society should be more rational with their thinking because of limited resources. So how do people make policy making more rational? How can people get political leaders and government agencies to make wiser choices and protect people better? Sikkim is situated at one of the most disaster prone areas in India. Many property, roads and lives of people are destroyed every year due to disasters mainly heavy rainfall, rainstorms, earthquakes, landslides, flashfloods, thunder lightening, hailstorm, fire etc. In this report, an attempt has been made to find out the human vulnerabilities due to Landslides in Sikkim. The case study of this report will also facilitate GIS analysis for human vulnerability due to Landslides in Sikkim and landslides Mitigation program for the state. A Geographic Information System (GIS) offers a valuable suit of tools and techniques for identifying and measuring the hazard and assessing its spatial manifestation. For example, spatial data of different types such as remotely sensed imagery, aerial photography, and digitized maps could be easily incorporated and analyzed in the GIS for hazard assessment. Here, an attempt is made to demonstrate the use of GIS in capturing the uncertainty associated with human vulnerability assessment. This is an important subject for further research by scholars and practitioners given that uncertainty is a pervasive characteristic of hazard assessment. GIS is the only tool to calculate vulnerable population in the geo-spatial domain. However, calculating human vulnerability using GIS with natural hazards is a challenge for decision makers.

Objectives of the study

The main objectives of the study are:

1. Inventory and GIS mapping of District wise landslides of Sikkim.
2. Study of landslide and its Mitigation consisting of different measures specific to Sikkim Himalayas.

Methodology of the study

Before starting the study, a working concept was drawn. Data for the study were collected from two sources; primary and secondary sources. Both primary and secondary data sources were carefully analysed to take advantage of the strengths of both types of data and to minimize their respective weaknesses. Secondary data of this study mainly included records available in different Government Departments and Organisation of Sikkim & India. The Mines Minerals and Geology Department's field survey data were used for case studies. Primary data were collected from some selected areas with field observation. To make the study more comprehensive, additional data sources as below were taken into consideration;

1. Literature review:

This approach assesses the concepts of vulnerability, terms of events, and effects on humans due to natural disasters. Review of existing literature on disaster was necessary to understand the underlying concepts of naturals disaster within different geo environmental settings and to use the terms or definition to describe a natural event.

2. Quantitative (survey, census data, secondary data, Meta analysis using regression etc.):

This part describes the nature, area-wise distribution and also the trend of affected people in Sikkim due to natural disasters. In this part, mainly the last twenty-five year data were used from the following Government Department - District Collector, Land Revenue and Disaster Management Department, Department of Forest, Department of Science & Technology, Department of Urban Development & Housing, Department of PHE, Department of Irrigation, Department of Agriculture, Department of Economics, Statistics, Monitoring & Evaluation, Department of Mines, Minerals & Geology database, Sikkim State Disaster Management Authority.

3. GIS techniques (use of GIS system; geo-referenced data):

This part of the report showed one case study; analyzed human vulnerability due to a single hazard i.e., Landslides with GIS aid. For the case study, a Geographic Information System (GIS) was focused in a historical data approach and a GIS based mapping approach. The database of the case study was collected by Field Officers of Disha Consultancy Services through Field Surveys and from the Department of Mines Minerals & Geology and Land Revenue and Disaster Management Department, Government of Sikkim.

4. Historical data approach:

In this approach different historical data were explored to show the Landslides and human vulnerability trends.

GIS based mapping approach

Geographic Information System (GIS) tools help to answer questions like who is vulnerable, where they are and why they are vulnerable? GIS was used to identify vulnerable areas using statistical tools. Although the data generated are usually integrated in the form of tables, graphs and/or charts, maps have the advantage of presenting data in an easily accessible, readily visible and eye-catching manner. The resulting maps combine information from different sectors to provide an immediately comprehensive picture of the geographical distribution of vulnerable groups at state level. By providing a visual overview of the major issues affecting Landslides and vulnerability, the maps highlight gaps and shortfalls in information and those areas needing attention. A GIS based approach is helpful for highly disaggregated data; it can easily perform statistical analysis as well as graphic presentation. Within the GIS analysis of this paper, we first modeled district wise geographic distribution of Landslides prone areas in Sikkim. Using available field surveys from Mines Minerals and Geological Department, Land Revenue & Disaster Management Department, UNDP, State Disaster Management Authority, Government of Sikkim and our Fields Officers, we developed various type of maps like 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. Which were extensively analyses with the help of GIS Software to form District wise landslides vulnerable areas of Sikkim.

Limitation of the Studies

The study was conducted under very limited resource in terms of time, past data and funds. Therefore, we could not engage latest technology like Landslides Monitoring Stations, Satellite Maps, Geographic Scanners, Geotechnical studies and Ariel Photo for our studies. In this regard, we would like to request the concern authorities to facilitate more funds for these types of study, so that new and latest technology could be incorporated in the study thereby making it more accurate and scientifically correct. This could help the Government to evaluate the hazard related with the Landslides and make the community safer.

PART TWO

AREA OF STUDY

(Map No -01) (Map No-02)

Source: Arc Explorer Internet

SIKKIM

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 sub-divisions, 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 2001

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 Donkya 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 ($27^0$59' N; $38^0$48' 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.

MAJOR RIVERS OF SIKKIM (Table no 02)

1	Teesta River	36	Rimbi Chu	71	Sebuchu
2	Rangeet River	37	Riyong Khola	72	Toklumchu
3	Takcham Chu	38	Bhari Khola	73	Semachu
4	Ramphu Chu	39	Meyong Chu	74	Sevochu
5	Aho Khola	40	Prekchu	75	Zemachu
6	Andheri Khola	41	Raman Khola	76	Chholamchu
7	Lachen chu	42	Song Khola	77	Lhonakchu
8	Lachung Chu	43	Pabong Khola	78	Nakuchu
9	Rathang Chu	44	Yalichu	79	Lhorachu
10	Dickling Kohla	45	Reshi Chu	80	Lungurachu
11	Rongli Khola	46	Kanaki	81	Gomachu
12	Dichu	47	Hee Khola	82	Thomp
13	Pachey Khola	48	Dentam Khola	83	Pokechu
14	Rongni Chu	49	Sangya Khola	84	Burungchu
15	Roro Chu	50	Manpur khola	85	Gyamthang Chu
16	Lungze chu	51	Rolu Khola	86	Kalep Chu
17	Biju Chu	52	Rab khola	87	Lasha Chu
18	Rate Chu	53	Seti Khola	88	Tholangchu
19	Bakcha Chu	54	Rabong Khola	89	Ringphichu
20	Resh Chu	55	Kaliz Khola	90	Umram Chu
21	Dick Chu	56	Rakel Chu	91	Rubel Chu
22	Reshi Chu	57	Talung Chu	92	Phensang Chu
23	Chakung Chu	58	Ringi Chu	93	Rateychu
24	Ongchu	59	Rahi Chu	94	Rangrang Chu
25	Rum Chu	60	Rongnek Chu	95	Rangchangchu
26	Monmu Chu	61	Rong Chu	96	Q Khola
27	Rang Phap Chu	62	Gangtok Chu	97	Martam Khola
28	Ramphu Chu	63	Khedum Chu	98	Neem Khola
29	Rangyong Chu	64	Byangya Chu	99	Chokchurang Chu
30	Kayam Chu	65	Bitchu Chu	100	Yangsha Chu
31	Relli Chu	66	Chyakum Chu	101	Chil Khola
32	Rothak Chu	67	Yumthang Chu	102	Bareli Khola
33	Reshi Chu	68	Damang Chu	103	khani Khola (Melli)
34	Kalej chu	69	Berungchu	Any other river that may be included by the Government, from time to time.	
35	Rong Dung Chu	70	Dongkhya Chu		

Source: Statistical Profile of Sikkim 04-05

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.

CLIMATE

SIKKIM CAN BASICALLY BE DIVIDED INTO FIVE RANGES CLIMATICALLY (Table no 03)

SL.NO.	RANGE	ALTITUDE
1	TROPICAL	Below 610mtrs.
2	SUB TROPICAL	610to 1524 mtrs.
3	TEMPERATE	1524 to 2743 mtrs.
4	SUB –ALPINE	2743 to 3962 mtrs.
5	ALPINE	3962 to 5128 mtrs

Statistical Profile of Sikkim 04-05

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 generalized soil sub-groups prepared by National Bureau of Soil Survey and Land Use Planning.*

FLORA & FAUNA

Sikkim is very rich in flora and fauna. Nowhere in the world in such a small area can find almost all varieties from tropical to alpine. The southern part of the state between 500 ft to 5000 ft has tropical forest including figs laurel, sal trees and bamboos. The area between 5,000 ft to 13,000 ft is dominated by temperate forest of oak, chestnut, birch, magnolia and silver fir. Juniper, Cupressus and Rhododendron grow in alpine zone above 13,000 ft. The perpetual snow areas that have been included in forest area by the Government of Sikkim lie above 16,000 ft. They together constitute 82.32 % of total geographical area as forest land.

POPULATION

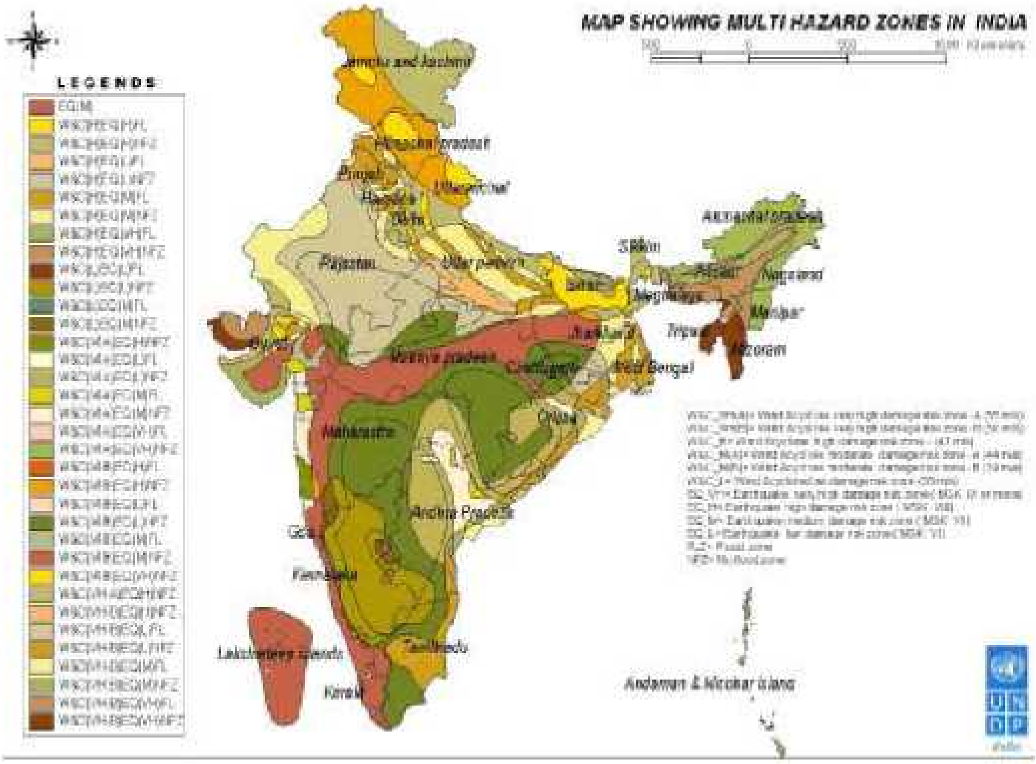
(Table no 04)

ITEMS	SECTOR/YEAR	UNIT	SIKKIM	INDIA
Population 2001	Total	No.	540851	1025251059*
	Rural	No.	480981	740255371*
	Urban	No.	59870	284995688*
No of Towns	1971	No.	7	3126
	1981	No.	8	4029
	1991	No.	8	4689
	2001	No.	9	N A
Urban Population as percentage to Total Population	1971	Percentage	9.37	19.91
	1981	Percentage	16.15	23.34
	1991	Percentage	9.1	25.73
	2001	Percentage	11.47	27.80*
Density of Population	1971	Per sq km	29	177
	1981	Per sq km	45	216
	1991	Per sq km	57	267
	2001*	Per sq km	76	324

Sikkim Vs India Source: Census of India 2001

Concepts of natural disaster and vulnerability over the world

(Map no 03)



Source: UNDP

Concepts and Definitions of Natural Disaster and Vulnerability

1. What is a natural hazard?

Natural hazards comprise phenomena such as earthquakes, volcanic activity, landslides, mudflows, tropical cyclones and other severe storms; tornadoes and high winds; river floods; wildfires and associated haze, drought and infestations.

2. What is Disaster?

A Disaster is an event of nature or man made causes that leads to sudden disruption of normalcy within society, causing damage to life and property, to such an extent that normal social and economic mechanisms available are inadequate to restore normalcy. The United Nations defines Disaster as "…the occurrence of a sudden or major misfortune which disrupts the basic fabric and normal functioning of a society (Community). It is an event or a series of events which gives rise to casualties and/ or damage or loss of property, infrastructure, essential services or means of livelihood on a scale that is beyond the normal capacity of the affected communities to cope with unaided.

The main features of a disaster are:

Unpredictability
Unfamiliarity
Threat

Speed
Urgency
Uncertainty

3. Types of Disaster?

There are two main types of Disaster namely, Natural and man made. Based on the source of origin or relativity of a disaster, it can be sub divided into the following types-

• Water and Climate:-Eg. Flood, Cyclone, Drought, Tornadoes, Hailstorm, Cloud burst, Heat wave, Cold wave, Thunder and Lightning.

• Geological: - E.g., Landslide, Mudflow, Earthquake, Volcano, Dam failure, and Mine fire.

• Chemical, Industrial and Nuclear Hazards or Disasters.

• Accidents: - Forest fires, Urban fires, Mine flooding, Major building collapse, Bomb blast, Electrical accidents, Air, road accidents, and Village fire.

Types of Disaster (experienced in the State) (Table no 05)

Common Natural Disaster	Man-made Disaster
Incessant Rainfall	Urban fire- house & forest
Flash Flood	Village fire- house & forest
Hailstorm	Road accidents
Earthquake	Communal disturbances
Landslide	Electrical accidents

4. What is a natural disaster?

A natural disaster is the consequence of the occurrence of a natural phenomenon affecting a vulnerable social system. Natural phenomena themselves do not necessarily lead to disasters. It is only their interaction with people and their environment that generates impacts, which may reach disastrous proportions

5. What is vulnerability to disasters?

Vulnerability to disasters is a status resulting from human action. It describes the degree to which a society is either threatened by or protected from the impact of natural hazards. This depends on the condition of human settlements and their infrastructure, the way in which public policy and administration are engaged in disaster management, the level of information and education about hazards and how to deal with.

6. Why target society’s vulnerability to disasters?

Although societies have always experienced major natural disasters, they have in recent years been increasingly affected by their adverse impact. In early 2001, three consecutive earthquakes in El Salvador and one in India, together with recurring floods in Mozambique caused significant loss of life and damage to economic and social infrastructures in these countries. This global development is directly linked to a number of trends such as increasing poverty, greater population growth and density particularly in the context of rapid urbanization, environmental degradation and climate change. As vulnerability to disasters is a result of human action, it is possible to reduce vulnerability through appropriate interventions. This way, human and economic losses can be reduced (Appel 2001).

7. Vulnerability concept and realities

Vulnerability is defined as "the extent to which a community, structure, service, or geographic area is likely to be damaged or disrupted by the impact of a particular hazard, on account of their nature, construction and proximity to hazardous terrain or a disaster prone area." The concept of vulnerability, therefore, implies a measure of risk combined with the level of social and economic ability to cope with the resulting event in order to resist major disruption or loss. This susceptibility and vulnerability to each type of threat will depend on their respective differing characteristics.

(a) Physical Vulnerability

Physical vulnerability relates to the physical location of people, their proximity to the hazard zone and standards of safety maintained to counter the effects. For example, people are only vulnerable to a flood because they live in a flood prone area. Physical vulnerability also relates to the technical capacity of buildings and structures to resist the forces acting upon them during a hazard event.

The word vulnerability is regularly deployed in discussion of disasters. We use it so often that we no longer trouble to explain or define it. Moreover, it is one of those fashionable words in development; others are participation and community that are used as a kind of shorthand for a variety of ideas and features. As a result of being used in this way, words soon become loose, imprecise terms. In everyday life, we cannot avoid such shorthand words, but they can leave us open to misinterpretation.

(b) In the socio-economic context, vulnerability is usually defined in a manner such as the following:

The degree to which a population is affected by a calamity will not lie purely in the physical components of vulnerability, but is contextual to the prevailing social and economic conditions and its consequential effect on human activities within a given society. Disparate capacities of people are exemplified in risk analysis. Effects are seen to be directly proportionate to the poverty gap and poverty-intensity in the society/ location as it is the poor that normally live in high concentration in marginal areas (unstable slopes, flood plains) with little infrastructure and fewer resources to cope.

Research in areas affected by earthquakes indicates that single parent families, women, handicapped people, children and the aged are particularly vulnerable social groups. A condition or set of conditions, which adversely affect people's ability to prepare for, withstand and/or respond to a hazard or concerns the propensity of a society to experience substantial damage disruption and casualties as a result of hazard

To show how vulnerability fits into the overall disaster picture, a number of writers have used pseudo-equations such as: disaster (or risk) = hazard x vulnerability. The uncertainty over whether vulnerability multiplies or adds to the disaster is revealing as:

$$\text{Disaster/risk} = \text{hazard} * \text{vulnerability}.$$

Vulnerability is too complicated to be captured by models and frameworks. There are so many dimensions to it: economic, social, demographic, political and psychological. There are so many factors making people vulnerable: not just a range of immediate causes but if one analyses the subject fully - a host of root causes too. There are no common measures or indicators of vulnerability. Vulnerability is a multidimensional concept. Although vulnerability is an intuitively simple notion, it is surprisingly difficult to define and even more difficult to quantify and operationalize. It is described in the literature in numerous and sometimes inconsistent ways.

VULNERABILITY DEFINITION FOCUSING ON DIFFERENT ISSUES

Gabor (1979) referred to vulnerability as a threat, to which a community is exposed, taking in to account not only the properties of the chemical agents involved, but also the ecological situation of the community and the general state of emergency preparedness, at any point in time.

Timmerman (1981) defined vulnerability as the degree to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a system's resilience (a measure of the system's capacity to absorb and recover from the event).

Bohle et al. (1993) defined vulnerability as an aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of harmful perturbations. He suggests a tri-partite causal structure of vulnerability based on the human ecology of production, expanded entitlements in market exchanges, and the political economy of accumulation and class processes.

Moser (1996) defined vulnerability as the insecurity of the well-being of individuals, households, or communities in the face of a changing environment. Generally speaking, therefore, vulnerability is the manifestation of social, economic and political structures, and environmental setting. Vulnerability can be seen to be mainly dealing with two elements that is exposure to hazard and coping capability of the people. People having more capability to cope with events of extreme nature are naturally also less vulnerable to risk. Several applications towards the concept of vulnerability are found in different international organizations. Vulnerability relates to the consequences of a perturbation, rather than its agent. Thus, people are vulnerable to loss of life, livelihood, assets and income, rather than to specific agents of disaster, such as floods, windstorms or technological hazards. This focuses vulnerability on the social systems rather than the nature of the hazard itself. The locus of vulnerability is an individual related to social structures of household, community, society and world-system. Places can only be ascribed a vulnerability ranking in the context of the people who occupy them. These concepts of vulnerability shift the focus of vulnerability away from a single hazard to the characteristics of the social system. Thus, vulnerability is explicitly a social phenomenon, a threat to a human system of social structure.

VULNERABILITY DEFINATIONS OF DIFFERENT ORGANISATION

The World Food Programme (WFP) and Food and Agricultural Organization (FAO) are mostly monitoring vulnerability for food crises. FAO refers vulnerability to the full range of factors that place people at risk of becoming food insecure. The degree of vulnerability for an individual, household or group of persons is determined by their exposure to the risk factors and their ability to cope with or withstand stressful situations.

The Vulnerability Analysis and Mapping (VAM) project of WFP (1999), also defines vulnerability in terms of food security. They defined vulnerability as the probability of an acute decline in food access or consumption levels below minimum survival needs. It is a result of both exposures to risk factors - such as drought, conflict or extreme price fluctuations - and also of underlying socio-economic processes which reduce the capacity of people's ability to cope. Thus, vulnerability can be viewed as follows:

Vulnerability = exposure to risk + inability to cope

The United States Agency International Development (USAID) (1999) referred to vulnerability as a relative measure in their Famine Early Warning System (FEWS). Their strategy on vulnerability was everyone is vulnerable, although their vulnerability differs in its causal structure, its evolution, and the severity of the likely consequences.

Commonwealth Secretariat (1997) argued that vulnerability is the consequence of two sets of factors: (1) the incidence and intensity of risk and threat and (2) the ability to withstand risks and threats (resistance) and to bounce back from their consequences (resilience). Such threats were perceived to emanate from three main sources: economic exposure; remoteness and insularity; and proneness to natural disasters.

United Nations (1982) has distinguished two important considerations in the notion of vulnerability. First, they have distinguished between economic vulnerability and ecological fragility, recognizing that economic vulnerability finds its origins partly in ecological factors (for example, cyclones). That is, vulnerability indices are meant to reflect relative economic and ecological susceptibility to exogenous shocks. Secondly, they make a distinction between structural vulnerability, which results from factors that are durably independent from the political will of countries, and the vulnerability deriving from economic policy, which results from choices made in a recent past, and is therefore conjectural.

UNDRO (1982) defined vulnerability as a degree of loss to the given elements of risk, resulting from the occurrence of a natural phenomenon of a given magnitude.

The Intergovernmental Panel on Climate Change-IPCC (1997) defined vulnerability as the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the sensitivity of a system to changes in climate (the degree to which a system will respond to a given change in climate, including both beneficial and harmful effects) and the ability to adapt the system to changes in climate (the degree to which adjustments in practices, processes or structures can moderate or offset the potential for damage or take advantage of opportunities created, due to a given change in climate). Under this framework, a highly vulnerable system would be one that is highly sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and one for which the ability to adapt is severely constrained.

The South Pacific Applied Geo-science Commission- SOPEC (1999) defined vulnerability as the potential for attributes of a system to respond adversely to the occurrence of hazardous events and resilience is the potential for attributes of a system to minimize or absorb the impact of extreme events. Economic vulnerability is concerned with external forces, which act on the economy, while social vulnerability occurs when natural or other disasters force massive upheavals of residence, traditions and society. Environmental vulnerability differs from vulnerability of human systems because the environment is complex, with different levels of organization from species to interdependent ecosystems and the complex linkages between them.

In summary, human vulnerability can be defined as the exposure to hazard by external activity (e.g. the climatic change) and coping capacity of the people to reduce the risk. So, vulnerability is the function of exposure to hazard and coping capacity at a certain point in time. Vulnerability is also connected with the access to opportunities, which defines the ability of people to deal with the impact of the hazard to which they are exposed. It means the characteristics of a person or a group of people in terms of their capacity to anticipate, copes with, resists, and recovers from the impact of the risk or hazard.

8. Human vulnerability and coping capacity

Who are the most vulnerable people: the people who are exposed to a hazard or those who don't have ability to cope with the risk or a combination of both? It is important to priorities risk in order identifying which are the most vulnerable people and what is their geographical distribution. One needs to rank vulnerability according to the most serious consequences. This information is imperative for decision makers for optimal utilization of limited resources.

Every year thousands of people die by different disasters, but the fate of many of them is never reported globally. There were more disasters in 2000 than in previous years of the decade. The good news is that the year 2000 saw significantly less people killed by disaster; some 20,000 as compared to the average of 75,000 per year during the decade. The bad news is that the number of people affected by disasters went up to 256 million compared with an average from 1991 to 2000 of 211 million per year (World Disaster Report 2001). In the figure no 1 shows the natural disasters trends (1975-2000) in events, people killed and affected worldwide (OEDA/CRED EM-DAT International Disaster database, http://www.cred.be).

The figure no 01 shows that in the year 2000 had the highest numbers of people killed, the number of people affected and the number of disaster events. The figure also shows the correlations between the natural disasters events, people killed and affected.

Vulnerability analysis is the basis for establishing mitigation and emergency plans for (i) execution of the mitigation measures for different components of the system, (ii) organization and preparation, and (iii) attention to the emergency. It requires a response before, during, and after the disaster and includes a combination of measures with the common objective of reducing the impact on provision of service and ensuring that drinking water and basic sanitation services are restored to the affected population in a timely manner.

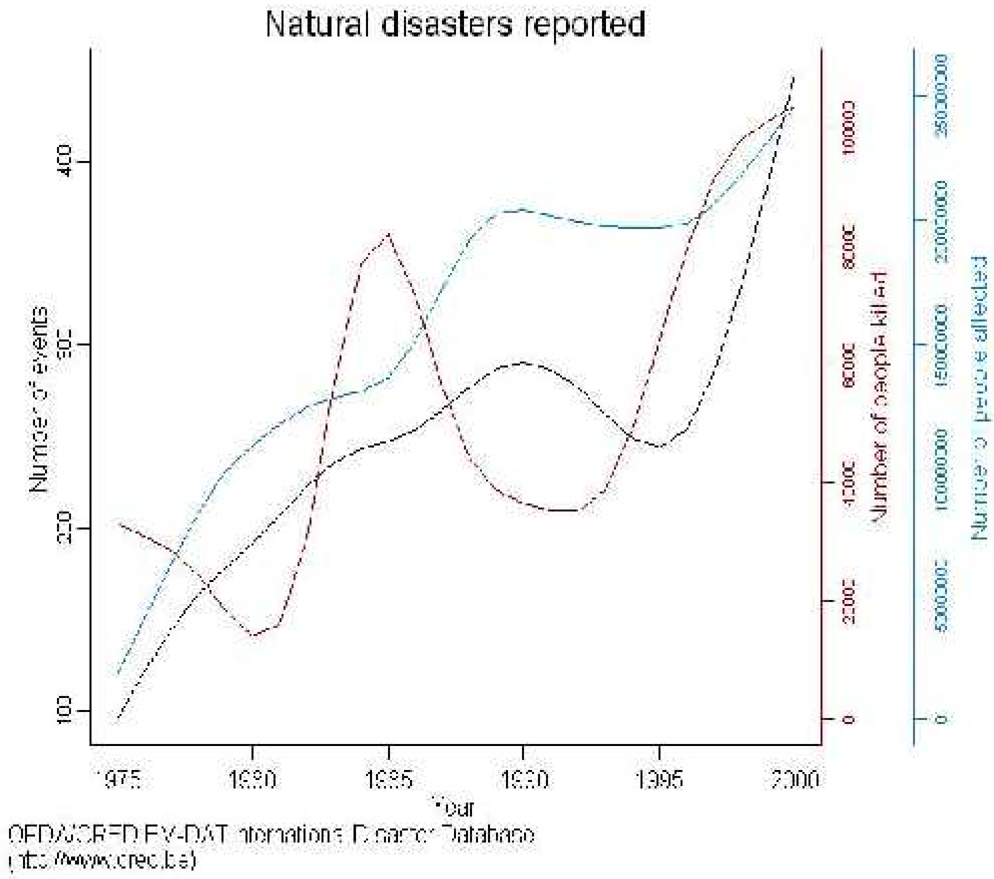
Types of consequences of natural disasters

(Table no 06)

Consequences	Measure	Losses	
		Tangible	Intangible
Deaths	No of People	Loss of economically active individual.	Social & Phychological effect on remaning Community.
Injuries.	No of injury Severity	Medical treatment needs, temporary loss of economic activity by productive individual	Social & phychological pain & recovery.
Physical damage	Inventory of damage element by number & damage level	Replacement repair cost.	Cultural losses.
Emergency operations.	Volume of labour workdays employed equipment & resources	Mobilization cost Investment in preparedness capability.	Stress & overwork in relief participate
Disruption of economy.	number of working days Lost, volume of production	Value of lost production	Opportunities, competitveness reputation
Social disruption	Number of displaced person, home less	Temporory housing relief, economic production.	Psychlogical, social contact, affects community moral.
Enviromental impact	Scale & severity.	Clean-up corts, repair cost.	Consequences on environment, health risk, risk of future disaster

Source: "Disaster Economics", Disaster Management Training Programme, UNDP/DHA, 1994.

Fig no 01: Trend line of numbers of disasters event, affected and killed people in worldwide due to natural disaster
(Fig no 01)



The natural hazards and local conditions must be taken into consideration when planning infrastructure projects. Many of the problems presented by natural hazards occur because these phenomena are not considered during the conception, design, construction, and operation of the system. The vulnerability analysis described in this document is important for both existing and planned constructions. Mitigation and emergency plans are based on the best possible knowledge of the system's vulnerability in terms of: (i) deficiencies in its capacity to provide services; (ii) physical weaknesses of the components to external forces; and (iii) organizational shortcomings in responding to emergencies. Vulnerability analysis identifies and quantifies these weaknesses, thereby defining the expected performance of the system and its components when disasters occur. The process also identifies strengths of the system and its organization (for example, staff with experience in operation, maintenance, design, and construction, who is also experienced in emergency response).

OBJECTIVEES OF VULNERABILITY ANALYSIS

a) Identification and quantification of hazards that can affect the system, whether they are natural or derive from human activity.

b) Estimation of the susceptibility to damage of components that are considered essential in case of disaster.

c) Definition of measures to be included in the mitigation plan.

d) Identification of measures and procedures for developing an emergency plan.

e) Evaluation of the effectiveness of the mitigation and emergency plans, and implementation of training activities, such as simulations, seminars, and workshops.

Spatial distribution of natural hazards in Sikkim

Sikkim (See map no 03) is among the India's most vulnerable regions to both natural and human-made disasters. A tough mesh of rampant and unplanned urbanisation has trapped its people. Every year a noticeable number of people in Sikkim are affected by natural disasters. Sikkim is prone to several kinds of natural disasters among which landslides, floods, and riverbank erosions are most active and frequent. Each year many people die and there are also damages to property, which is one of the main constraints for development. Landslides are major disasters in Sikkim because of its mountainous geographical location. The occurrences of earthquakes, at times, make significant impact both on social life and the topography of the State. Earthquakes are a threat to all urban parts of Sikkim. The registered number of major earthquakes in the last decades seems to be relatively low compared to the potentialities.

LANDSLIDE HAZARD AND PREDICTION IN SIKKIM

(Table No 07)

LAND-SLIDE NAME	TYPE OF SLIDE &MATERIAL	MAGNITUDE & INTESNSITY	AREA IN DANGER	TRIGGERS	WARNING	STRIKE TIME	DAMAGE DONE
1	2	3	4	5	6	7	9
9TH Mile NH 31 A Namli	Rotational(deep) sheared phyllite and quartzite debris	=30ha. Slow, Slump, creep subsidence	NH 31A Namli Village	Weak geo, Steep Slope High water regime Vibration	Subsidence Bent trees Seepage	1957	NH 31 A Houses, land forest
Manual	Debris Topple Gneisses, schists	Debris avalanche	North-Sikkim Highway	Steep Slope, weak geology, Heavy rain	Sudden	11/9/1983	65 dead GREF Camp Wiped out
Burdang Singtam-Rangpo	Translational (shallow) Faulted and joint Phyllite and quartzite rock debris	=10 ha. Fast, Rock/ Soil Topple Avalanche	NH 31A State Road Silinge RF	Weak geo, Steep Slope High Rainfall Vibration	Fault and cracks in rocks, Rock/Soil Topple	Oct. '97	NH 31A Silinge RF
Tsochen Pheri	Complex Rock & Overburden debris	Huge fast Avalanche	Rongli Bazaar	Heavy Rain Thick Debris On steep slope	No warning	21/5/97 12.30pm	Agriculture Roads Bridge Houses
Ao Khola Rongli	Debris flow (shallow) Overburden of gneiss and schist	Huge Fast Avalanche	Rongli Bazaar	Heavy rain Thick debris On steep slope	No warning	21/5/97 12.30pm	07 person dead, one injured
Gangtok & Vicinity	All type Rock/Soil Materials	Widespread Fast Mud & debris flow	Dev. Area Rongnek Syari Minotokgang Sichey	Heavy rain overflow of drain water etc.	2-3 days before strike, cracks in roads and subsidence	8-9.30pm 08/06/97	43 persons dead, 300 house completely 1000 partially

Contd/-

Source: T. Tashi , 2007

LAND-SLIDE NAME	TYPE OF SLIDE &MATERIAL	MAGNITUDE & INTESNSITY	AREA IN DANGER	TRIGGERS	WARNING	STRIKE TIME	DAMAGE DONE
1	2	3	4	5	6	7	8
Deorali Gangtok	Mudslide (shallow) Rock/soil/ Construction Materials	Localised Fast flow & Avalanche	Kopibari School Area Deorali	Water supply pipe burst and rain	No Warning	9.30pm 05/9/95	32 people dead, 08 houses completely
Gyalshing Bazar	Translational (shallow)Rocks & soil debris	Localised Fast Avalanche	Road to Kyongsa and Legship and Houses	Wayward rain water	No warning	Morning 26/9/2000	05 person dead 28 families evacuated
Rakdong	Rotational Boulders, Debris, soil	Large	3rd Mile Rakdong	Steep slope Weak geology rain	Persistent rainfall subsidence bent trees	12.30AM 26/9/2005	03 person dead
Chawang	Complex gneisses, schist debris &boulders	25ha. Fast Rock/soil falls	North Sikkim Highway	Steep slope Loose-Overburden Vibration Rain	Subsidence Persistent rain	19/7/2005	41 families
Sardong	Rotational, Complex Debris	Widespread avalanches	Dentam – Pelling road	Steep slope Weak rock Subsidence heavy rain		30/9/2005	15 houses
Manzing	Complex	Massive fast Avalanche	22Kms from Ravangla to Lingmoo	Very high rainfall steep slope weak geology	Persistent rain subsidence	5PM 24/9/2005	07 person dead 28 families evacuated

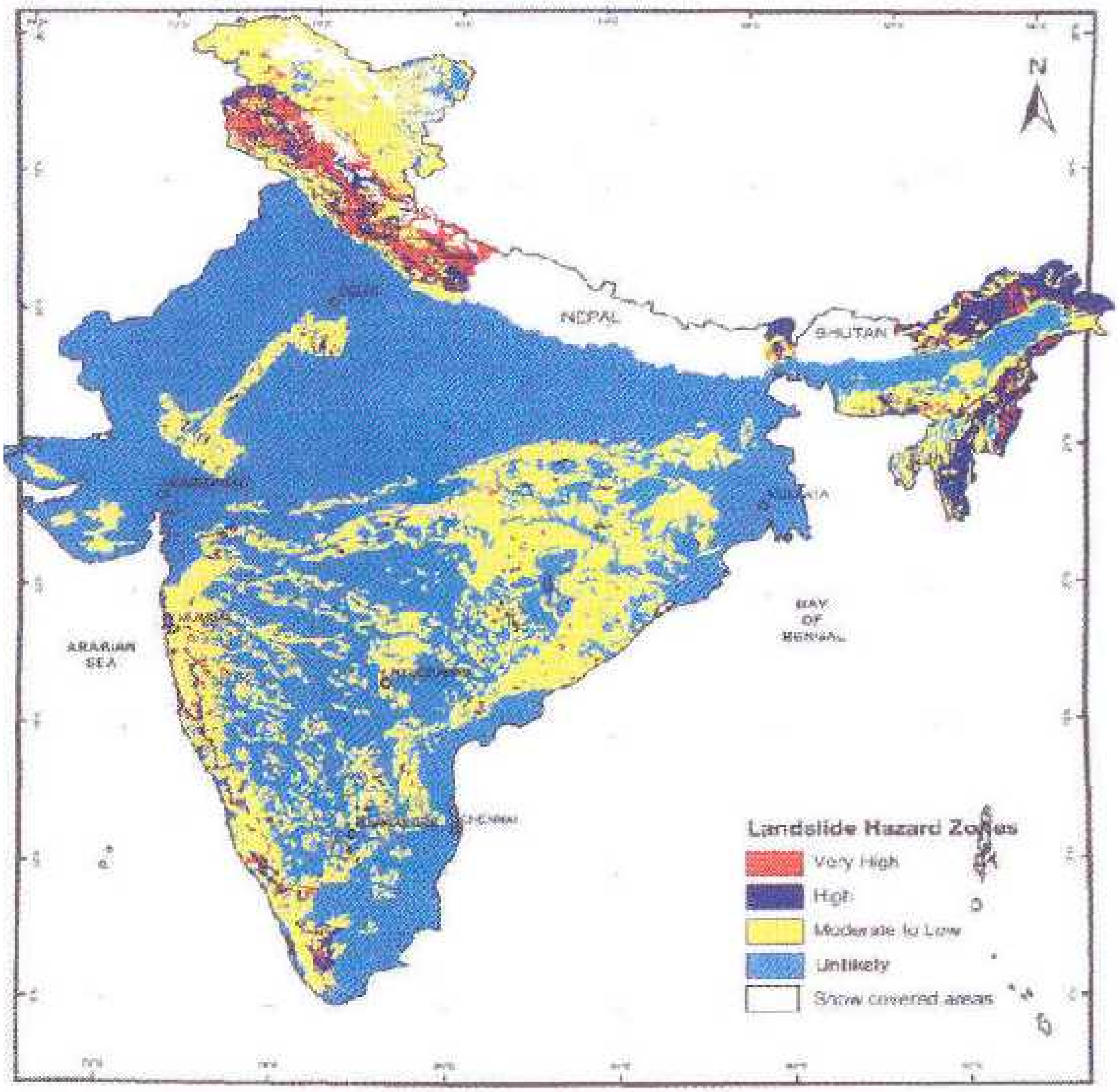
Threats of Landslide and Seismicity in Sikkim Himalayas by T Tashi, 2007

PART THREE

Landslides and its Mitigation in Sikkim.

LANDSLIDES HAZARD ZONATION MAP OF INDIA

Map No 04



LANDSLIDES IN SIKKIM

The common sight of high relief, swathes of verdant forest, raging fast flowing rivers and rivulets, steep slope that are under failing and failed condition, high seismicity and so on characterize the mountain ecosystem of the Sikkim Himalaya. Considering the fragility, diversity and complexity of the existing geo-environmental setting and the ecosystem, manipulation of natural constant either by nature or man in an unsustainable manner can lead to irreparable short as well as long term negative side effects and devastation.

Sikkim is the Twenty second State of Union of India with an area of 7, 096 sq. Kilometers situated in the mountainous Eastern Himalayas. Its origin being recent, it is characterized by rugged topography. The Morphotechonic setting at a glance consists of, deep ravines, river terraces, ancient and recent flood plains, steeps and gently sloping hills various geo-tectonic features such as faults, folds etc. The altituded of areas vary from 300 m.a.s.l to 8598 m.a.s.l The State of Sikkim is plagued by various type of mass movement. The triggering factors are invariably excessive water, earthquakes, ruggedness etc. Landslides triggered by heavy rain been constant sources of destruction of property and loss of lives. Landslide at Gyalshing during the third and last week of August 2000 claimed eleven lives. Dormants as well as active slides are threat to human life and property. Their study and monitoring has become imperative to safeguard against destruction by them. Developmental activities, to be sustainable, must be confined away from landslides prone and landslide affected locations. Meyong Chub in North Sikkim is a glaring example.

The Sikkim Himalaya has never been and will never be free from ubiquity of weak geology, slope instability, frequent seismicity, soil erosion etc. mainly due to natural causes and partly as a result of accelerated degradation. These adverse conditions in tandem can exacerbate the existing fragile, vulnerable and multi-functional mountain ecosystem. So far disaster caused by landslides, earthquake, flood etc. have not lead to large scale human tragedy in Sikkim in recent memory. However, there is ever increasing human demand of natural resources, especially land for urban development and mega dams in an apparently unsustainable manner, making some of the denizens to adapt and survive at dangerous margins. The emerging crisis can perhaps be minimized by indigenous knowledge based and modern technological interventions. To safeguard against accelerated degradation and improve the living standard of the hill people, the Government (center and state) need to address hill specific issued through systematic and effective integration of the ecosystem service and development, highland and lowland linkages etc. Without a replicable and hill specific development policy, the ever present threat from devastating landslides, earthquake, flood etc. remains and option and the opportunities of the progeny in jeopardy. A beginning has been made by the state Government of Sikkim by asking the Department of Science & Technology (DST), Government of India to undertake systematic study of landslide problems in the State. The DST accordingly prepared a status report on landslide in Sikkim. Based on the report, the DST, Government of India, is considering establishment of a multi-disciplinary cell dedicated to landslide studies, not only in Sikkim but the entire Northeastern state. Such a initiative has become imperative because past experience shows that different agencies carry out landslide studies at will and without coordination with each other. Results of such exercise never actually got disseminated and proved futile. Whereas the seismicity monitoring is concerned, site response studies using digital accelrograms located at seven – station –strong motion network in Sikkim by year 2000 and twelve –station network by year 2006 has been done by IIT, Kharagpur and study results widely are published. Mass wasting processes area universal phemonia in mountain, hill and hilly areas of the world. Their magnitude, frequency and type differ from place to place and on the material that is undergoing displacement either through chemical or mechanical means. In the Himalayas, mass wasting process is dominated by landslides. The magnitude, intensity and frequency of Himalayan landslides vary from East to West and from South to North. The variation is controlled, mainly be climate, neo-tectonism and seismicity. The eastern Himalaya including Sikkim is a hot-spot for natural hazards, particularly landslides and earthquakes. Landslides of all types and size occur in almost all types of rocks and quaternary formations of Sikkim. The Daling Group of rocks, especially, Gorubathan Formation appears more prone to landslides than the inhomogeneous quaternary deposits and gneisses and schists of Higher Himalaya. The high landslide susceptibility of the Daling Group of rocks has been attributed to their severe shear distortion due to loading and unloading during orogenesis, higher rate of weathering and mineral composition. A cursory survey of frequency of occurrence of landslides in Sikkim was done in 1991 and the result clearly showed that the East and South Districts where Daling rocks dominate are affected by maximum number of landslides (Table no 13).Landslides are common phenomenon in a mountainous area having high relief. Landslides and other types of mass movements have always attracted the attention of human in the same way as other uncontrollable phenomenon of natural disasters like earthquakes, volcanoes and floods, which threaten the life and property of inhabitants. In some areas, the occurrence of landslides or other types of mass movements are less, but in a mountainous region with higher relief accompanied by tectonic activities as in Sikkim, various shapes or types of mass movements can take up disastrous turn at times. The mountain slopes are governed by laws of gravity and with the forces of lubrication like water, the unstable slope-forming material shall continue to move downwards and cause economic loss in terms of life and property. We can only take precautions to reduce the number and magnitude. Landslide with heavy rainfall causes flash floods in the valleys. Landslide or mass movement phenomena in a mountainous state like Sikkim lying over the young mountain chain can be attributed to the following causative factors solely or in combination with:

1. Geology of the area.
2. Geo-technical condition.
3. Rainfall.
4. Slope angle and slope forming materials.
5. Hydrological condition of the area.

Rainfall particularly in the Sikkim Himalaya is often punctuated by flashes of cloudburst. A cloudburst comes with the speed of thunder, lasts for a few minutes to as long as three hours at a stretch of time, and usually leaves behind a trail of devastation worse than inflicted by the combined effect of rainfall in the same area, for the rest of the season. Rainfall record of the Teesta Valley for the period 1891-1965 speaks of rainfall intensities exceeding 250 mm in 24 hours, repeated more than 40 times! Taking the mean annual precipitation as 5000 mm for the Teesta Valley, the Event Coefficient (Ce = precipitation record of the event/mean annual precipitation) can be calculated. Thus, event coefficients (Ce) do range between 0.06 and 0.36, which are remarkably high values from any standards and are usually associated with landslides' on the lower side of the scale and landslide disasters on the higher side of the scale. Admittedly, conclusions derived from study of 'event coefficients' alone, without cognizance of rainfall records prior to the event and without knowledge of landslide history of the area may be deceptive. However, the fact remains that 'cloud bursts' of intensities exceeding 1000 mm in 24 hours ($Ce > 0.2$) trigger mass movements practically in any circumstances, and for $0.1 < Ce < 0.2$, probability of mass-movement is pretty high. For $Ce < 0.1$, biunivocal (unequivocal) relationship between rain and slides does not seem to exist.

Landslide types and classification

Various scientific disciplines have developed taxonomic classification systems to describe natural phenomena or individuals, like for example, plants or animals. These systems are based on specific characteristics like shape of organs or nature of reproduction. Differently, in landslide classification, there are great difficulties due to the fact that phenomena are not perfectly repeatable; usually being characterised by different causes, movements and morphology, and involving genetically different material. For this reason, landslide classifications are based on different discriminating factors, sometimes very subjective.

In the following, factors are discussed by dividing them into two groups:

(A) The first one is made up of the criteria utilised in the most widespread classification systems that can generally be easily determined.

(B) The second one is formed by those factors that have been utilised in some classifications and can be useful in descriptions.

Type of movement

This is the most important criteria, even if uncertainties and difficulties can arise in the identification of movements, being the mechanisms of some landslides often particularly complex. The main movements are falls, slides and flows, but usually topples, lateral spreading and complex movements are added to these.

Material Involved

Rock, earth and debris are the terms generally used to distinguish the materials involved in the landslide process. For example, the distinction between earth and debris is usually made by comparing the percentage of coarse grain size fractions.

If the weight of the particles with a diameter greater than 2mm is less than 20%, the material will be defined as earth; in the opposite case, it is debris.

Activity

The classification of a landslide based on its activity is particularly relevant in the evaluation of future events. The recommendations of the WP/WLI (1993) define the concept of activity with reference to the spatial and temporal conditions, defining the state, the distribution and the style. The first term describes the information regarding the time in which the movement took place, permitting information to be available on future evolution, the second term describes, in a general way, where the landslide is moving and the third term indicates how it is moving.

Movement velocity

This factor has a great importance in the hazard evaluation. A velocity range is connected to the different type of landslides, on the basis of observation of case history or site observations.

The age of the movement

Landslide dating is an interesting topic in the evaluation of hazard. The knowledge of the Landslide frequency is a fundamental element for any kind of probabilistic evaluation. Furthermore, the evaluation of the age of the landslide permits to correlate the trigger to specific conditions, as earthquakes or periods of intense rains. It should be noted that, it is possible that phenomena could be occurred in past geological times, under specific environmental conditions which no longer act as agents today. For example, in some Alpine areas landslides of the Pleistocene age are connected with particular tectonic, geomorphologic and climatic conditions.

Geological conditions

These represent a fundamental factor of the morphological evolution of a slope. Bedding attitude and the presence of discontinuities or faults control the slope morphogenesis.

Morphological Characteristics

As the landslide is a geological volume with a hidden side, morphological characteristics are extremely important in the reconstruction of the technical model.

Geographical location

These criterions describe, in a general way, the location of landsides in the physiographic context of the area. Some authors have therefore identified landslides according to their geographical position so that it is possible to describe "alpine landslides", "landslides in plains", "hilly landslides" or "cliff landslides". As a consequence, specific morphological contexts are referred characterised by slope evolution processes.

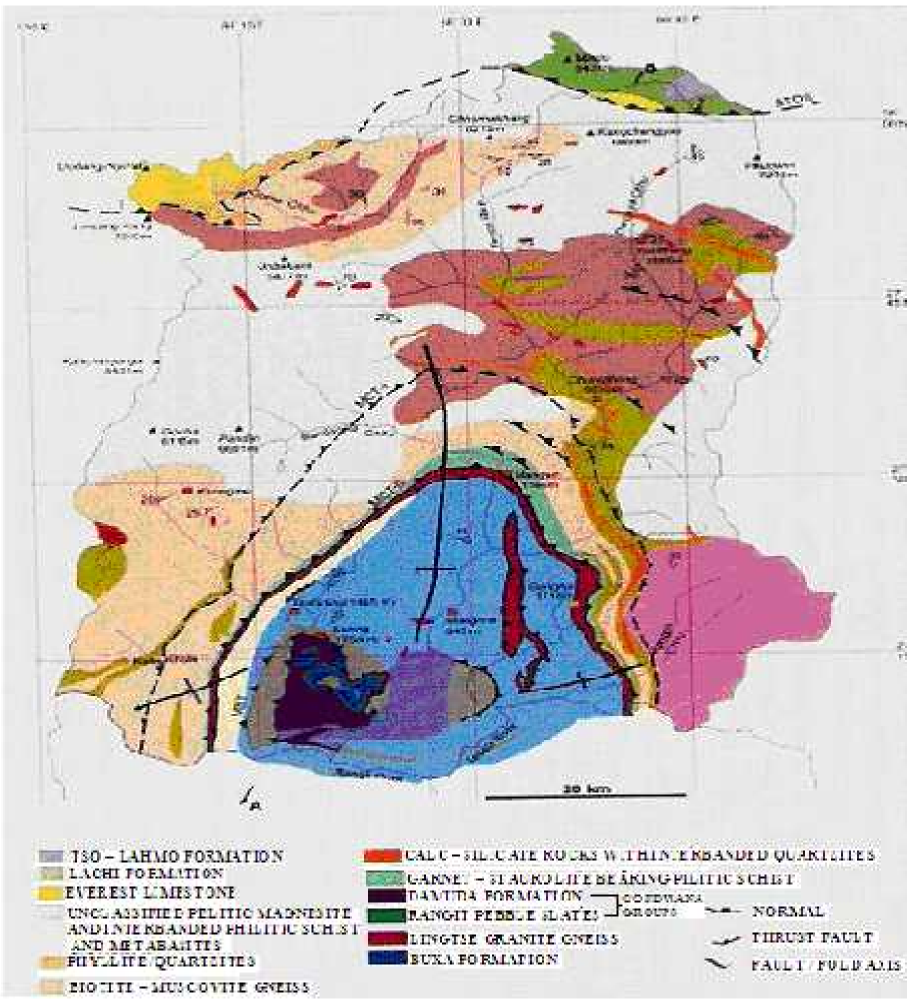
Topographical criteria

With these criteria, landslides can be identified with a system similar to that of the denomination of formations. Consequently, it is possible to describe a landslide using the name of a site in particular, the name will be that of the locality where the landslide happened with a specific characteristic type.

Type of climate

These criteria give particular importance to climate in the genesis of phenomena for which similar geological conditions can, in different climatic conditions, lead to totally different morphological evolution. As a consequence, in the description of a landslide, it can be interesting to understand in what type of climate the event occurred.

Map no 05



Geology and Stratigraphy of Sikkim (from CCSTB, CISMHE)

GEOLOGY AND TECTONICS

Mallet (1875) & Bose (1891) were the first explorers who gave an account of geology and mineral resources of Sikkim Himalaya. Subsequent exploration by Auden (11935),Heim and Gansser5 (1939), Ray (1947) Ghosh (1952), Raina and Srivastava (1980), Thakur (1986) , Ravikant(1993), Neogi et al (1989),Ray (2000) and others gave others gave important and valuable contributions towards understanding of geology of Sikkim .

The current literature described geology of Sikkim similar to that of the Eastern Himalayas where four, distinct geomorphology based transverse zone or tectonic stratigraphic domains, separated by major tectonic dislocations, are exposed in Sikkim. The Lesser, Higher and Tethys Himalaya of Sikkim are typically arranged in a domal shape or arch of thrust surface in the form of culmination across Teesta river, popularly known as Teesta culmination (Mcclay, 1992, Ray, 2000). The core of the Teesta culmination is occupied by Proterozoic Lesser Himalaya crystalline complex, the main central Thrust (MCT) separates the Lesser and Higher Himalaya. Gondovana (carboniferous to permain) and Buxa Group of rocks are exposed in the Rangit window Zone, small window near Rorathang, east Sikkim and as thurst/ fault slices in South Sikkim. The Tethys Himalaya is represented by cambrain to Eocenefossilferous sediments of North Sikkim Tethyan Zone which tectonically overlie the Higher Crystalline Complex.

CAUSES OF MOVEMENTS

Terzaghi describes causes as "internal" and "external" referring to modifications in the conditions of the stability of the bodies. Whilst the internal causes induce modifications in the material itself which decrease its resistance to shear stress, the external causes generally induce an increase of shear stress, so that block or bodies are no longer stable. It should be noted that the triggering causes induce the movement of the mass. Predisposition to movement due to control factors is determining in landslide evolution. Structural and geological factors, as already described, can determine the development of the movement, inducing the presence of mass in kinematic freedom.

TYPE AND CLASSIFICATION

In the following table no 08 shows a schematic landslide classification adopting the classification of Varnes 1978 and taking into account the modifications made by Cruden and Varnes, in 1996. Some integration has been made by using the definitions of Hutchinson (1988) and Hungretal 2001.

(Table No 08)

<table>
<tr><td colspan="3" rowspan="3">Type of Movement</td><td colspan="3">Type of Material</td></tr>
<tr><td rowspan="2">Bedrock</td><td colspan="2">Engineering Soils</td></tr>
<tr><td>Predominantly fine</td><td>Predominantly coarse</td></tr>
<tr><td colspan="3">Falls</td><td>Rock fall</td><td>Earth fall</td><td>Debris fall</td></tr>
<tr><td colspan="3">Topples</td><td>Rock topple</td><td>Earth topple</td><td>Debris topple</td></tr>
<tr><td rowspan="2">Slides</td><td>Rotational</td><td></td><td>Rock slump</td><td>Earth slump</td><td>Debris slump</td></tr>
<tr><td>Translational</td><td>Few units
Many units</td><td>Rock block slide
Rock slide</td><td>Earth block side
Earth slide</td><td>Debris block slide
Debris slide</td></tr>
<tr><td colspan="3">Lateral spreads</td><td>Rock spread</td><td>Earth spread</td><td>Debris spread</td></tr>
<tr><td colspan="3" rowspan="2">Flows</td><td>Rock flow
Rock avalanche</td><td>Earth flow</td><td>Debris flow
Debris avalanche</td></tr>
<tr><td>(Deep creep)</td><td colspan="2">(Soil creep)</td></tr>
<tr><td colspan="3">Complex and compound</td><td colspan="3">Combination in time and / or space of two or more principal types of movement.</td></tr>
</table>

CAUSES OF LANDSLIDES

Causes may be considered to be factors that made the slope vulnerable to failure, that predispose the slope to becoming unstable. The trigger is the single event that finally initiated the landslide. Thus, causes combine to make a slope vulnerable to failure, whilst the trigger finally initiates the movement. Landslides can have many causes, but can only have one trigger as shown in the next figure. Usually, it is relatively easy to determine the trigger after the landslide has occurred (although it is generally very difficult to determine the exact nature of landslide triggers ahead of a movement event).

1. **Geological Factors**
   a. **Weak materials**
   b. **Sensitive materials**
   c. **Weathered materials**
   d. **Sheared materials**
   e. **Jointed or fissured materials**
   f. **Adversely orientated discontinuities**
   g. **Permeability contrasts**
   h. **Material contrasts**
2. **Morphological causes**
   a. **Slope angle**
   b. **Uplift**
   c. **Rebound**
   d. **Fluvial erosion**
   e. **Wave erosion**
   f. **Glacial erosion**
   g. **Erosion of Lateral margins**
   h. **Subterranean erosion**
   i. **Slope loading**

j. **Vegetation change**

3. **Physical causes**
    a. **Intense rainfall**
    b. **Rapid snow melt**
    c. **Prolonged precipitation**
    d. **Rapid drawdown**
    e. **Earthquake**
    f. **Volcanic eruption**
    g. **Thawing**
    h. **Freeze-thaw**
    i. **Shrink – swell**
    j. **Ground water changes**
    k. **Other mass movements**
4. **Human causes**
    a. **Excavation**
    b. **Loading**
    c. **Drawdown**
    d. **Land use change**
    e. **Water management**
    f. **Mining**
    g. **Quarrying**
    h. **Vibration**
    i. **Water leakage**

Example of landslide causation and triggering

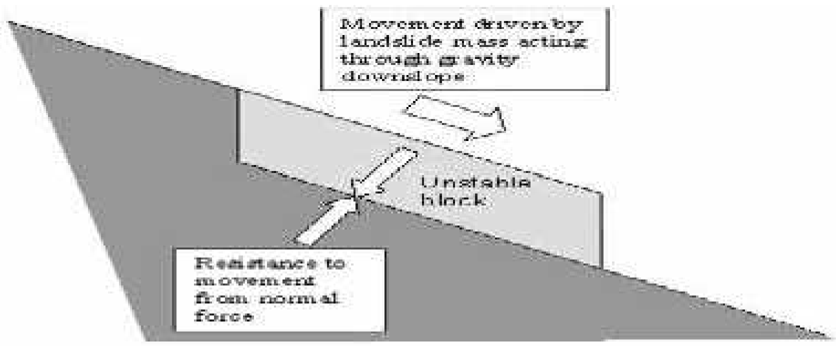
RAINFALL AS A TRIGGER

In the majority of cases, the main trigger of landslides is heavy or prolonged rainfall. Generally, this takes the form of either an exceptional short lived event, such as the passage of a tropical cyclone or even the rainfall associated with a particularly intense thunderstorm or of a long duration rainfall event with lower intensity, such as the cumulative effect of monsoon rainfall in South Asia. In the former case, it is usually necessary to have very high rainfall intensities, whereas in the latter the intensity of rainfall may be only moderate - it is the duration and existing pore water pressure conditions that are important. The importance of rainfall as a trigger for landslides cannot be under-estimated. Almost all the landslides in Sikkim occur after prolonged exposure to monsoon rains and occasionally during or just after cloudbursts or precipitation intensity exceeding 135-145 mm in 24 hours.

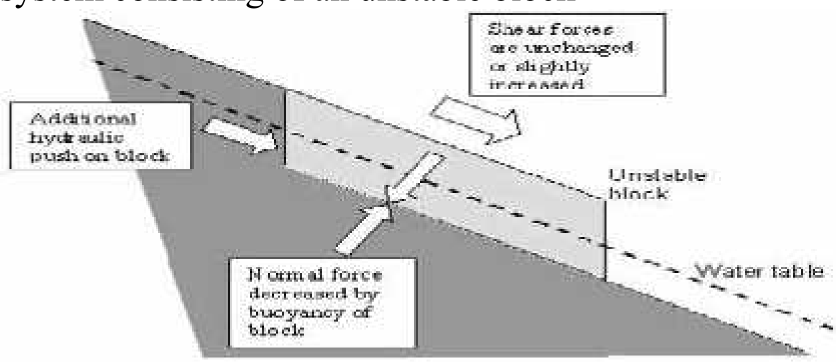
The red letter mouth of October 1968 was consider the most disaster month disastrous month in recent years of Sikkim history. On 5th September 1995 heavy rain triggered off a mud avalanche near Gangtok Killing 32 people. Similarly, non-stop heavy rain since early June 1997 damaged 300 house completely, 1000 houses partially and caused death of 51 people in east and North district of the state. Rain, therefore, has been one of the main triggers besides weak geology, steep slopes with thick overburden, frequent earthquake etc., causing landslides.(insert rainfall data of sikkim and see table of landslides)So why does rainfall trigger so many landslides? Principally, this is because the rainfall drives an increase in pore water pressures within the soil.

The Figure A illustrates the forces acting on an unstable block on a slope. Movement is driven by shear stress, which is generated by the mass of the block acting under gravity down the slope.

Resistance to movement is the result of the normal load. When the slope fills with water, the fluid pressure provides the block with buoyancy, reducing the resistance to movement. In addition, in some cases fluid pressures can act down the slope as a result of groundwater flow to provide a hydraulic push to the landslide that further decreases the stability. Whilst the example given in Figures A and B is clearly an artificial situation, the mechanics are essentially as per a real landslide.



A: Diagram illustrating the resistance to, and causes of, movement in a slope system consisting of an unstable block



B: Diagram illustrating the resistance to, and causes of, movement in a slope system consisting of an unstable block

In some situations, the presence of high levels of fluid may destabilise the slope through other mechanisms, such as:

• Fluidization of debris from earlier events to form debris flows.

• Loss of suction forces in silty materials, leading to generally shallow failures (this may be an important mechanism in residual soils in tropical areas following deforestation).

• Undercutting of the toe of the slope through river erosion.

Considerable efforts have been made to understand the triggers for land sliding in natural systems, with quite variable results. For example, geologist in Puerto Rico, Larsen and Simon found that storms with a total precipitation of 100-200 mm, about 14 mm of rain per hour for several hours, or 2-3 mm of rain per hour for about 100 hours can trigger landslides in that environment. Rafi Ahmad, working in Jamaica, found that for rainfall of short duration (about 1 hour) intensities of greater than 36 mm/h were required to trigger landslides. On the other hand, for long rainfall durations, low average intensities of about 3mm/h appeared to be sufficient to cause landslide as the storm duration approached approximately 100 hours. Corominas and Moya (1999) found that the following thresholds exist for the upper basin of the Llobregat River, Eastern Pyrenees area. Without antecedent rainfall, high intensity and short duration rains triggered debris flows and shallow slides developed in colluvium and weathered rocks. A rainfall threshold of around 190 mm in 24 h initiated failures whereas more than 300 mm in 24-48 h were needed to cause widespread shallow landslide. With antecedent rain, moderate intensity precipitation of at least 40 mm in 24 h reactivated mudslides and both rotational and translational slides affecting clayey and silty-clayey formations. In this case, several weeks and 200 mm of precipitation were needed to cause landslide reactivation. A similar approach is reported by Brand et al. (1988) for Hong Kong, who found that if the 24 hour antecedent rainfall exceeded 200 mm then the rainfall threshold for a large landslide event was 70 mm hr-1. Finally, Caine (1980) established a worldwide threshold:

I = 14.82 D - 0.39 where: I is the rainfall intensity (mm h-1), D is duration of rainfall (h)

This threshold applies over time periods of 10 minutes to 10 days. It is possible to modify the formula to take into consideration areas with high mean annual precipitations by considering the proportion of mean annual precipitation represented by any individual event. Other techniques can be used to try to understand rainfall triggers, including:

• Actual rainfall techniques, in which measurements of rainfall are adjusted for potential evaporation, transpiration and then correlated with landslide movement events.

• Hydro geological balance approaches, in which pore water pressure response to rainfall is used to understand the conditions under which failures are initiated.

• Coupled rainfall - stability analysis methods, in which pore water pressure response models are coupled to slope stability models to try to understand the complexity of the system.

• Numerical slope modeling, in which finite element (or similar) models are used to try to understand the interactions of all relevant processes.

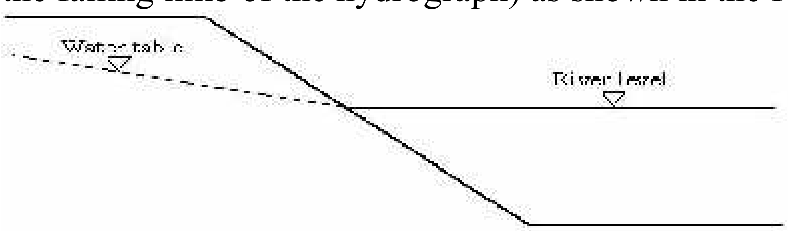
OTHER WAYS THAT WATER CAN ACT AS A TRIGGER

Snowmelt

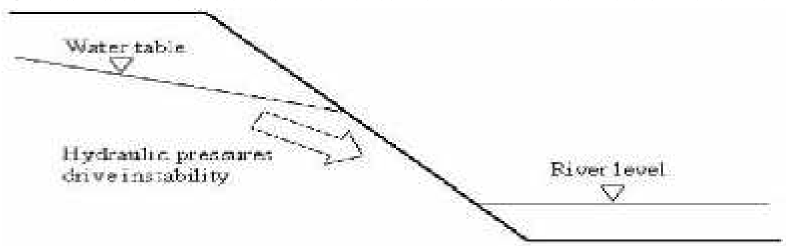
In many cold mountain areas, snowmelt can be a key mechanism by which landslide initiation can occur. This can be especially significant when sudden increases in temperature lead to rapid melting of the snow pack. This water can then infiltrate into the ground, which may have impermeable layers below the surface due to still-frozen soil or rock, leading to rapid increases in pore water pressure, and resultant landslide activity. This effect can be especially serious when the warmer weather is accompanied by precipitation, which both adds to the groundwater and accelerates the rate of thawing.

Water-level change

Rapid changes in the groundwater level along a slope can also trigger landslides. This is often the case where a slope is adjacent to a water body or a river. When the water level adjacent to the slope falls rapidly the groundwater level frequently cannot dissipate quickly enough, leaving am artificially high water table. This subjects the slope to higher than normal shear stresses, leading to potential instability. This is probably the most important mechanism by which river bank materials fail, being significant after a flood as the river level is declining (i.e. on the falling limb of the hydrograph) as shown in the following figures.



Groundwater conditions when the river level is stable



Groundwater conditions on the falling limb of the hydrograph

If the fall in river levels is sufficiently rapid then the high water levels in the slope can provide a hydraulic push that destabilizes the slope, sometimes triggering bank collapse. It can also be significant in coastal areas when sea level falls after a storm tide, or when the water level of a reservoir or even a natural lake rapidly falls.

Undercutting at the toe

In some cases, failures are triggered as a result of undercutting of the slope by a river, especially during a flood. This undercutting serves both to increase the gradient of the slope, reducing stability, and to remove toe weighting, which also decreases stability. These types of effect are seen lot in Sikkim after every rainy season, when toe erosion occurs along the river sores. This instability can continue to occur for a long time afterwards, especially during subsequent periods of heavy rain and flood events.

Seismic triggers

The second major factor in the triggering of landslides is seismicity. Landslides occur during earthquakes as a result of two separate, but interconnected processes: seismic shaking and pore water pressure generation.

(A) Seismic shaking

The passage of the earthquake waves through the rock and soil produces a complex set of accelerations that effectively act to change the gravitational load on the slope. So, for example, vertical accelerations successively increase and decrease the normal load acting on the slope. Similarly, horizontal accelerations induce a shearing force due to the inertia of the landslide mass during the accelerations. These processes are complex, but can be sufficient to induce failure of the slope. These processes can be much more serious in mountainous areas in which the seismic waves interact with the terrain to produce increases in the magnitude of the ground accelerations. This process is termed 'topographic amplification'. The maximum acceleration is usually seen at the crest of the slope or along the ridge line, meaning that it is a characteristic of seismically triggered landslides that they extend to the top of the slope.

(B) Pore pressure generation

The passage of the earthquake waves through a granular material such as a soil can also induce a process termed liquefaction, in which the shaking causes a reduction in the pore space of the material. This densification drives up the pore pressure in the material. In some cases this can change a granular material into what is effectively a liquid, generating 'flow slides' that can be rapid and thus very damaging. Alternatively, the increase in pore pressure can reduce the normal stress in the slope, allowing the activation of translational and rotational failures.

The nature of seismically-triggered landslides

For the main part, seismically generated landslides usually do not differ in their morphology and internal processes from those generated under non-seismic conditions. However, they tend to be more widespread and sudden. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes. However, almost every other type of landslide is possible, including highly disaggregated and fast-moving falls; more coherent and slower-moving slumps, block slides, and earth slides; and lateral spreads and flows that involve partly to completely liquefied material (Keefer, 1999). Rock falls, disrupted rock slides, and disrupted slides of earth and debris are the most abundant types of earthquake-induced landslides, whereas earth flows, debris flows, and avalanches of rock, earth, or debris typically transport material the farthest. There is one type of landslide that is essential uniquely limited to earthquakes - liquefaction failure, which can cause fissuring or subsidence of the ground. Liquefaction involves the temporary loss of strength of sands and silts which behave as viscous fluids rather than as soils. This can have devastating effects during large earthquakes.

REGIONAL SEISMICITY

The tectonic frame work and the seismicity of the northern eastern state including state including Sikkim are considered as a result of collision tectonics in the Himalayan are and sub-duction tectonics below the Myanmarese arc. Studies have indicated a very complex tectonic setting of the region due to constant movement of the Indian plate from South to North and Myanmarese from East to West. The two major structural elements in the Eastern Himalaya are the Main Central Thrust (MCT) and The Main Boundary Thrust (MBT). The Foot Hill Thrust (FHT)/Main Frontal Thrust (MFT) along the Southern edge of the Himalayan bring the Siwaliks in Juxta-position with the thick recent sediments of the Indo-gangetic plain. There are also a large number of prominent lineaments in this region, some of which are reported to extend foe several kilometers beneath the Himalayan Fordeep. The Teesta lineaments which pass through Parbatipur area of Bangladesh to Bhadrapur area of Nepal, is considered to demarcate the Western limit of Eastern Himalayan seismicity.

The North Eastern India was subjected to severe shaking by a number of damaging earthquakes. The systematic account of which is available from the middle of 19th century only. Besides the Cachar earthquake of 10th January 1869(Mag: 7.5), twenty other earthquakes exceeding magnitude of 7 and affecting the region during the past 100 years have been tabulated (Ramchandaran et al, 1981). Among the recorded earthquakes, the most damaging ones and macroseismically studied are the great Assam earthquake of 12th June 1897(M= 7), Srimangal earthquake of July 8, 1918(M =7.1), Dhurbi earthquake of July 3, 1930 (M=7.1), Assam earthquake of August 15, 1950(M=

8.6), Assam earthquake of July 1975(M=6.7), Cachar earthquake of December 3, 1984(M=5.4), Manipur- Burma earthquake of August 6, 1988(M= 7.3), Assam-Tripura earthquake of April 13 , 1989 (M= 5.7) and Manipur earthquake of January 10, 1990 (M=5.4). In the Eastern Himalayas, the seismicity is considered as a result of collision tectonics and correlated with the MBF & MCT (Gupta S.K. 2003). The MCT is shown passing through Gangtok to Mangan and then to lower Tolung to north of Sada from where it cuts through North of Labdang-Tashiding to Gyalshing and then Kaluk to Soreng before coming out of Sikkim border at an area where it meets the MBF (India – Nepal border). The IIT, Kharagpur has carried out site response studies using strong motion network of acclerographs in Sikkim during the past 10 years. The findings are available in the form of a paper with site response contour maps (Nath, et al 2000) and a paper with micronization maps (Nath, et al 2006). The existing record shows (Table no13) that the state has been subjected to local earthquakes of M= 5.0 to M=- 6.5 and non- local high magnitude earthquakes of above M=8.0 (1897 and 1950 of Assam), (1934 of Bihar). The whole of the State is therefore, has been slotted in Seismic Zone IV of IS: 1893-9184 and categorized as High Damage Risk Zone of MSK VIII. Considering the seismically vulnerability of the State all new constructions are subjected to strict observance of BIS codes or seismic codes. The existing unsafe and non-engineered building stock still remains and is practically impossible to address the entire such building stock. The alternative left is to retrofit only the life line buildings such Hospitals, Schools, Cinema halls, multi- storied hostels and apartments etc.

Landslides associated with volcanoes

Some of the largest and most destructive landslides known have been associated with volcanoes. These can occur either in association with the eruption of the volcano itself, or as a result of mobilisation of the very weak deposits that are formed as a consequence of volcanic activity. Essentially, there are two main types of volcanic landslide: lahars and debris avalanches, the largest of which are sometimes termed flank collapses.

Humans as a trigger for landslides

In recent years, it has become increasingly apparent that humans are key factor in the initiation of landslides. This is illustrated in the following Figure, based upon a detailed landslide database compiled for Sikkim for the period 1957 - 2005.

DETAILED LANDSLIDE IN SIKKIM

(Table no 37)

DISTRICT	VERY SEVERE	SEVERE	MODERATE	TOTAL
NORTH	32	NA	NA	32
SOUTH	90	148	130	368
EAST	5*	9*	3*	153
WEST	40	16	33	89
	167	173	166	642

The rise in landslide occurrence since 1995 is probably attributable to the role of humans. It is clear that since the mid-1990s, there has been a substantial increase in the occurrence of landslides in Sikkim, probably associated with human activities. For the most part, however, humans are a cause of landslides rather than a trigger - for example destabilising a slope through deforestation. However, on occasion humans may actually trigger a failure. In the following, the principal human triggering of landslides is chematised:

1. Excavation of a slope at its toe;
2. Drawdown;
3. Road cut.

Landslides (See table no 13) can be triggered by many often concomitant causes. In addition to shallow erosion or reduction of shear strength caused by seasonal rainfall, causes triggered by anthropic activities such as adding excessive weight above the slope, digging at mid-slope or at the foot of the slope, can also be included. However, often individual phenomena join together to generate instability, also after some time has elapsed, which, other than in well-instrumented limited areas, do not allow a reconstruction of the evolution of the occurred landslide. It is therefore pointless, for the purpose of planning landslide hazard mitigation measures, to classify the work as a function of the phenomenon or of more important phenomena, renouncing any attempt to precisely describe all the causes or the conditions which, at different times, contribute to the occurrence of the landslide. Therefore, slope stabilisation methods in rock or in earth, can be collocated into three types of measure:

- Geometric methods, in which the geometry of the hillside is changed (in general the slope)
- Hydro geological methods, in which an attempt is made to lower the groundwater level or to reduce the water content of the material
- Chemical and mechanical methods in which attempts are made to increase the shear strength of the unstable mass or to introduce active external forces (e.g. anchors, rock or ground nailing) or passive (e.g. structural wells, piles or reinforced ground) to contrast the destabilising forces.

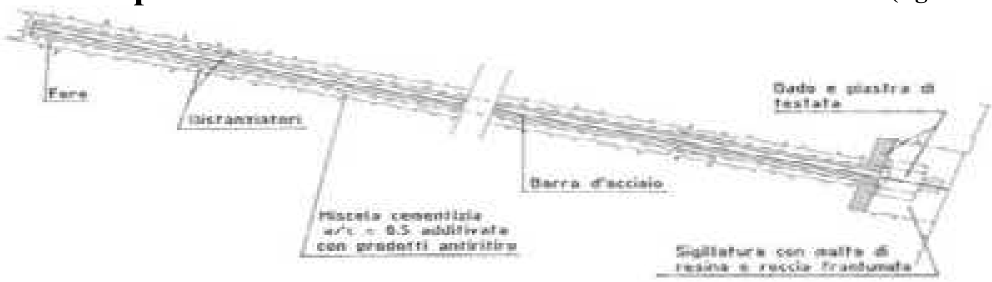
The different type of material conditions the engineering solution adopted; although, it always comes back, in principle, to the previously introduced classification.

DIFFRENT MITIGATION MEASURES TAKEN FOR LANDSLIDES

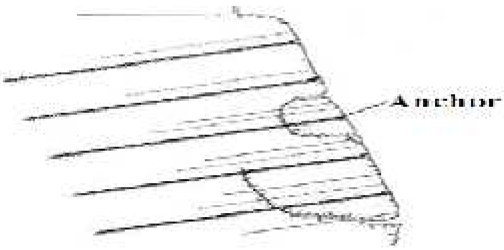
Installation of anchors and nails on unstable rocky hillside

Reinforcement measures generally consist of the introduction of metal elements whose purpose is to increase the shear strength of the rock and to reduce the stress release created, for example, following cutting. Reinforcement measures are made up of metal rock nails or anchors. Anchorage can be classified as active anchorage, in the case in which they are subjected to pre-tensioning, and passive anchorage. Passive anchorage can be used both to nail single unstable blocks and to reinforce large portions of rock. They can also be used as the pre-reinforcement elements of a scarp to be re-profiled in order to limit hillside decompression associated with cutting. In an anchorage are defined: the header: the set of elements (anchorage plate, blocking device, etc.) the header: the set of elements (anchorage plate, blocking device, etc.) the header: the set of elements (anchorage plate, blocking device, etc.) part of the anchor, concreted and otherwise, placed under traction; can be constituted by a metal rod, a metal cable, a strand, etc; the length of the foundation: the deepest portion of the anchor, fixed to the rock with chemical bonds or mechanical devices, which transfer the load to the rock itself, the free length: the non-concreted length. When the anchorage acts over a short length it is defined as a bolt. It is, therefore, a specific type of anchorage, not structurally connected to the free length, made up of an element resistant to traction, normally a steel bar of less than 12 m, protected against corrosion by a concrete sheath. As far as the anchorage device to the ground is concerned, it can be chemical, or use mechanical expansion or concreting.

Rock slopes: Reinforcement measures **(fig no 02)**



Anchor structure **(fig no 03)**



In the first case, some polyester resin cartridges are placed in the perforation to fill the ring space around the end part of the bolt. The main advantage of this type of anchorage lies in its simplicity and in the speed of installation. The main disadvantage is in its limited strength. In the second case, the anchorage is composed of steel wedges driven into the sides of the hole. The advantage of this type of anchorage lies in the speed of installation and in the fact that the tensioning can be achieved in the instant the anchorage is put to work. The main disadvantage with this type of anchorage is that it can only be used with hard rock. Moreover, the maximum traction force is limited.

In the third case, the anchorage is obtained by concreting the whole metal bar. This is the most-used method since the materials are cheap and installation is simple. Injected concrete mixes can be used in many different rocks and grounds; moreover, the concrete sheath protects the bar from corrosion. The concrete mixture is generally made up of water and cement in the ratio W/C = 0.40-0.45, since in this way a sufficiently fluid mixture is obtained to allow pumping into the hole, while at the same time, when set, providing high mechanical strength. As far as the working mechanism of a rock nail is concerned, the strains of the rock induce a stress state in the nail composed of shear and traction stress, due to the roughness of the joints, to their opening and to the direction of the nail, generally non-orthogonal to the joint itself. The execution phases of setting up the nail provides for:

- Formation of any header niche and perforation.
- Setting up of a reinforcement bar (e.g. a 4–6 m long FeB44k bar).
- Concrete injection of the bar.
- Sealing of the header or of the top part of the hole. It is, anyway, suitable to close up and cement any cracks in the rock to prevent pressure caused by water during the freeze-thaw cycles from producing progressive breaking in the reinforcement system set up. To this purpose, a procedure is provided.

1. Cleaning out and washing of the cracks.
2. Plastering of the crack.
3. Predisposition of the injection tubes at suitable inter-axes, parallel to the crack, through which the concrete mix is injected.
4. Sequential injection of the mixture from bottom to top and at low pressure (1-3 atm.) until refusal or until no flow back of the mixture is noted from the tubes placed higher up. The injection mixtures will have approximately the following composition:

Cement - 10 Kg
Water - 65 L
Fluidity and anti-shrinkage additive or bentonite - 1 to 5 Kg
Spriz-Beton (shot Crete)

As defined by the American Concrete Institute "Shot Crete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface. There are two distinct processes of shot Crete application: dry process and wet process. Often the term gunite is used, which refers exclusively to the dry process.

Drainage

The presence of water within a rocky hillside is one of the major factors leading to instability. Knowledge of the water pressure and of the runoff mode is the basis for being able both to carry out credible stability analyses, and to plan measures aimed at improving hillside stability. Hoek and Bray (1981) provide a scheme of possible measures that can be actuated on a hillside to reduce not only the amount of water, which they believe in itself to be negligible as an instability factor, but above all the pressure brought to bear by the water. The proposed scheme was elaborated taking three principles into account:

• Preventing water entering the hillside through open or discontinuity traction cracks.

• Reducing water pressure in the vicinity of potential breakage surfaces through selective shallow and sub-shallow drainage.

• Placing drainage in order to reduce water pressure in the immediate vicinity of the hillside.

The measures that can be achieved to reduce the effects of water can be shallow or in depth. Shallow drainage work has the main function of intercepting surface runoff water and keeping it away from potentially unstable areas. In reality, on rocky hillsides, this type of measure although contributing to reducing the amount of infiltration, alone is insufficient to stabilise a hillside.

Deep Drainage

Deep drainage is the most effective with this type of slope. Sub-horizontal drainage is very effective in reducing pore-pressure along crack surfaces or potential breakage surfaces. In rocks the choice of drain spacing, slope, and length is subordinated to, apart from the hillside geometry, the structural formation of the mass features such as position, spacing and discontinuity opening persistence condition, apart from the mechanical characteristics of the rock, the water runoff mode inside the mass. Therefore, only by intercepting the mostly drained discontinuities can there be an efficient result. The sub horizontal drains are accompanied by surface collectors which gather the water and take it away through networks of small surface channels.

Vertical Drainage

Vertical drainage is generally associated with sunken pumps which have the task of draining the water and lowering the groundwater level. The use of continuous cycle pumps implies very high running costs conditioning the use of this technique for only limited periods. Drainage galleries are rather different in terms of efficiency. They are considered to be the most efficient drainage system for rocks even if they have the drawback of requiring very high technological and financial investment.

In particular, used in rocks this technique can be highly efficient in lowering water pressure. Drainage galleries can be associated with a series of radial drains which augment their efficiency. The positioning of this type of work is certainly connected to the local morphological, geological and structural conditions.

Geometry modification

This type of measure is used in those cases in which, below the material to be removed, the rock face is sound and stable (for example unstable material at the top of the hillside, rock blocks thrusting out from the hillside profile, vegetation that can widen the rock joints, rock blocks isolated from the joints). Detachment measures are carried out where there are risk conditions due to infrastructures or the passage of people at the foot of the hillside. Generally this type of measure can solve the problem by eliminating the hazard. However, it should be ensured that once the measure is carried out, the problem does not re-emerge in the short term. In fact, where there are very cracked rocks, the shallower rock portions can undergo mechanical incoherence, sometimes encouraged by extremes of climate, causing the isolation of unstable blocks. The measure can be affected in various ways, which range from demolition with pick axes to the use of explosives. In the case of high and/or not easily accessible faces, it is necessary to turn to specialists who work acrobatically. When explosives are used, sometimes controlled demolition is needed, with the aim of minimising or nullifying the undesired effects resulting from the explosion of the charges, safeguarding the integrity of the surrounding rock. Controlled demolition is based on the drilling of holes placed at a short distance from each other and parallel to the scarp to be demolished. The diameter of the holes generally varies from 40 to 80 mm; the spacing of the holes is generally about 10 to 12 times the diameter. The charge fuse times are established so that those at the outer edges explode first and the more internal ones successively, so that the area of the operation is delimited.

Protection measures

The protection of natural and quarry faces can have two different aims:

1. Protecting the rock from alterations and
2. Protecting the infrastructure and towns from rock falls.

It is, therefore, necessary to identify above all the cause of the alteration or the possibility of rock fall. Successively, the area of operations needs to be delimited the most suitable procedure to solve the problem and finally to control the effectiveness of the measure itself over a period of time.

The most-used passive protection measures are:

1. Boulder-gathering trenches at the foot of the hillside,
2. Metal containment nets, and
3. Boulder barriers.

As far as the boulder barriers are concerned, they are generally composed of suitably rigid metal nets. Moreover, lately, various structural types have been put on the market for which the manufactures specify the kinetic energy of absorption. One of the structural control methods for boulder containment nets starts from the concept of projectile collision, on the basis of which the maximum applied force and the corresponding resultant buckling are expressed, by means of a static analysis, leading to the quantification of the forces divided up among the various structural elements.
Another type of boulder containment barrier is the earth embankment, possibly reinforced with geo-synthetics (reinforced ground). The advantage of this type of work, compared to nets, is easier maintenance and lower environmental impact minor the absorption of kinetic energy is generally greater than that of metal nets.

GEOMETRY MODIFICATION

Soil slopes

The operation of re-profiling a slope with the aim of improving its stability can be achieved through various procedures:

• Lowering the slope

• Positioning infill at the foot of the slope

Slope re-profiling work

Slopes can be reduced by digging out the brow of the slope. This is effective for correcting shallow forms of instability, where movement is limited to layers of ground near to the surface and when the slopes are higher than 5m. Moreover, the steps created in this way and suitably achieved also reduce surface erosion. However, caution should be exercised to avoid the onset of local breakage following the cuts made. Infill at the foot of the slope, instead, has a stabilising effect in the case of translational or deep rotational landslide, in which the landslide surface at the top submerges and describes a sub-vertical surface that re-emerges in the area at the foot of the slope. The choice of reducing the slope and infilling at the foot is rarely a problem since there are generally specific constraints to be respected at the top or at the foot of the slope.

Generally, in slope stabilisation where there are no constraints (often this occurs for natural slopes) a combination of slope reduction and infilling at the foot of the slope is adopted to avoid heavy work of just one type. Included among work at the foot of the slope are the beam and some gravitational structures like gabions or reinforced ground, that is, concrete blocks. In the case of natural slopes, the choice of re-profiling scheme is not as clear as in the case of artificial slopes. Often the profile is highly irregular with large areas of not recent natural creep, so that its shallow development can make some areas unserviceable as a cutting or infill point. Where the buried shape of the old landslide is complicated, depositing of infill material in one area can lead to destabilising another. When planning this type of work the stepping effect of the cuts and infill should be taken into account: their beneficial influence on the increase in Safety Factor will be reduced in relationship to the size of the landslide under examination. Moreover, it is very important to ensure that neither the cuts nor the infill mobilize the existing or potential creep plane of the landslide. Generally, infilling at the foot of the landslide should be preferred to cutting at the top (to reduce weight at the top of the slope), since the latter solution proves to be often more expensive than the former. Moreover, in complex and compound landslides, infill at the foot of the slope, at the tip of the foot itself, has a lesser probability of interfering with the interaction of the individual landslide elements. An important aspect of stabilisation work that changes the morphology of the slope is that in more precisely mechanical terms, effecting cuts and infill generates non-drained charge and discharge stresses. In fact, in the case of positioning infill, the safety factor SF, will be less in the short term than in the long term. In the case of affecting a cut in the slope, SF will be less in the long term rather than in the short term. Therefore, in both cases, it is opportune to calculate the SF both in the short and the long term. Finally, it should be remembered that the effectiveness of infill increases with time on condition that it is associated with an appropriate infill drainage system, obtained through an underlying drainage cover or appropriate shallow drainage. More generally, therefore, re-profiling systems are associated with and integrated by surface protection of the slope against erosion and by regulation of meteoric waters through drainage systems made up of ditches and small channels (clad or unclad and prefabricated) to run off the water collected.

(Picture no 01)

Surface water run off system by prefabricated channels

These surface water regulation systems are obtained by modeling the land itself around the body of the landslide large ground ditches in the case of incoherent material landslides) or by means of flexible suitably placed drainage pipes able to collect the water.

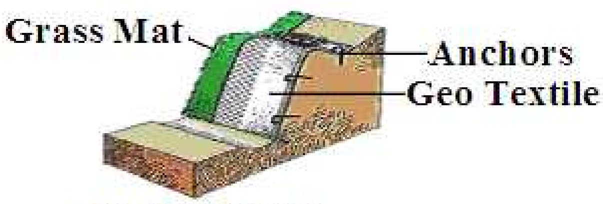
(Picture no 02)
Micro-perforated flexible drainage tubes

These provisions will serve the purpose of avoiding penetration of the landslide body by circulating water or into any cracks or fissures, further decreasing ground shear strength. A problem that could be caused by water near the surface of the hillside is the erosion of surface material due to water runoff. This proves hazardous in terms of stability since it tends to weaken the slope by removing material as well as triggering excess pressure due to the water flow. For defense against erosion, a series of solutions can be used, such as:

- Geo-mats
- Geo-grids
- Brushwood mats

Geo-mats

These measures share the superficial character of their installation given their low environmental impact. Geo-mats or rather anti-eroding bio mats or bio-nets are purpose-made synthetic products for the protection and grassing of slopes subject to surface wash through two main erosion control mechanisms: the containment and reinforcement of the surface ground; the protection from the impact of the raindrops.



Picture No 03
Typical anti-erosion solutions with geo-mats

Picture No 04
Anti-erosion solutions with the use of bio-nets: typical scheme

Anti-erosion solutions with the use of bio-nets: types of bio-nets

Geo-grids

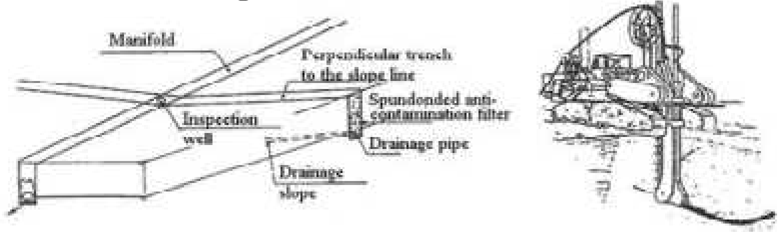
Wicker or brushwood mats are made of vegetal material. Very long and flexible willow branches can be used, which are then covered with infill soil. Alternating stakes of different woody species are used and they are woven to form a barrier against the downward drag of the material eroded by the free water on the surface

Picture NO 06: Typical brushwood solutions

Draining techniques

Drainage systems are adopted to reduce the neutral stresses in potentially unstable hillside. In terms of safety for global stability, these measures translate into the lowering of water level inside the mass, which consequently leads to reduction in pore-pressure in the ground and an increase in the shear strength available in particular along the potential creep surface. In relation to hillside morphology, the kinematics of movement predicted and to the depth of the creep surfaces, reduction in pore-pressure by drainage can be obtained using shallow and deep drains. Usually, shallow drainage is adopted when the potential hillside movement is foreseen as shallow landslide affecting the ground to a depth of about 5-6m. When there is deeper surface slipping, deep drainage has to be introduced, but shallow drainage systems can be provided anyway with the aim of running off that aliquot of surface water directly connected to seasonal rainfall.

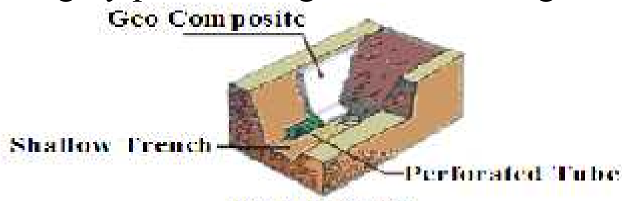
Shallow drainage



Picture no. 07. Typical shallow drainage trenches

There are two types of shallow drainage solution:-

Shallow drainage trenches: Traditional drainage trenches are cut in an unbroken length and filled with highly permeable granular draining material;



Picture No 08

Shallow drainage trenches equipped with Geo-Composite: typical scheme Shallow drainage trenches equipped with geo-composites, these systems consist of unbroken trenches with scarped sides covered with geo-composites, generally with 25m long panels having draining characteristics. The bottom of the trench houses a drainage tube with the task of bottom discharge placed in continuity the geo-composite canvas.

Deep drainage

Deep drainage acts by modifying the filtration routes in the ground. Often they are more expensive than shallow drains, but they are usually more effective because they remove the quantity of water that induces instability in the hillside, from within the ground and diminish the neutral stresses directly where necessary. Deep drainage in earth slopes can be obtained by means of the following works: large diameter drainage wells equipped with sub-horizontal drains. These systems can have just a structural function, just a draining function or both. The draining elements are the micro-drains, perforated and positioned sub-horizontally and fanned out, orientated uphill to favor water discharge by gravity.

The size of the wells is chosen with the aim of allowing the insertion and functioning of the perforation equipment for the micro-drains. Generally, the minimum internal diameter to be adopted must be greater than 3.5 m, for drains with a length of 20 to 30 m.

Longer drains require wells with a diameter of up to 8-10 m. To determine the network of micro-drains planners have to take into consideration the makeup of the subsoil and the hydraulic regime of the slope, to provide for the correct number and distribution of the micro-drains. The drainage in these wells is passive, realised by linking the bottom of adjacent wells by sub-horizontal perforations (provided with temporary sheathing pipes) in which the micro-drains are placed at a gradient of about 15-20° and are equipped with micro-perforated PVC pipes, protected by non-filtering fabric along the draining length.

Once all the drain is inserted in the hole and having embedded the latter in the ground, the temporary sheathing is completely removed and the head of the drain is cemented to the well. In this way, a discharge line is created linking all the wells emerging to the surface downhill, where the water is discharged naturally without the help of raising pumps.

The wells are placed at such a distance apart that the individual collecting areas of the micro-drains, appertaining to each well, are overlaid. In this way all the volume of the slope involved with the water table is drained. Medium-diameter drainage wells linked at the bottom. The technique involves the dry cutting with temporary sheathing pipes, of aligned drainage wells, with a diameter of 1200-1500 mm, positioned at an inter axis of 6-8 m, their bottoms linked together to a bottom tube for the discharge of drained water. In this way, the water discharge takes place passively, due to gravity by perforated pipes with mini-tubes, positioned at the bottom of the wells themselves. The linking pipes, generally made of steel, are blind in the linking length and perforated or windowed in the length corresponding to the well. The wells have a concrete bung at the bottom and are filled, after withdrawal of the temporary sheathing pipe, with dry draining material and are closed with an impermeable clay bung.

In normal conditions, these wells reach a depth of 20-30 m, but, in especially favorable cases, a depth of even 50 m can be reached. Some of these wells have drainage functions across their whole section and others can be inspected. The latter serve for maintenance of the whole drainage screen. Such wells that can be inspected are also a support point for the creation of new drainage wells and access for the installation, also on a later occasion, for a range of sub-horizontal drains at the bottom or along the walls of the wells themselves, with the purpose of increasing the drainage capacity of the well.

• Isolated wells fitted with drainage pumps this system provides for the installation of a drainage pump for each well. The distribution of the wells is established according to the permeability of the land to be drained, the lowering of the water pressure to be achieved and the area that has to be involved in this work, so that the water pressure area deriving from the depression fans generated by the single drainage points, responds to the needs of the plan. The use of isolated wells with a drainage pumps leads to high running costs and imposes a very time-consuming level of control and maintenance.

• Deep drainage trenches-Deep drainage trenches consist of unbroken cuts with a small cross-section that can be covered at the bottom with geo-fabric canvas having a primary filter function. They are filled with draining material that has a filtering function and exploits the passive drainage to carry away the drained water downhill. The effectiveness of these systems is connected to the geometry of the trench and the continuity of the draining material along the whole trench. As far as the geometry of the cut is concerned attention should be paid to the slope given to the bottom of the cut. In fact, deep drainage trenches do not have bottom piping that is inserted in the end part of the trench, downhill, where the depth of the cut is reduced until the campaign level is reached.

• Drainage galleries fitted with micro-drains-Drainage galleries constitute a rather expensive stabilisation provision for large, deep landslide movements, to be carried out where the ground is unsuitable for cutting trenches or drainage wells and when it is impossible to work on the surface owing to a lack of space for the work machinery. Their effectiveness is due to the extensiveness of the area to be drained. Moreover, these drainage systems have to be realised on the stable part of the slope. The drainage systems are placed inside the galleries and are made up of micro-drains, with lengths that can reach 50–60 m and are spatially orientated in a suitable direction. The sizes of the galleries are conditioned by the need to insert the drain perforation equipment. For this reason, the minimum transversal internal size of the galleries vary from a minimum of 2 m, when using special reduced size equipment, and to at least 3.5 m, when using traditional equipment.

• Siphon drain - This is a technique conceived and developed in France, which works like the system of isolated drainage wells but overcoming the inconvenience of installing a pump for each well. In fact, the system on the principle that once motion is triggered in the siphon tube, avoiding the entry of air into the loop, the motion is uninterrupted. For this reason, in this system, the condition that the two ends of the siphon tube are submerged in the water of the two permanent storage tanks, must always be checked. This drain is created vertically starting from the campaign level (figure 25), but can also be sub-vertical or inclined. The diameter of the well can vary from 100 to 300 mm; inside a PVC pipe is placed or a perforated or micro-perforated steel pipe, filled with draining material. The siphon drain in this way carries off of drainage water by gravity without the need for drainage pumps or pipes linking the bottom of each well. This system proves to be economically advantageous and relatively simple to set up even if it necessitates a program of controls and maintenance.

• Micro-drains are a simple to create drainage system with contained costs. They consist of small diameter perforations, made from surface locations, in trenches, in wells or in galleries. The micro-drains are set to work in a sub-horizontal or sub-vertical position, according to the type of application.

Reinforcement measure

The stabilization of the hillside in terms of an increase in the mechanical characteristics of the potentially unstable ground can be effected by means of two different approaches:

• Insertion of reinforcement elements in the ground.

• The improvement of the mechanical characteristics of the ground volume affected by landslide through chemical, thermal or mechanical treatment.

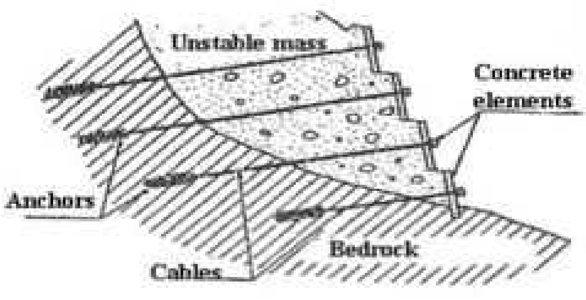
Insertion of reinforcement elements in the ground

This category of work uses:

- Large diameter wells supported by one or more crowns of consolidated and possibly reinforced earth columns;
- Anchors
- Networks of micro-piles
- Nailing/Rock Bolting
- Geo-grids for reinforced ground
- Cellular faces

Large diameter wells supported by one or more crowns of consolidated and possibly reinforced earth columns to guarantee slope stability it may be necessary to insert very rigid, strong element. These elements are large diameter full section or ring section reinforced concrete wells. The wells can have a circular or elliptical section. The depth of the static wells can reach 30-40m. Often the static stabilising action of the wells is integrated with a series of micro-drains laid out radially on several levels, also to reduce pore-pressure, if it is hazardous.

Anchors



Picture No 09: Stabilization using anchors

The equilibrium of an unstable slope also can be achieved by increasing resistance to land sliding by means of the application of active forces to the unstable ground. These forces increase the normal stress and therefore resistance to friction along the creeping surface. Anchors can be applied for this purpose, linked at the surface to each other by a beam frame, which is generally made of reinforced concrete. Here, the anchors are installed at node points. The anchors are then fixed in a certainly stable place. They are usually realised with orthogonal axes to the slope surface and therefore, at first approximately orthogonal to the surface of the creep. The adoption of this system sometimes gives anchorage problems, as in the case of silt-clayey ground. In fact, where there is water or the anchors are embedded in a clayey sub-layer, the adherence of the anchor to the ground has to be assured. Moreover, it is opportune that the surface contained within the grid of the beam frame is protected, using geo-fabrics, in order to avoid erosion removing the ground underlying the beam frame.

Networks of micro-piles

This solution provides for a plant of a series of micro-piles that make up a three-dimensional grid, variably tilted and linked at the head by a rigid reinforced concrete mortise. This structure constitutes reinforcement for the ground, inducing an intrinsic improvement of the ground characteristics incorporated in the micro-piles. A measure of this type proves effective in cases of not very extensive landslide.

The effectiveness of solutions with micro-piles is linked to the possibility of inserting micro-piles over the whole width of the landslide area. In the case of rotational landslides in soft clay, the piles contribute to increasing the resisting moment by friction on the upper part of the pile shaft found in the landslide. This functionality is usually valid for micro-piles working using the point. In the case of suspended piles, strength is governed by the part of the pile offering the least resistance. As an operational method, those piles that destined to the most unstable area of the slope should be positioned first, subsequently those around the unstable area, in order to reduce any possible lateral ground displacements.

Preliminary design methods for the micro-piles, nowadays, are entrusted to the use of codes that carry out numerical simulations, but which are subject to simplifications in the models that necessitate characterisations of rather precise potential landslide material.

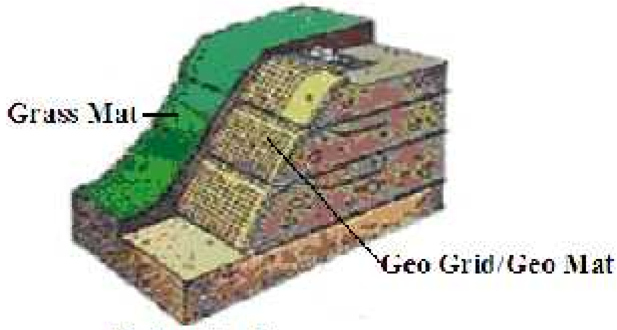
Nailing/Rock Bolting

The soil-nailing technique applied to temporarily and/or permanently stabilise natural slopes and artificial scarps, fall back on a fundamental principle in the field of construction technique: mobilizing the intrinsic mechanical characteristics of the ground, such as cohesion and the angle of internal friction, so that the ground actively collaborates with the stabilisation work. Nailing, on a par with anchors, induce normal stress to the advantage of stability. One nailing solution is that of rapid response diffuse nailing: CLOUJET, where the nails are embedded in the ground by means of an expanded bulb obtained by means of injecting mortar at high pressure into the anchorage area.

Drainage is an integral part of the CLOUJET project since the hydraulic regime, considered in the form of pore-pressure applied normally to the fractured surfaces, directly influences the characteristics of the system.

The drained water, both through fabric and by means of pipes embedded in the ground with a pre-determined gradient, flows together at the foot of the slope where it is collected in a suitable collector parallel to the direction of the face.

Another system suitable for stabilizing slopes and landslides is a soil nails and root technology (SNART). Here, steel nails are inserted very rapidly into a slope by percussion, vibration or screw methods. Grid spacing is typically 0.8 to 1.5 m, nails are 25 to 50 mm in diameter and may be as long as 20 m. Nails are installed perpendicular to and through the failure plane (or potential failure plane), and as such are designed in bending and shear (rather than tension) using geotechnical engineering principles. Potential failure surfaces less than 2 m deep normally requires the nails to be wider near the top and is typically achieved with steel plates fastened at the nail heads. An effective and aesthetic facing to prevent soil loss between the nails can be designed using plant roots.



Picture No 10

Picture No 11

Picture No 12

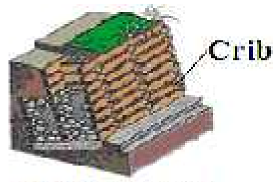
Rock Bolting at Pabong Bridge, South Sikkim

Typical geo-grid solution

Geo-grids

The geo-grids are synthetic materials used to reinforce the ground. The insertion of geo-synthetic reinforcements, (generally in the direction in which the deformation has developed) therefore, has the function of reinforcing the ground conferring greater stiffness and stability upon it and the capacity to be subjected to greater deformations without reaching fracture point.

Cellular faces



Picture No 13
CRIB WALL

Cellular faces, also known by the name of "crib faces" are special supporting walls realised by means of head grids prefabricated in reinforced concrete or in wood (treated externally with preservatives). The heads have a length of about 1-2m and the work can also reach 5m in height.

Compacted granular material is inserted in the spaces of the grid. The characteristic modularity of the system confers notable flexibility of use on its use both in terms of adaptability to the morphology of the ground and because the structure does not require any deep foundation other than a laying plane of lean concrete useful to make the support plane of the whole structure regular. This solution can also take vegetal ground into the grid spaces, to favour the camouflaging of the work into the surroundings by means of the vegetation rooting on the exposed face.

Improvement in the mechanical characteristics of the soil volume affected by landslide by means of chemical, thermal or mechanical treatment

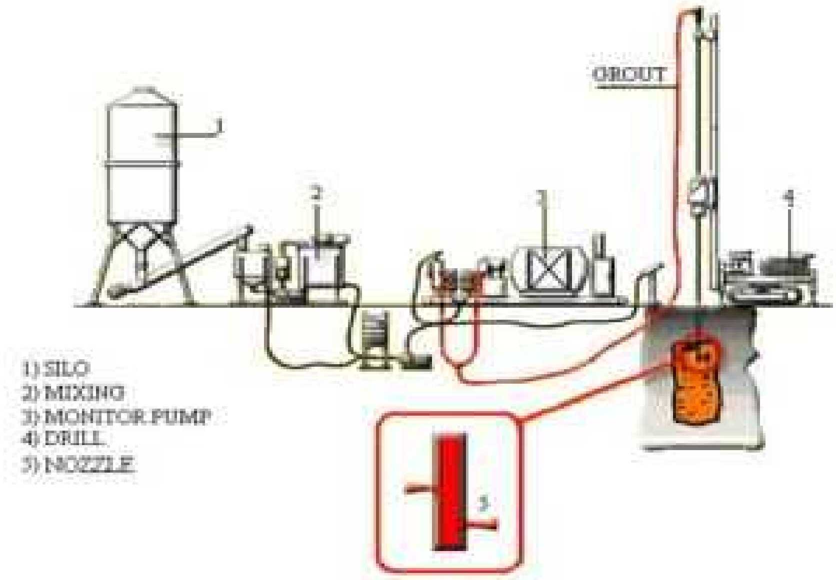
Among the treatments belonging to the group of intrinsic improvements of a mechanical character in the ground, the technique of jet-grouting is often used, in particular as a substituting and/or integrating element for technologies used for the previously described structural measures. The phases of this work are:

PHASE I Perforation phase

Insertion, with perforation, destroying the nucleus of a set of poles into the ground upto the depth of treatment required by the project.

PHASE II Extraction and programmed injection phase

Injection of the mixture at very high pressure is done during the extraction phase of the set of poles. It is in this phase that through the insistence of the jet in a certain direction for a certain interval of time, the effect is obtained by the speed of extraction and rotation of the set of poles, so that volumes of ground can be treated in the shape and size desired.



Picture No 14: Jet-grouting device

The high energy jet produces a mixture of the ground and a continuous and systematic "clauage" with only a local effect within the radius of action without provoking deformations at the surface that could induce negative consequences on the stability of adjacent constructions. The projection of the mixture at high speed through the nozzles, using the effect of the elevated energy in play, allows the modification of the natural disposition and mechanical characteristics of the ground in the desired direction and in accordance with the mixture used (cement, bentonite, water, chemical, mixtures etc.). Depending on the characteristics of the natural ground, the type of mixture used, and work parameters; compression strength from 1 to 500 Kgf/cm² (100 KPa to 50 MPa) can be obtained in the treated area.

The realization of massive consolidated ground elements of various shapes and sizes (buttresses and spurs) within the mass to be stabilized, is achieved by acting opportunely on the injection parameters. In this way the following can be obtained: thin diaphragms, horizontal and vertical cylinders of various diameter and generally any geometrical shapes.

Another improvement system of the mechanical characteristics of the ground is that of thermal treatment of potentially unstable hillsides made up of clayey materials. Once on the railways, for the treatment of unstable slopes in clayey grounds, the lighting of wood or coal fires was used in holes dug into the slope, to harden the surrounding ground. In large diameter holes (from 200 to 400 mm), about 0.8-1.2m apart and horizontally interconnected, burners were introduced to form cylinders of hardened clay. The temperatures reached were around 800°C. These clay cylinders worked like piles giving greater shear strength to the creep surface. This system was useful for surface creep, as in the case of an embankment. In other cases the depth of the holes or the amount of fuel necessary led to either the exclusion of this technique or made the effort ineffective.

Other stabilization attempts were made by using electro-osmotic treatment of the ground. This type of treatment is applicable only in clayey grounds. It consists of subjecting the material to the action of a continuous electrical field, introducing pairs of electrodes embedded in the ground. These electrodes, when current is introduced cause the migration of the ion charges in the clay. Therefore the inter-pore waters are collected in the cathode areas and they are dragged by the ion charges. In this way a reduction in water content is achieved. Moreover, by suitable choice of anodic electrode a structural transformation of the clay can be induced due to the ions freed by the anode triggering a series of chemo-physical reactions improving the mechanical characteristics of the unstable ground.

This stabilization method, however, is effective only in homogeneous clayey grounds. This condition is hard to find in unstable slopes; therefore, electro-osmotic treatment after some applications has been abandoned.

PART FOUR

GSI MAPPING OF LANDSLIDE VULNERABLE AREAS OF NORTH SIKKIM

INTRODUCTION

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 average elevation of over 2500 m asl is desolate and bleak without any sign of healthy vegetation and prospect for scale are cultivation Ice, glaciers and glaciated area with ice [819.84km^2 and barren land, rock exposure and talus fields [1033.16km^2] and glaciated valley, moraines & alpine meadow [1200km^2] 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 Km^2 (2.96%) as farmers of cultivable area 125.72Km^2 (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).

The main aim of this study is to gain first hand knowledge of geological geo-environmental processes at work at high altitude watershed level. The other objectives of the study are to ground-truth existing geological, glaciological and hydrological systems of the area and also find out the probable flood behavior of Lachen and Lachung chu, re-evaluate the report of the reconnoitery survey of short spells carried out by the Govt. during 1998-99, particularly along Tsungthang-Lachen-Thangu-Gurudongmar and Tsungthang-Lachung-Yumthang-Tumesamdong-Tenbawa sections and the primary field data collected during the survey. Special attention was given to sections between 2500 meters to 4500 meter altitude levels. As rest of the area, the terrain had been under glacial domain, as exhibited by old and new glacial, periglacial and fluvioglacial landforms. Quaternary deposits such as moraines, tills, windblown sand, and outwash sand with immature soil profiles formed, perhaps, during interglacial periods, basins with sand and gravel lenses in glacial outwash, frost shattered rock strewn undulating & jagged surfaces over ridge areas and valley sides were carefully observed and samples collected for analyses. (Table 6) An attempt has been made to calculate the most probable peak and lean water discharge values of Lachen and Lachung chu (Table 3-4) by conventional field methods.

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.

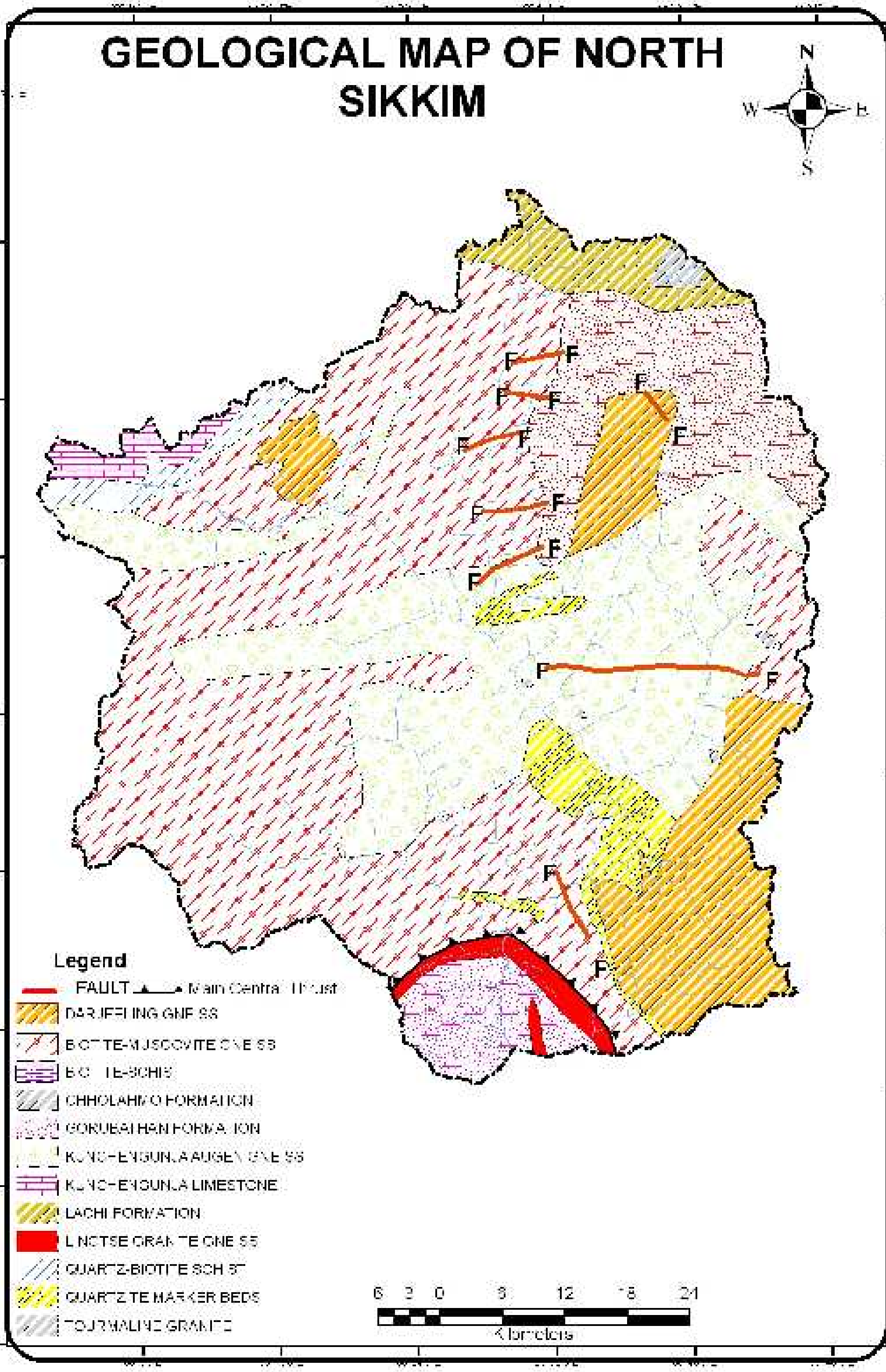
Chhubakha Series – Fine grained granite with Garnet, Tourmaline and Hornblende inclusions, Pegmatite, Lime Silicates etc.

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

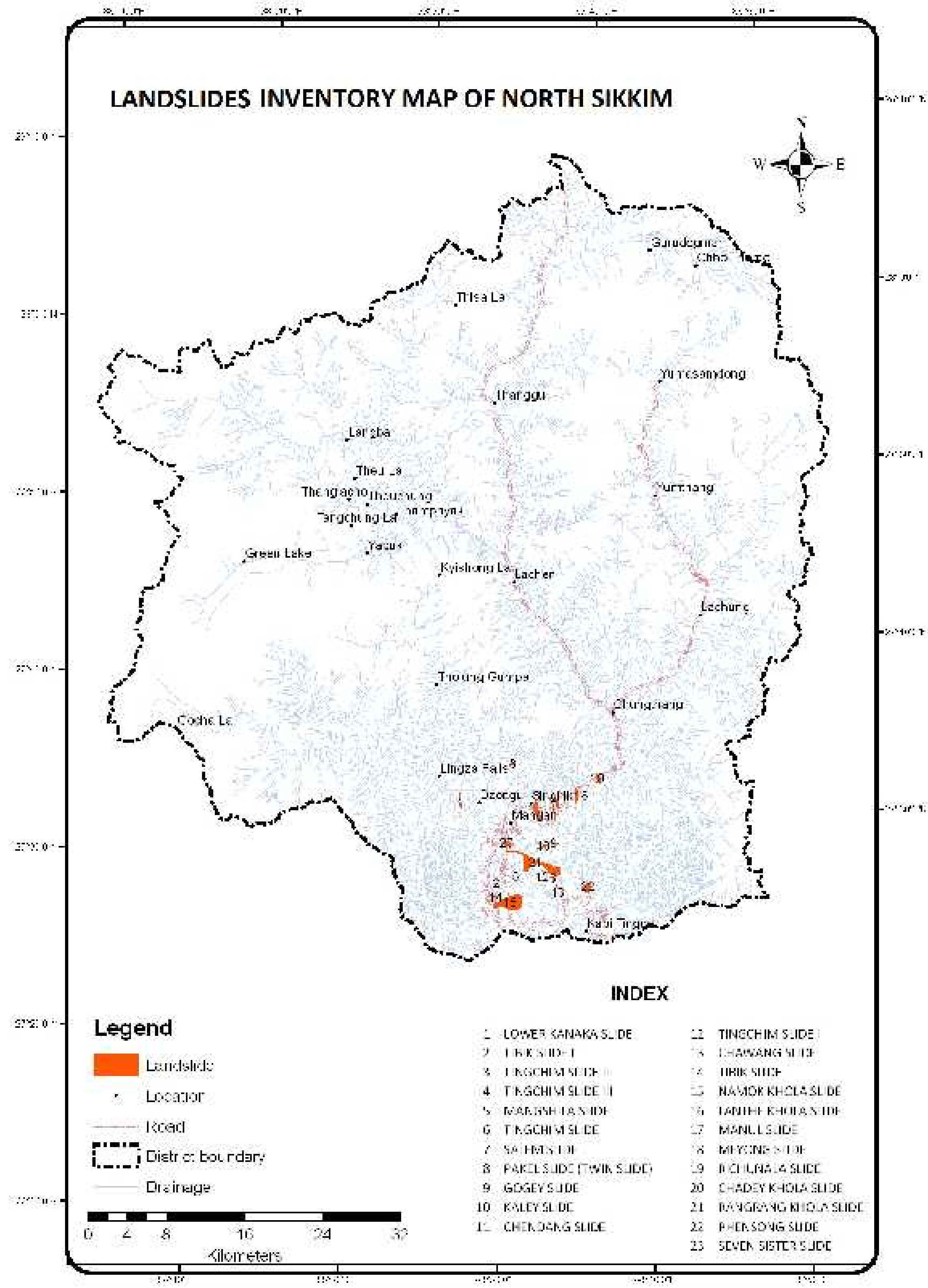
Leema on Tsungthang-Lachung road and upto Jorephul area on Lachen road section. The Quartzites in the area are exposed as alternating bands with the gneisses. The bands vary in thickness and have inclusions of Garnet at Bop area on Lachung road section. The gneiss show compositional bandings in the form 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 calc-silicate rocks of this area are marked by intense folding and characteristics of differential weathering.

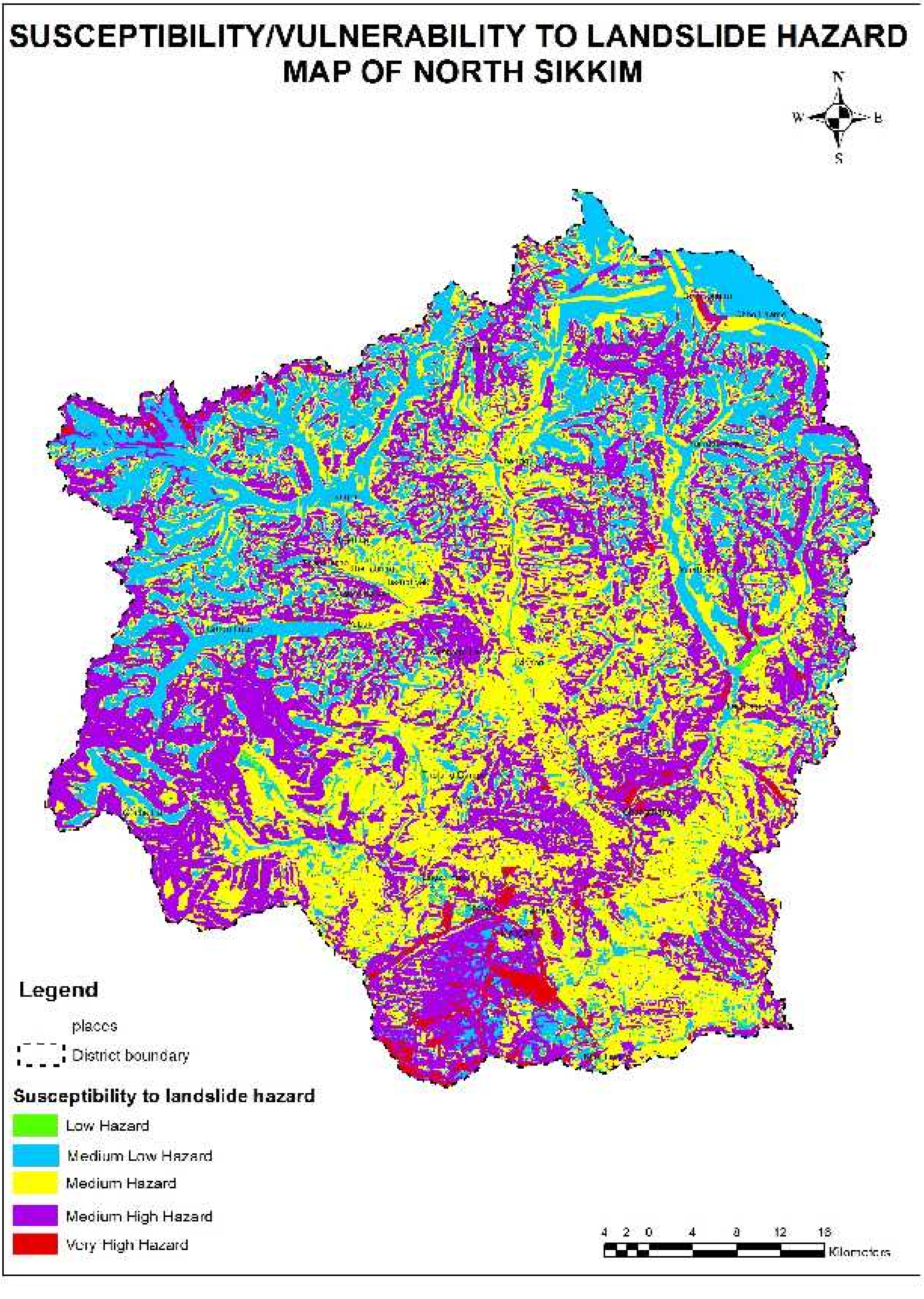
The overlying sequence of Tsungthang series are the rocks of Chhubakha series (Raina & Bhattacharya 1962). The rock belongs to the Precambrian age just as that of the Tsungthang rock sequences. The rock types present in these sequences are Calc-gneiss, Granulites with intercalation of Quartzite, quartz 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 pre-dominance of feldspar and hornblende. The gneisses of Chhubakha series however, show rusty brown appearance in most of the exposures.

(Map No 05)


GEOLOGICAL MAP OF NORTH SIKKIM
N
W
E
S
Legend
FAULT
Main Central Thrust
DARJEELING GNEISS
BIOTITE-MUSCOVITE GNEISS
BIOTITE-SCHIST
CHHOLAHMO FORMATION
GORUBATHAN FORMATION
KUNCHENGUNJA AUGEN GNEISS
KUNCHENGUNJA LIMESTONE
LACHI FORMATION
LINGTSE GRANITE GNEISS
QUARTZ-BIOTITE SCHIST
QUARTZITE MARKER BEDS
TOURMALINE GRANITE
6 3 0 6 12 18 24
Kilometers

(Map No 06)


LANDSLIDES INVENTORY MAP OF NORTH SIKKIM
N
S
W
E
Thanggu
Yumthang
Green Lake
Lachen
Lachung
Chungthang
Mangan
Legend
Landslide
Location
Road
Drainage
0
4
8
16
24
32
Kilometers
INDEX
1 LOWER KANAKA SLIDE
3 TINGCHIM SLIDE II
4 TINGCHIM SLIDE II
6 TINGCHIM SLIDE
8 PAKEL SLIDE (TWIN SLIDE)
9 GOGEY SLIDE
10 KALEY SLIDE
11 CHENDANG SLIDE
12 TINGCHIM SLIDE I
14 TIRIK SLIDE
15 NAMOK KHOLA SLIDE
17 MANUL SLIDE
20 CHADEY KHOLA SLIDE
22 PHENSONG SLIDE
23 SEVEN SISTER SLIDE


SUSCEPTIBILITY/VULNERABILITY TO LANDSLIDE HAZARD
MAP OF NORTH SIKKIM
N
W
E
S
Legend
places
District boundary
Susceptibility to landslide hazard
Low Hazard
Medium Low Hazard
Medium Hazard
Medium High Hazard
Very High Hazard
4 2 0 4 8 12 16
Kilometers

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 Quartzites are grayish 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 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 asl. are dominate 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 asl. 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. An 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 aquifers 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 4^{th}. 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 remodeled 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;

(Table No 09)

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;

(Table No 10)

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 INCIDENCE

The entire land cover of the earth is affected by mass movements or mass wasting processes. The magnitude, intensity and frequency of such processes vary from one geographical region to another and are triggered by a contributing factor or a number of contributing factors in tandem. The most common form of erosion or mass movement in the Himalayas is the landslides. The North Eastern Himalayas experience very high incidence of landslides practically every year. The landslide events are episodic, time dependent and climate controlled. During monsoons, landslides destroy road communication systems, civil structures, life and property.

The Government of Sikkim is well aware of the negative impact of landslides to the State and the Nation. It has consistently mandated few of the State Government departments to carry out systematic study of landslide problems in the State. Prior to undertaking such a systematic study, the DSTs (Govt. of India & Sikkim) felt the need of a status report on landslides in Sikkim which will be the basis for preparation of an action plan for undertaking landslide studies in the State. To tackle the topical issue of landslide problems in the State, a number of aficionados of landslide had visited Sikkim and published their findings in journals and presented at symposia. The Geological Survey of India (GSI) had also carried out a large amount of work on landslide problems of the State in the past and its findings were published in their records, memoirs and special publications. After the Tenth Five Year Plan, the GSI was declared as the nodal agency to carry out landslide incidence studies in the country and provide appropriate solutions to address the menace. The Department of Mines, Minerals and Geology, Government of Sikkim, as mandated carried out a number of landslide studies in the past and records are available. Prior to year 2002, the Department of Science and Technology, (DST), Government of India, was seriously contemplating in establishing a multi-disciplinary cell dedicated to landslide studies only in the State of Sikkim. A team of geo-scientists visited the State in 2002 to meet the Chief Secretary, the Vice Chancellor of Sikkim Manipal

University and other concerned Secretaries to discuss the issue of establishing a cell dedicated to landslide studies. The team found that there is a clear lack of coordination among agencies working on landslide problems in the State. As stated the GSI as the nodal agency for landslide studies in the country should now think of the proposal mooted by DST to address the problem in the border State of Sikkim. If a multi-disciplinary cell dedicated to landslide problems is established by GSI, it will have far reaching benefits of economic development and environmental sustainability for the state. The cell should give due attention to geotechnical aspect of landslide studies which is generally absent today and detailing on large scale maps [1:1000 or 1:5000] also. This report contains details of landslides in the form of an inventory for each landslide so that the reader is provided with all the necessary information on any slide in the State. Landslides can be seen, can be experienced but cannot be explained explicitly or completely by everyone due solely to specificities of individual locations. Therefore, landslide study will remain forever topical.

1. NAME OF SLIDE: - TINGCHIM SLIDE II

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Tingchim slide II	
3.	Location	Latitude	N 27^{o}.45074208’
		Longitude	E 88^{o}.57831328’
4.	Altitude		
5.	Geological Setting	Highly disturbed daling group of rocks.	
6.	Slide Type	Subsidence	
7.	Slide Material	Debris with huge boulders.	
8.	Average Depth (In Mts)	8m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	450m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	22500m^2	
13.	Failed Volume(M^3)	180000m^3	
14.	Damage Done	Forest, agriculture field	
15.	Age	Old	
16.	Triggers	Adverse geology, High ground/rain water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	No point, beyond human intervention	

2. NAME OF SLIDE: - TINGCHIM SLIDE III

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Tingchim slide III	
3.	Location	Latitude	N 27 ^{o}.44918495'
		Longitude	E 88 ^{o}.56609410'
4.	Altitude		
5.	Geological Setting	Adverse geology	
6.	Slide Type	Debris slide	
7.	Slide Material	Debris with boulders and fines	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	60m	
11.	Width (In Mts)	25m	
12.	Area (M^2)	1500m^2	
13.	Failed Volume(M^3)	7500m^3	
14.	Damage Done	Agriculture land, forest, houses	
15.	Age	Old	
16.	Triggers	High ground & rain water, slope, bad geology.	
17.	Likely Return Period	Dormant	
18.	Coping Mechanism	Effective drainage, Afforestation.	

3. NAME OF SLIDE: - MANGSHILA SLIDE

<table>
<tr><th>SL. NO</th><th>PARTICULARS</th><th colspan="2">COMMENTS</th></tr>
<tr><td>1.</td><td>District</td><td colspan="2">North Sikkim</td></tr>
<tr><td>2.</td><td>Name Of The Slide</td><td colspan="2">Mangshila slide</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">Location</td><td>Latitude</td><td>N 27 °.45317238’</td></tr>
<tr><td>Longitude</td><td>E 88 °.54025871’</td></tr>
<tr><td>4.</td><td>Altitude</td><td colspan="2"></td></tr>
<tr><td>5.</td><td>Geological Setting</td><td colspan="2">Highly disturbed geological formation</td></tr>
<tr><td>6.</td><td>Slide Type</td><td colspan="2">Debris slide</td></tr>
<tr><td>7.</td><td>Slide Material</td><td colspan="2">Debris with boulders & soil</td></tr>
<tr><td>8.</td><td>Average Depth (In Mts)</td><td colspan="2">5m</td></tr>
<tr><td>9.</td><td>Maximum Depth (In Mts)</td><td colspan="2">8m</td></tr>
<tr><td>10.</td><td>Length (In Mts)</td><td colspan="2">300m</td></tr>
<tr><td>11.</td><td>Width (In Mts)</td><td colspan="2">15m</td></tr>
<tr><td>12.</td><td>Area (M^2)</td><td colspan="2">4500m^2</td></tr>
<tr><td>13.</td><td>Failed Volume(M^3)</td><td colspan="2">22500m^3</td></tr>
<tr><td>14.</td><td>Damage Done</td><td colspan="2">Agricultural land, road, houses</td></tr>
<tr><td>15.</td><td>Age</td><td colspan="2">Old</td></tr>
<tr><td>16.</td><td>Triggers</td><td colspan="2">Bad geology, high ground/rain water</td></tr>
<tr><td>17.</td><td>Likely Return Period</td><td colspan="2">NA</td></tr>
<tr><td>18.</td><td>Coping Mechanism</td><td colspan="2">Effective drainage, retaining walls</td></tr>
</table>

4. NAME OF SLIDE: - TINGCHIM SLIDE

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Tingchim slide	
3.	Location	Latitude	N 27 ^{o}.45657820’
		Longitude	E 88 ^{o}.53853194’
4.	Altitude		
5.	Geological Setting	Bad geology	
6.	Slide Type	Debris slide	
7.	Slide Material	Debris with boulders & soil	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	8m	
10.	Length (In Mts)	350m	
11.	Width (In Mts)	20m	
12.	Area (M^2)	7000m^2	
13.	Failed Volume(M^3)	35000m^3	
14.	Damage Done	Road, house, agricultural land	
15.	Age	Old	
16.	Triggers	Bad geology, steep slope, water	
17.	Likely Return Period	NA	
18.	Coping Mechanism	Good drainage system, Effective walls.	

5. NAME OF SLIDE: - SALEM SLIDE

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Salem slide	
3.	Location	Latitude	N 27^{o}.54162600'
		Longitude	E 88^{o}.50190454'
4.	Altitude	1190 m amsl.	
5.	Geological Setting	High grade Metamorphic terrain gneissic rocks.	
6.	Slide Type	Debris fall	
7.	Slide Material	Soil & Rock fragments	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)		
10.	Length (In Mts)	426m	
11.	Width (In Mts)	130m	
12.	Area (M^2)	55380m^2	
13.	Failed Volume(M^3)	553800m^3	
14.	Damage Done	Forest	
15.	Age	Recent	
16.	Triggers	Adverse geology, slope, rainfall	
17.	Likely Return Period	NA	
18.	Coping Mechanism	Avoid	

6. NAME OF SLIDE: - PAKEL SLIDE (TWIN SLIDES)

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Pakel slide (Twin slides)	
3.	Location	Latitude	N 27 °.55880500’
		Longitude	E 88 °.53944869’
4.	Altitude	1430 m amsl	
5.	Geological Setting	High grade Metamorphic rocks represented by high grade gneiss/schist.	
6.	Slide Type	Debris flow	
7.	Slide Material	Soil & Rock fragments	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	13m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	90m	
12.	Area (M^2)	45000m^2	
13.	Failed Volume(M^3)	450000m^3	
14.	Damage Done	Forest	
15.	Age	Recent	
16.	Triggers	Adverse geology steep slope, rainfall, ground water activities	
17.	Likely Return Period	NA	
18.	Coping Mechanism	Avoid	

7. NAME OF SLIDE: - TINGCHIM SLIDE I

<table>
<tr><th>SL. NO</th><th>PARTICULARS</th><th colspan="2">COMMENTS</th></tr>
<tr><td>1.</td><td>District</td><td colspan="2">North Sikkim</td></tr>
<tr><td>2.</td><td>Name Of The Slide</td><td colspan="2">Tingchim slide I</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">Location</td><td>Latitude</td><td>N 27°.45651137’</td></tr>
<tr><td>Longitude</td><td>E 88°.57043028’</td></tr>
<tr><td>4.</td><td>Altitude</td><td colspan="2"></td></tr>
<tr><td>5.</td><td>Geological Setting</td><td colspan="2">Complex, geological setup within daling group of rocks.</td></tr>
<tr><td>6.</td><td>Slide Type</td><td colspan="2">Subsidence</td></tr>
<tr><td>7.</td><td>Slide Material</td><td colspan="2">Debris & soil with boulder</td></tr>
<tr><td>8.</td><td>Average Depth (In Mts)</td><td colspan="2">30m</td></tr>
<tr><td>9.</td><td>Maximum Depth (In Mts)</td><td colspan="2">45m</td></tr>
<tr><td>10.</td><td>Length (In Mts)</td><td colspan="2">150m</td></tr>
<tr><td>11.</td><td>Width (In Mts)</td><td colspan="2">50m</td></tr>
<tr><td>12.</td><td>Area (M^2)</td><td colspan="2">7500m^2</td></tr>
<tr><td>13.</td><td>Failed Volume(M^3)</td><td colspan="2">225000m^3</td></tr>
<tr><td>14.</td><td>Damage Done</td><td colspan="2">Agricultural land, Forest, Settlement</td></tr>
<tr><td>15.</td><td>Age</td><td colspan="2">Old</td></tr>
<tr><td>16.</td><td>Triggers</td><td colspan="2">Bad geology, High water regime</td></tr>
<tr><td>17.</td><td>Likely Return Period</td><td colspan="2">Perennial</td></tr>
<tr><td>18.</td><td>Coping Mechanism</td><td colspan="2">To live with it</td></tr>
</table>

8. NAME OF SLIDE: - CHAWANG SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Chawang slide	
3.	Location	Latitude	N 27°.44306172’
		Longitude	E 88°.58116486’
4.	Altitude	2080 m amsl	
5.	Geological Setting	Medium grade Metamorphics, daling group of rocks.	
6.	Slide Type	Debris flow.	
7.	Slide Material	Rock/soil mix debris	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	7m	
10.	Length (In Mts)	620m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	31000m^2	
13.	Failed Volume(M^3)	155000m^3	
14.	Damage Done	Forest, Settlement, Agriculture	
15.	Age	Recent	
16.	Triggers	Adverse geology, steep slope, rain water, scouring by nala.	
17.	Likely Return Period	NA	
18.	Coping Mechanism	Geo-Bio engineering, retaining structures, drainage etc.	

9. NAME OF SLIDE: - NAMOK KHOLA SLIDE

SL NO.	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Namok khola slide	
3.	Location	Latitude	N 27^{o} 27' 57.5"
		Longitude	E 88^{o} 30' 45.9"
4.	Altitude	1479 m	
5.	Geological Setting	Sericitic phyllite/ quarzite inter banding sequence with thick rock/soil mix cover.	
6.	Slide Type	Complex, fault controlled	
7.	Slide Material	Rock soil mix debris	
8.	Average Depth (In Mts)	25m	
9.	Maximum Depth (In Mts)	35m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	75m.	
12.	Area (M^2)	37500m^2	
13.	Failed Volume(M^3)	937500m^3	
14.	Damage Done	Road, forest, agriculture land.	
15.	Age	Old	
16.	Triggers	Weak geology, excess water	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Difficult to cope, effective drainage may help	

10. NAME OF SLIDE: - LANTHE KHOLA SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Lanthe khola slide	
3.	Location	Latitude	N 27° 30’ 44.4”
		Longitude	E 88° 33’ 54.8”
4.	Altitude	867 m	
5.	Geological Setting	Disturbed gneissic terrain with thick debris with boulder cover.	
6.	Slide Type	Complex	
7.	Slide Material	Boulders with debris	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	30m	
10.	Length (In Mts)	3 Km(300m)	
11.	Width (In Mts)	100m.	
12.	Area (M^2)	30000m²	
13.	Failed Volume(M^3)	450000m³	
14.	Damage Done	Road, forest, agriculture land.	
15.	Age	Old	
16.	Triggers	Weak geology (Jointed rock /sheared) excess water, steep slope, vibration.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Effective drainage, effective retaining structures, avoid, if possible	

11. NAME OF SLIDE: - MANUAL (OLD PLACE OF DISASTER)

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Manual	
3.	Location	Latitude	N 27°31.40'
		Longitude	E88°35.60'
4.	Altitude	1230m amsl	
5.	Geological Setting	Rock Soil mix debris over disturbed gneissic terrain.	
6.	Slide Type	Complex, debris flow or fall dominating	
7.	Slide Material	Debris with boulders.	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	300m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	15000m²	
13.	Failed Volume(M^3)	75000m³	
14.	Damage Done	Casualties at GREFF Camp 10/11 September 1983	
15.	Age	43 years, Struck in 1967 killing 65 GREF workers	
16.	Triggers	Weak geology, excess water	
17.	Likely Return Period	Dormant mostly	
18.	Coping Mechanism	Afforestation, Geo-Engineering, Drainage.	

12. NAME OF SLIDE: - MEYONG SLIDE

<table>
<tr><th>SL NO.</th><th>PARTICULARS</th><th colspan="2">COMMENTS</th></tr>
<tr><td>1.</td><td>District</td><td colspan="2">North Sikkim</td></tr>
<tr><td>2.</td><td>Name Of The Slide</td><td colspan="2">Meyong slide</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">Location</td><td>Latitude</td><td>N 27° 31’ 41.1”</td></tr>
<tr><td>Longitude</td><td>E 88° 36’ 25.4’’</td></tr>
<tr><td>4.</td><td>Altitude</td><td colspan="2">1444 m</td></tr>
<tr><td>5.</td><td>Geological Setting</td><td colspan="2">Favorably dipping high grade gneissic rock sequence with quartzite, thin soil cover, rocks highly jointed</td></tr>
<tr><td>6.</td><td>Slide Type</td><td colspan="2">Wedge failure</td></tr>
<tr><td>7.</td><td>Slide Material</td><td colspan="2">Debris & boulders</td></tr>
<tr><td>8.</td><td>Average Depth (In Mts)</td><td colspan="2">2m</td></tr>
<tr><td>9.</td><td>Maximum Depth (In Mts)</td><td colspan="2">5m</td></tr>
<tr><td>10.</td><td>Length (In Mts)</td><td colspan="2">150m</td></tr>
<tr><td>11.</td><td>Width (In Mts)</td><td colspan="2">50m.</td></tr>
<tr><td>12.</td><td>Area (M^2)</td><td colspan="2">7500m^2</td></tr>
<tr><td>13.</td><td>Failed Volume(M^3)</td><td colspan="2">15000m^3</td></tr>
<tr><td>14.</td><td>Damage Done</td><td colspan="2">Road distance.</td></tr>
<tr><td>15.</td><td>Age</td><td colspan="2">Recent</td></tr>
<tr><td>16.</td><td>Triggers</td><td colspan="2">Steep slope, highly jointed & fractured rocks, excess water, vibration</td></tr>
<tr><td>17.</td><td>Likely Return Period</td><td colspan="2">Active</td></tr>
<tr><td>18.</td><td>Coping Mechanism</td><td colspan="2">Geo-engineering, Bio-Engineering, rock bolts.</td></tr>
</table>

13. NAME OF SLIDE: - RICHU NALA NEAR TONG

SL NO.	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Richu Nala near Tong	
3.	Location	Latitude	N 27^{o} 32’ 41.0”
		Longitude	E 88^{o} 37’ 45.7”
4.	Altitude	1439 m	
5.	Geological Setting	Boulders and Soil mixed huge size.	
6.	Slide Type	Complex	
7.	Slide Material	Debris/soil with boulders	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	250m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	12500m^2	
13.	Failed Volume(M^3)	125000m^3	
14.	Damage Done	Road	
15.	Age	Very old	
16.	Triggers	Highly jointed rocks, debris overburden of rock & soil on both abutment & scouring by active water	
17.	Likely Return Period	Active	
18.	Coping Mechanism		

14. NAME OF SLIDE: - CHANDEY KHOLA SLIDE

SL NO.	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Chadey khola slide	
3.	Location	Latitude	N 27^o 29' 05.1"
		Longitude	E 88^o 31' 43.2"
4.	Altitude	826 m	
5.	Geological Setting	Quartzite phyllite	
6.	Slide Type	Rotational	
7.	Slide Material	Debris – Soil cover	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	1.5m	
11.	Width (In Mts)	500ft.(152.4m)	
12.	Area (M^2)	228.6m^2	
13.	Failed Volume(M^3)	3429m^3	
14.	Damage Done	Road strike, overburden material, boulders	
15.	Age	30 years	
16.	Triggers	Hydrology, weak geology, Slope Failure.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Sausage, high walls bio-engineering etc.	

15. NAME OF SLIDE: - RANGRANG SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Rangrang slide	
3.	Location	Latitude	N 27° 27’ 57.5”
		Longitude	E 88° 30’ 45.9”
4.	Altitude	1050 m	
5.	Geological Setting	Quartzite/phyllite inter band	
6.	Slide Type	Planner on the catchment of Nalas main tributary	
7.	Slide Material	Loose overburden mass with rock slide oriented along the slope	
8.	Average Depth (In Mts)	30m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	1.5km (1500m)	
11.	Width (In Mts)	300m.	
12.	Area (M^2)	450000m²	
13.	Failed Volume(M^3)	13500000m³	
14.	Damage Done	Forest	
15.	Age	Old	
16.	Triggers	Hydrology, weak geology, Forest load	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Drainage, Rock bolts, Bio-engineering, Geo-engineering.	

16. NAME OF SLIDE: - PHENSONG SLIDE

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Phensong slide	
3.	Location	Latitude	N 27^{o} 26’ 20.84”
		Longitude	E 88^{o} 36’ 40.64”
4.	Altitude	1560 m amsl	
5.	Geological Setting	Medium grade Metamorphic rocks represented by Daling sequence	
6.	Slide Type	Subsidence	
7.	Slide Material	Debris with boulders and soil	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	50000m^2	
13.	Failed Volume(M^3)	750000m^3	
14.	Damage Done	Road highway, settlements, agricultural fields	
15.	Age	Very old	
16.	Triggers	Adverse geology ground water & vehicular vibration	
17.	Likely Return Period	Active	
18.	Coping Mechanism	To avoid	

17. NAME OF SLIDE: - SEVEN SISTERS SLIDE

SL. NO	PARTICULARS	COMMENTS	
1.	District	North Sikkim	
2.	Name Of The Slide	Seven Sisters slide	
3.	Location	Latitude	N 27 ^{o} 26’ 23.21”
		Longitude	E 88 ^{o}35’ 34.54”
4.	Altitude	1520 m amsl	
5.	Geological Setting	Medium grade Metamorphic rocks represented by daling group of rocks.	
6.	Slide Type	Debris flow	
7.	Slide Material	Rock soil mix debris.	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	7m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	40m	
12.	Area (M^2)	6000m^2	
13.	Failed Volume(M^3)	30000m^3	
14.	Damage Done	Road, forest cover.	
15.	Age	Recent	
16.	Triggers	Adverse geology, steep slope, vehicular traffic vibration.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope dressing, retaining structures drainage.	

PART FIVE

GSI MAPPING OF LANDSLIDE VULNERABLE AREAS OF EAST SIKKIM

INTRODUCTION

The area under investigation constitutes a part of the lesser Himalayas in Sikkim, with elevations ranging from 350mts to about 1,800mts characteristically; the terrain is highly dissected, with steep gorges, broad valleys, fairly sharp peaks and ridges. This area is bounded by latitudes 27^0 08`N to $27^0$ 23`N and longitudes 88^0 25` E to $88^0$ 45`E and covers an area of about 549 Km^2.

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, e.g., the Rangit Window of West and South Sikkim and the Pache Khola window of East Sikkim, where the Gondwana and the Buxa sequences are exposed below the covered unit of Daling Metamorphic.

Moreover, there is 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-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.**(iv)** The Trans-Axial Belt – is represented by the Tethyan sequence, Lachi Series (equivalent to lower Gondwana) and Chholhamo Series (Jurassic).

a. **Daling Formation: -** The Greywacke is the most significant mappable 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-Sericite-phyllites, with alternate bands of variable thickness of Micaceous Quartzite, with small amounts of fine-grained elastic Quartz, 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.

b. **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.

c. **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 anhedral 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.

d. **Basic Rocks: -** 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, 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 are also noted. The basic rocks occasionally contain splashes and disseminations of sulphide minerals - mainly chalcopyrite, with some Pyrite and Pyrrhotite.

e. **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 Quartzite-phyllite 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

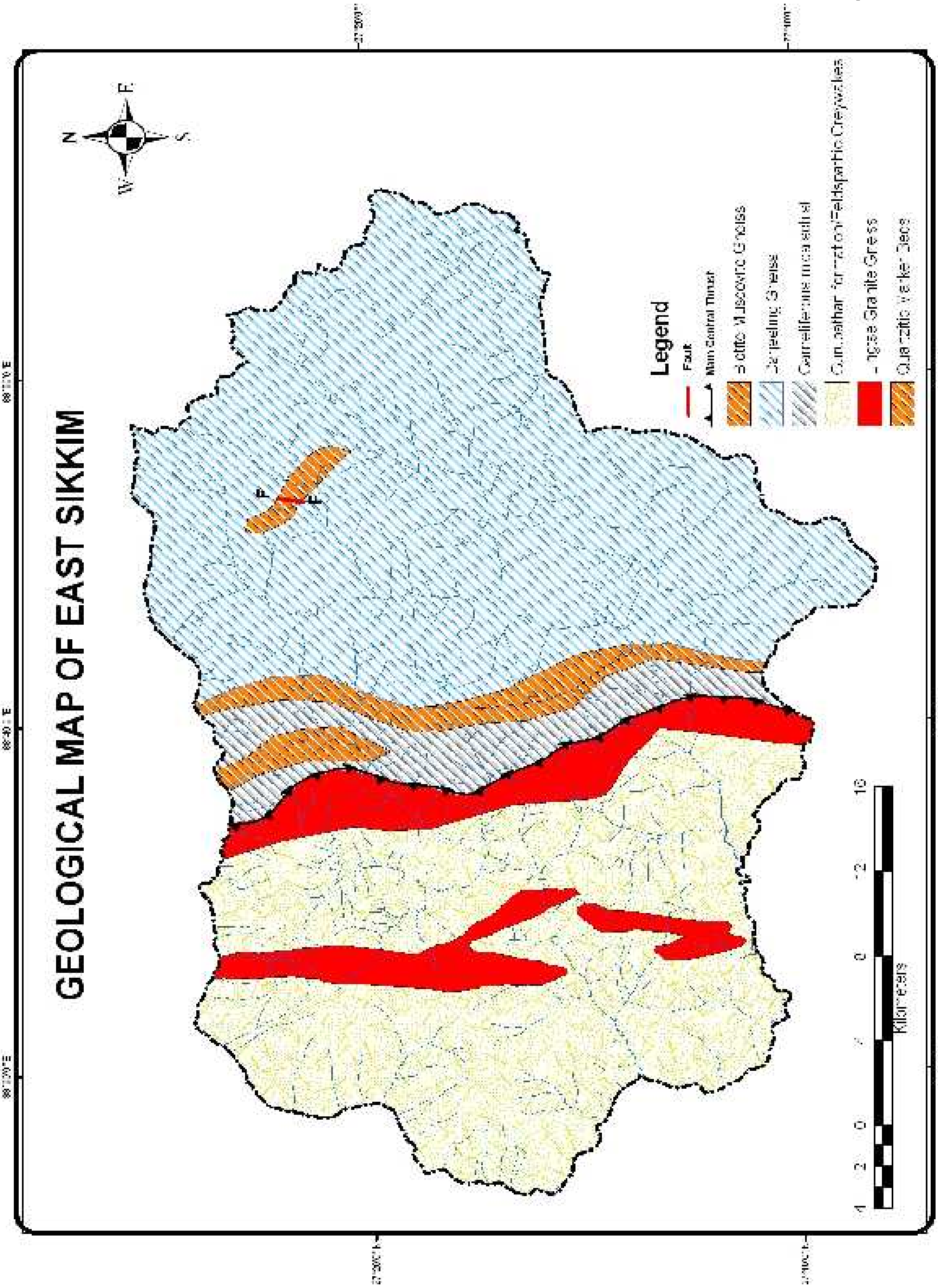
The Tista River, running almost N-S in the western part of the area, is the major drainage channel, to which there are numerous tributaries of various orders. The main tributaries are the Rangpo Chu, Rishi Chu, Rongli Chu, Mandum Khola, Pache Khola, Khani Khola and Kali Khola. The major rivers and tributaries are characterized by aride meanders with well-developed 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 400 to 500cms.

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 Rangpo, Rorathang, etc., in the vicinity of river beds, the summer is quite hot and sultry.

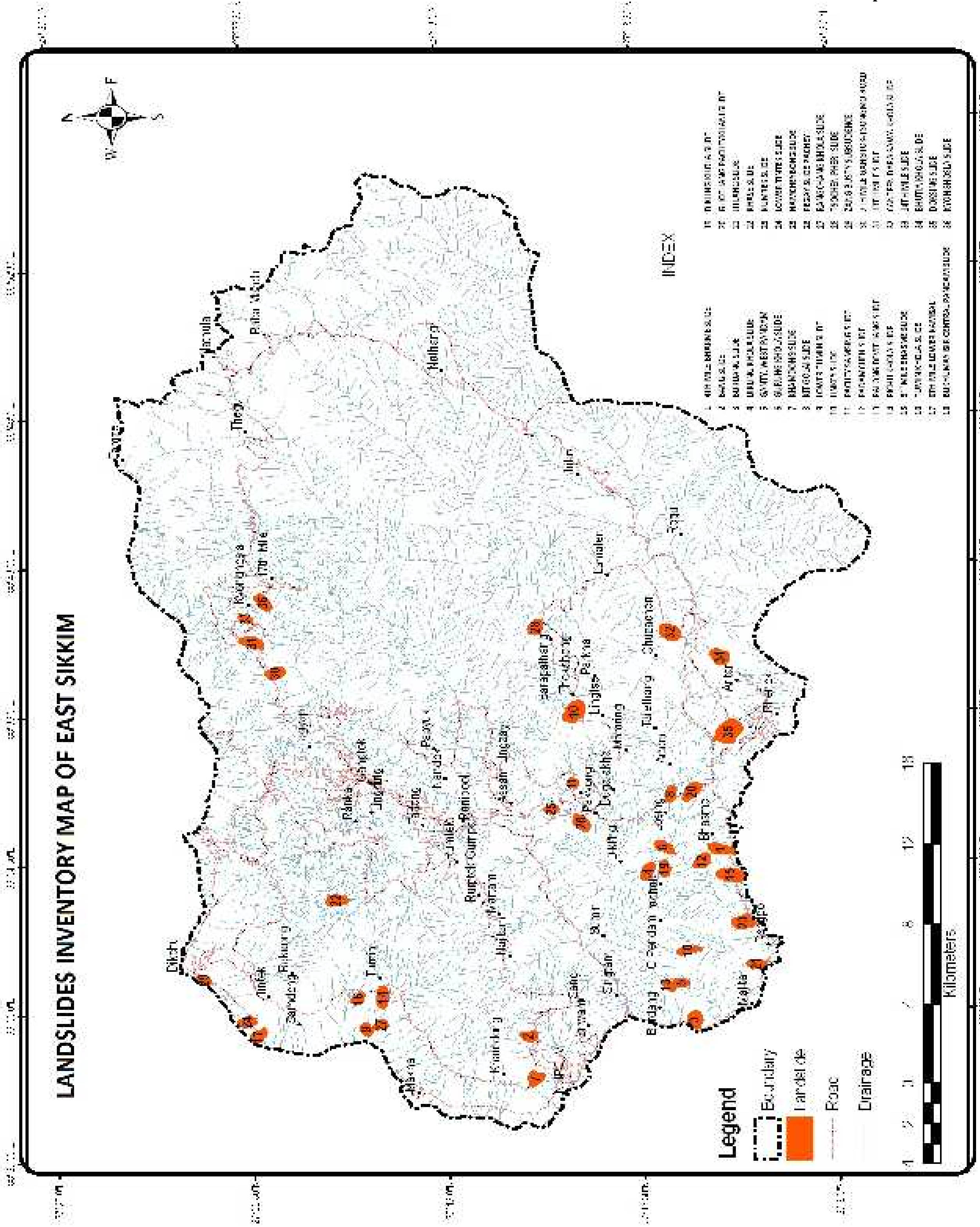
LAND-USE AND LAND-COVER

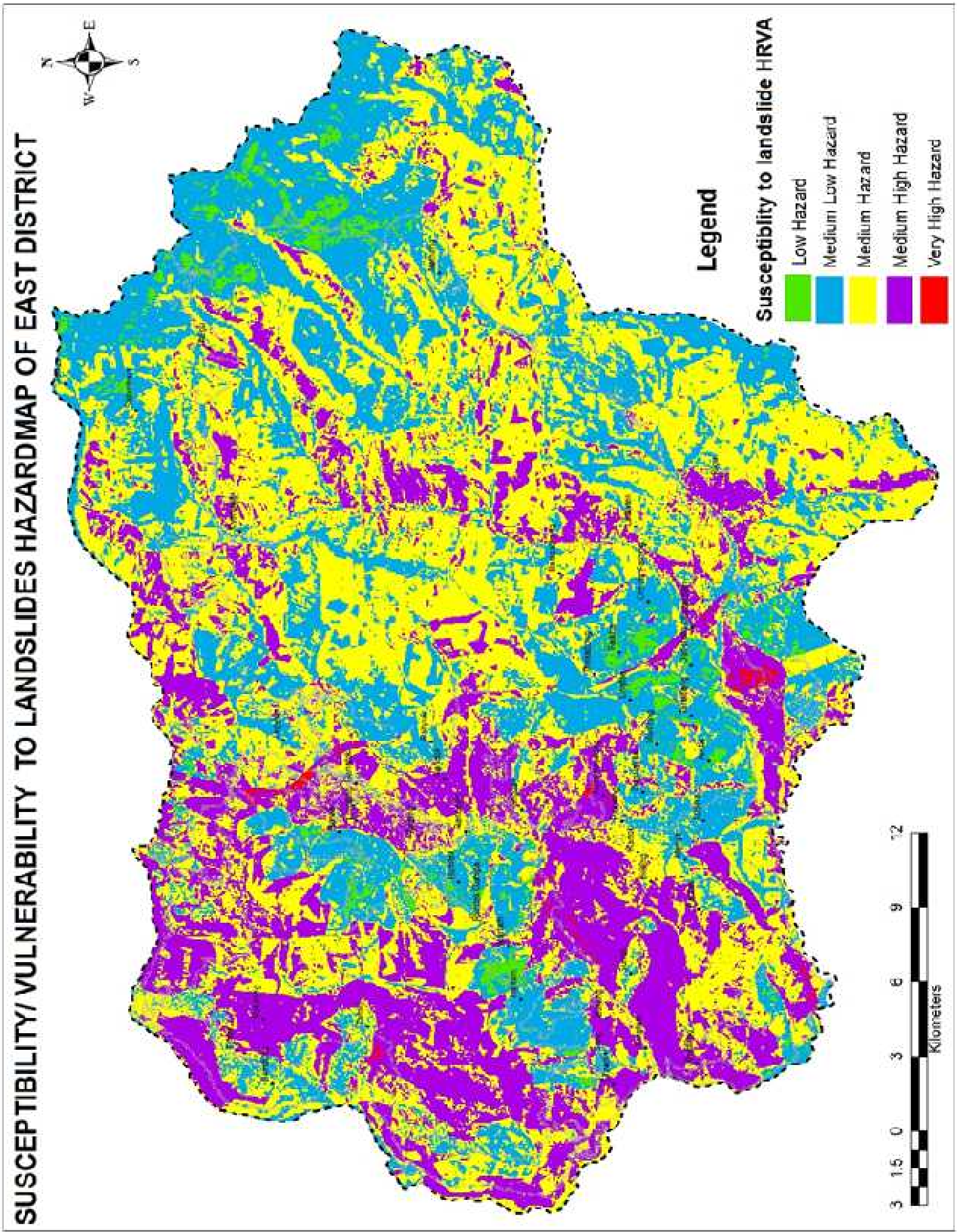
Gently sloping and flat areas throughout the eastern hill slopes are extensively used for paddy cultivation by bundh irrigation system and steeper slopes with perennial source of water are being used for cardamom cultivations. The practice has lead to excessive seepage within the unconsolidated mass 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.

Map No 07


GEOLOGICAL MAP OF EAST SIKKIM
Legend
Fault
Main Central Thrust
Biotite Muscovite Gneiss
Darjeeling Gneiss
Kilometers

Map No 08


LANDSLIDES INVENTORY MAP OF EAST SIKKIM
Legend
Boundary
Landslide
Road
Drainage
Kilometers
INDEX



LANDSLIDE INCIDENCE

1. NAME OF THE SLIDE: - 4TH MILE BHASME

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	4th mile Bhasme	
3.	Location	Latitude	N 27^0 11.410
		Longitude	E 88^0 34.828
4.	Altitude	462m	
5.	Geological Setting	Failed slope forming material, no bedrock exposures	
6.	Slide Type	Complex	
7.	Slide Material	Rock/ soil mix debris. Boulders of different dimension	
8.	Average Depth (In Mts)	25m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	120m	
12.	Area (M^2)	$24000m^2$	
13.	Failed Volume(M^3)	$600000m^3$	
14.	Damage Done	Road, Agriculture, Forest, Habitation	
15.	Age	Old	
16.	Triggers	Toe erosion, adverse geology	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, Road alignment	

2. NAME OF THE SLIDE: - BENG SLIDE (ALONG NALA)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Beng slide (along nala)	
3.	Location	Latitude	N 27^o 16.005’
		Longitude	E 88^o 29.137’
4.	Altitude	1119m	
5.	Geological Setting	Quartzite/phyllite, interbanding sequence down slope dipping thin soil cover. Highly jointed rocks fall/topple	
6.	Slide Type	Planner- debris slide	
7.	Slide Material	Rock/ soil mix debris. Boulders of different dimension with fine	
8.	Average Depth (In Mts)	3m	
9.	Maximum Depth (In Mts)	5m	
10.	Length (In Mts)	50m	
11.	Width (In Mts)	10m	
12.	Area (M^2)	500m^2	
13.	Failed Volume(M^3)	1500m^3	
14.	Damage Done	Forest/agriculture land	
15.	Age	Recent	
16.	Triggers	Surface water, adverse geology-toe cutting.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Toe protection, sausage gabions. Nala traning	

3. NAME OF THE SLIDE: - BORDANG SLIDE ON RANGPO – SINGTAM ROAD

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Bordang slide on Rangpo- Singtam road	
3.	Location	Latitude	N 27° 12.459’
		Longitude	E 88° 29.359’
4.	Altitude	488m	
5.	Geological Setting	Daling formation, sheared rock fragments Steep slope	
6.	Slide Type	Complex	
7.	Slide Material	Phyllite & quartzite rock fragments with rock flour & soil	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	25m	
10.	Length (In Mts)	700m	
11.	Width (In Mts)	500m	
12.	Area (M^2)	350000m^2	
13.	Failed Volume(M^3)	5250000m^3	
14.	Damage Done	N H 31 A	
15.	Age	40 years	
16.	Triggers	Adverse geology, steep slope	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Effective drainage, rock bolting, check dams, retrain structures, slope dressing.	

4. NAME OF THE SLIDE: - DIKLING KHOLA SLIDE (RIGHT)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Dikling khola slide (Right)	
3.	Location	Latitude	N 27^0 13.120
		Longitude	E 88^0 34.379
4.	Altitude	913m	
5.	Geological Setting	Phyllitic terrain, pulverized/sheared Seri cite phyllite	
6.	Slide Type	Translational	
7.	Slide Material	Rock soil mix material	
8.	Average Depth (In Mts)	25m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	300m	
12.	Area (M^2)	$60000m^2$	
13.	Failed Volume(M^3)	$1500000m^3$	
14.	Damage Done	Road, forest, Pachak village	
15.	Age	Old	
16.	Triggers	Steep slope, toe erosion, ground water, sheared slope farming material	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, slope dressing, drainage improvement, and retraining structures.	

5. NAME OF THE SLIDE: - GANTEY, WEST PENDAM ALONG-SINGTAM-PENDAM ROAD

<table>
<tr><th>SL NO</th><th>PARTICULARS</th><th colspan="2">COMMENT</th></tr>
<tr><td>1.</td><td>District</td><td colspan="2">East Sikkim</td></tr>
<tr><td>2.</td><td>Name Of The Slide</td><td colspan="2">Gantey, West Pendam along-Singtam-Pendam road</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">Location</td><td>Latitude</td><td>N 27° 12.709’</td></tr>
<tr><td>Longitude</td><td>E 88° 30.771’</td></tr>
<tr><td>4.</td><td>Altitude</td><td colspan="2">1120m</td></tr>
<tr><td>5.</td><td>Geological Setting</td><td colspan="2">Daling formation, alternating, sequence of thin quartzite, Sericite & Chlorite as bedrock. At the location on bedrock.</td></tr>
<tr><td>6.</td><td>Slide Type</td><td colspan="2">massive subsidence & rotational</td></tr>
<tr><td>7.</td><td>Slide Material</td><td colspan="2">Mixture of huge boulders, rock fragments and soil</td></tr>
<tr><td>8.</td><td>Average Depth (In Mts)</td><td colspan="2">At the body portion=100 meters</td></tr>
<tr><td>9.</td><td>Maximum Depth (In Mts)</td><td colspan="2">150m</td></tr>
<tr><td>10.</td><td>Length (In Mts)</td><td colspan="2">Over 1000m</td></tr>
<tr><td>11.</td><td>Width (In Mts)</td><td colspan="2">450m</td></tr>
<tr><td>12.</td><td>Area (M^2)</td><td colspan="2">150000m</td></tr>
<tr><td>13.</td><td>Failed Volume(M^3)</td><td colspan="2"></td></tr>
<tr><td>14.</td><td>Damage Done</td><td colspan="2">Road, agricultural land, forest, habitation</td></tr>
<tr><td>15.</td><td>Age</td><td colspan="2">Old</td></tr>
<tr><td>16.</td><td>Triggers</td><td colspan="2">Excessive Ground water thick slope material</td></tr>
<tr><td>17.</td><td>Likely Return Period</td><td colspan="2">Considering size of subsidence, no return estimate</td></tr>
<tr><td>18.</td><td>Coping Mechanism</td><td colspan="2">Effective drainage system, avoidance of wet cultivation and rock bolting</td></tr>
</table>

6. NAME OF THE SLIDE: - GURUNG KHOLA SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Gurung Khola Slide	
3.	Location	Latitude	N 27° 12.839
		Longitude	E 88° 34.839
4.	Altitude	999m	
5.	Geological Setting	Well foliated sequence of ferruginous sheared phyllites with quartzite	
6.	Slide Type	Translation	
7.	Slide Material	Rock fragments with soil	
8.	Average Depth (In Mts)	25m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	250m	
11.	Width (In Mts)	200m	
12.	Area (M^2)	50000m^2	
13.	Failed Volume(M^3)	1250000m^3	
14.	Damage Done	Road, forest	
15.	Age	Old	
16.	Triggers	Down slope dipping foliation, steep slope, toe cutting	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, rock bolting bio-stabilization.	

7. NAME OF THE SLIDE: - KHAMDONG (NEAR CHURCH)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Khamdong (Near Church)	
3.	Location	Latitude	N 27^{o} 16.064’
		Longitude	E 88^{o} 27.958’
4.	Altitude	1205m	
5.	Geological Setting	Quartzite with Phyllite intercalation	
6.	Slide Type	Subsidence	
7.	Slide Material	Rock boulders with different dimensions with fire	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	30m	
12.	Area (M^2)	3000m^2	
13.	Failed Volume(M^3)	15000m^3	
14.	Damage Done	Road, Agriculture, Trees	
15.	Age	Recent	
16.	Triggers	Steep slope, weak geology	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Drainage, walls	

8. NAME OF THE SLIDE: - KIT GOLAI PACHE KHANI

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Kit Golai Pache Khani	
3.	Location	Latitude	N 27^0 12.824’
		Longitude	E 88^0 36.503’
4.	Altitude	838m	
5.	Geological Setting	Sheared formation of phyllite rocks	
6.	Slide Type	Rotational	
7.	Slide Material	Sheared rock consisting of ferruginous quartzite	
8.	Average Depth (In Mts)		
9.	Maximum Depth (In Mts)		
10.	Length (In Mts)	300m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	30000m^2	
13.	Failed Volume(M^3)		
14.	Damage Done	Road, Agricultural land, Habitation, Forest	
15.	Age	Old	
16.	Triggers	Sheared rocks, ground water, Toe erosion, rock flour	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Effective drainage, slope dressing, Toe protection, retaining structure	

9. NAME OF THE SLIDE: - LOWER TUMIN SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Lower Tumin slide	
3.	Location	Latitude	N 27° 19.833’
		Longitude	E 88° 29.514’
4.	Altitude	894m	
5.	Geological Setting	Quartzite/phyllite interbanding sequence with debris cover, weak geology	
6.	Slide Type	Rotational	
7.	Slide Material	Rock boulders & debris	
8.	Average Depth (In Mts)	40m	
9.	Maximum Depth (In Mts)	60m	
10.	Length (In Mts)	750m	
11.	Width (In Mts)	75m	
12.	Area (M^2)	$56250m^2$	
13.	Failed Volume(M^3)	$2250000m^3$	
14.	Damage Done	Damage to Houses & Housing site, Road, Agriculture	
15.	Age	Old	
16.	Triggers	Steep slope, water, adverse geology, wet agriculture proactive, vibrations.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Retaining walls, Drainage, Realignment of road.	

10. NAME OF THE SLIDE: - LINKEY SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East	
2.	Name Of The Slide	Linkey slide	
3.	Location	Latitude	N 27° 15.081
		Longitude	E 88° 39.206
4.	Altitude	1424m	
5.	Geological Setting	High grade metamorphic terrain, huge blocks of rocks-moved	
6.	Slide Type	Complex, wedge type dominating	
7.	Slide Material	Boulder debris	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	65m	
10.	Length (In Mts)	1000m	
11.	Width (In Mts)	1500m	
12.	Area (M^2)	1500000m^2	
13.	Failed Volume(M^3)	75000000m^3	
14.	Damage Done	Thekabong road, houses, fields, Forest, Cardamom	
15.	Age	Perennial	
16.	Triggers	Jointed, blocky nature of bedrock	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Drainage, retraining structures Bio-engineering, changing agricultural practice	

11. NAME OF THE SLIDE: - PACHE-SAMSING SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Pache-Samsing slide	
3.	Location	Latitude	N 27^{o} 15.034'
		Longitude	E 88^{o} 36.921'
4.	Altitude	1320M	
5.	Geological Setting	Well bedded alternate layer of Quartzite & phyllite	
6.	Slide Type	Translational	
7.	Slide Material	Rock slabs, debris	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	30m	
10.	Length (In Mts)	400m	
11.	Width (In Mts)	110m	
12.	Area (M^2)	44000m^2	
13.	Failed Volume(M^3)	880000m^3	
14.	Damage Done	Pache-Samsing road, Agricultural land, Forest.	
15.	Age	Recent about 30 years old	
16.	Triggers	Down slope dipping Daling group of rocks.	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Rock bolting, drainage, biological stabilization	

12. NAME OF THE SLIDE: - PADAMCHEN SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Padamchen slide	
3.	Location	Latitude	N 27^0 12.041’
		Longitude	E 88^0 34.638’
4.	Altitude	964m	
5.	Geological Setting	Massive & jointed quartzite with the phyllite intercalation	
6.	Slide Type	Rotational	
7.	Slide Material	Rock fragments, soil with huge boulder	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	75m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	20000m^2	
13.	Failed Volume(M^3)	1000000m^3	
14.	Damage Done	Road, Agriculture land	
15.	Age	Old	
16.	Triggers	Adverse geology, quarrying, steep slope ground water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Rock bolting, Drainage, Retaining structures	

13. NAME OF THE SLIDE: - RALONG DEVITHAN, WEST PENDAM

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Ralong Devithan, West Pendam	
3.	Location	Latitude	N 27^0 12.965
		Longitude	E 88^0 30.756
4.	Altitude	1176m	
5.	Geological Setting	Daling group of rocks-alternating sequence of Quartzite, Chlorite & Sericite Phyllite	
6.	Slide Type	Rotational, active subsidence	
7.	Slide Material	Mix of rock frequents, soil & huge boulders	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	75m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	120m	
12.	Area (M^2)	24000m^2	
13.	Failed Volume(M^3)	1200000m^3	
14.	Damage Done	Road	
15.	Age	Old	
16.	Triggers	Ground water seepage, adverse geology(wedge failure in brittle country rock	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Drainage system, Realignment of road, retaining structures	

14. NAME OF THE SLIDE: - RICHU KHOLA

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Richu khola	
3.	Location	Latitude	N 27^{o} 19.540'
		Longitude	E 88^{o} 30.590'
4.	Altitude	1418m	
5.	Geological Setting	Adverse geology in quartzitic/phyllitic interbanding sequence highly disturbed and thick soil overburden	
6.	Slide Type	Subsidence	
7.	Slide Material	Debris with boulders of all dimension	
8.	Average Depth (In Mts)	30m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	1500m(sec Map)	
11.	Width (In Mts)	50m	
12.	Area (M^2)	75000m^2	
13.	Failed Volume(M^3)	2250000m^3	
14.	Damage Done	Forest	
15.	Age	Old	
16.	Triggers	Excessive water runoff & weak geology	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Drainage, Toe protection,	

15. NAME OF THE SLIDE: - 3RD MILE, BHASME SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	3rd mile, Bhasme slide	
3.	Location	Latitude	27^{o} 11.279’
		Longitude	88^{o} 33.988’
4.	Altitude	485m	
5.	Geological Setting	Daling group consisting of alternating phyllite & quartzite	
6.	Slide Type	Translational	
7.	Slide Material	Rock fragments, Rock flour, Soil	
8.	Average Depth (In Mts)	30m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	700m	
11.	Width (In Mts)	400m	
12.	Area (M^2)	$280000m^2$	
13.	Failed Volume(M^3)	$8400000m^3$	
14.	Damage Done	Road, Agricultural land	
15.	Age	Old	
16.	Triggers	Toe erosion, Water, Adverse, geology	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, Slope dressing, Retaining structures, Effective drainage	

16. NAME OF THE SLIDE: - TUMIN KHOLA SLIDE (UPPER TUMIN)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Tumin khola slide (Upper Tumin)	
3.	Location	Latitude	N 27° 20.018’
		Longitude	E 88° 30.490’
4.	Altitude	1491m	
5.	Geological Setting	Adverse geology, quartzite/phyllite interbands highly jointed & dislocated rocks with huge boulders	
6.	Slide Type	Complex	
7.	Slide Material	Debris with boulders of different dimensions	
8.	Average Depth (In Mts)	3000m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	75m	
11.	Width (In Mts)	1000m	
12.	Area (M^2)	75000m^2	
13.	Failed Volume(M^3)	225000000m^3	
14.	Damage Done	Trees, Road	
15.	Age	Old	
16.	Triggers	Surface runoff, Adverse geology	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Drainage, Jhora training, Walls	

17. NAME OF THE SLIDE: - 9TH MILE LOWER KAMBAL

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	9th mile Lower Kambal	
3.	Location	Latitude	N 27^{o} 22.470’
		Longitude	E 88^{o} 29.327’
4.	Altitude	868m	
5.	Geological Setting	Quartzite with phyllite interbands.	
6.	Slide Type	Subsidence	
7.	Slide Material	Rock boulders of various dimensions with debris	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	100m	
12.	Area (M^{2})	10000m^{2}	
13.	Failed Volume(M^{3})	150000m^{3}	
14.	Damage Done	10 years old house of Santiram Bhatrai Damaged, Trees Road	
15.	Age	Old	
16.	Triggers	Weak geology, Slope, Vibration	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Road alignment, Drainage & retaining structures	

18. NAME OF THE SLIDE: - BUKHUMEY BIR, CENTRAL PANDAM KARMITHANG BLOCK

SL NO	PARTICULARS	COMMENT	
1.	District	EAST	
2.	Name Of The Slide	Bukhumey Bir, Central Pandam Karmithang Block	
3.	Location	Latitude	N 27^0 12.775
		Longitude	E 88^0 31.422
4.	Altitude	1314m	
5.	Geological Setting	Massive quartzite, with intercalation Quartz Chlorite & Sericite	
6.	Slide Type	Wedge type failure	
7.	Slide Material	Rock fragments with large boulders mixed in soil & rock flour	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	75m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	20000m^2	
13.	Failed Volume(M^3)	1000000m^3	
14.	Damage Done	Road, agriculture land, health quarters	
15.	Age	Old	
16.	Triggers	Adverse geology, ground water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Effective drainage & retaining system, rock bolting etc.	

19. NAME OF THE SLIDE: - DIKLING KHOLA SLIDE (LEFT)

SL NO	PARTICULARS	COMMENT	
1.	District	EAST	
2.	Name Of The Slide	Dikling khola slide (left)	
3.	Location	Latitude	N 27^0 13.078’
		Longitude	E 88^0 34.401’
4.	Altitude	943m	
5.	Geological Setting	Into the slope dripping phyllite with thin quartzite band	
6.	Slide Type	Rotational controlled by wedge failure	
7.	Slide Material	Rock fragment, soil & boulders	
8.	Average Depth (In Mts)	30m	
9.	Maximum Depth (In Mts)	75m	
10.	Length (In Mts)	300m	
11.	Width (In Mts)	75m	
12.	Area (M^2)	22500m^2	
13.	Failed Volume(M^3)	675000m^3	
14.	Damage Done	Road, agriculture land	
15.	Age	Old	
16.	Triggers	Wedge failure, toe cutting by dikling khola	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, slope dressing, retaining walls	

20. NAME OF THE SLIDE: - GHOTHLANG, PACHE KHANI

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Ghothlang, Pache Khani	
3.	Location	Latitude	N 27^0 12.595
		Longitude	E 88^0 36.419
4.	Altitude	887 Meters	
5.	Geological Setting	Thick slope forming material consisting of boulders, rock fragment, Red soil	
6.	Slide Type	Rotational	
7.	Slide Material	Slope forming debris	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	400m	
11.	Width (In Mts)	75m	
12.	Area (M^2)	30000m^2	
13.	Failed Volume(M^3)	600000m^3	
14.	Damage Done	Road, Agricultural land, Forest	
15.	Age	Old	
16.	Triggers	Adverse geology & slope, poor drainage ground water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Realignment of road, Drainage, Retaining structures	

21. NAME OF THE SLIDE: - JITLANG SLIDE, RANGPO

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Jitlang slide, Rangpo	
3.	Location	Latitude	N 27^{o} 10.621'
		Longitude	E 88^{o} 31.272'
4.	Altitude	324	
5.	Geological Setting	Faulted, sheared Chlorite & Sericitic phyllite with quartzite intercalations	
6.	Slide Type	Complex	
7.	Slide Material	Sheared Daling group of rocks	
8.	Average Depth (In Mts)	30m	
9.	Maximum Depth (In Mts)	75m	
10.	Length (In Mts)	750m	
11.	Width (In Mts)	1000m	
12.	Area (M^2)	750000m^2	
13.	Failed Volume(M^3)	22500000m^3	
14.	Damage Done	N H 31 A, habitation	
15.	Age	Old	
16.	Triggers	Sheared rock, sleep slope	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Effective drainage, Retaining structures, Benching, Afforestation	

22. NAME OF THE SLIDE: - KHASE SLIDE (KHAMDONG -TINTEK ROAD)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Khase slide (Khamdong-Tintek road)	
3.	Location	Latitude	N 27° 20.496’
		Longitude	E 88° 33.445’
4.	Altitude	1562m	
5.	Geological Setting	Quartzite with bands of Chloritic-Sericitic phyllitic, highly jointed rocks	
6.	Slide Type	Rock topple and complex failure	
7.	Slide Material	Rock boulders, fragments	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	30m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	120m	
12.	Area (M^2)	18000m^2	
13.	Failed Volume(M^3)	360000m^3	
14.	Damage Done	Road, Trees, Agriculture	
15.	Age	-recent-	
16.	Triggers	Water, Adverse geology, Steep slope	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope dressing, Rock-bolting-drainage, appropriate retaining structures.	

23. NAME OF THE SLIDE: - 2^{ND} MILE, KUMREK SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	2^{nd} mile, Kumrek slide	
3.	Location	Latitude	N 27^{o} 11.102
		Longitude	E 88^{o} 32.569
4.	Altitude	397m	
5.	Geological Setting	Adverse geology consisting of well foliated quartzite bands, with intercalations of phyllite	
6.	Slide Type	Complex	
7.	Slide Material	Rock fragments, Rock flour, Soil	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	100m	
10.	Length (In Mts)	1200m	
11.	Width (In Mts)	1000m	
12.	Area (M^2)	1200000m^2	
13.	Failed Volume(M^3)	60000000m^3	
14.	Damage Done	Road, Forest	
15.	Age	Old	
16.	Triggers	Adverse geology, Steep slope, Toe cutting	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, Retaining structure, Effective drainage, Slope dressing	

24. NAME OF THE SLIDE: - LOWER TINTEK MARCHAK SLIDE (5KM FROM DIKCHU TO SINGTAM)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Lower Tintek Marchak Slide(5km form Dikchu)to Singtam	
3.	Location	Latitude	N 27^{o} 22.661’
		Longitude	E 88^{o} 29.810’
4.	Altitude	878m	
5.	Geological Setting	Highly disturbed quartzite with phyllite intercalation.	
6.	Slide Type	Debris avalanche	
7.	Slide Material	Rock boulders of various dimensions with debris	
8.	Average Depth (In Mts)	3m	
9.	Maximum Depth (In Mts)	5m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	5000m^2	
13.	Failed Volume(M^3)	15000m^3	
14.	Damage Done	Road, houses(9 houses) buried, Agriculture land,	
15.	Age	Old	
16.	Triggers	Weak geology, excusive rainfall (unmanaged drain (upside is wet farming paddy field	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Rock bolting, Drainage, appropriate retaining structure, Toe protection, change in cultivation pattern.	

25. NAME OF THE SLIDE: - NAMCHEYBONG SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Namcheybong slide	
3.	Location	Latitude	N 27^o 15.360’
		Longitude	E 88^o 15.870’
4.	Altitude	1029m	
5.	Geological Setting	Serecite phyllite dipping along slope with high surface, sub-surface water activity.	
6.	Slide Type	Complex: Translational type mainly	
7.	Slide Material	Degraded rocks, soil etc.	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	700mts (apporx)	
11.	Width (In Mts)	900mts	
12.	Area (M^2)	630000m^2	
13.	Failed Volume(M^3)	6300000m^3	
14.	Damage Done	Agriculture land, houses, forest, road	
15.	Age	Old	
16.	Triggers	Bedrock dipping down slope, High ground water, Steep sloppy	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Toe protection, Drainage, Cropping pattern change, Bio-Engineering, Geo-Engineering etc.	

26. NAME OF THE SLIDE: - PEGAY SLIDE, PACHEY, PAKYONG -LINKEY ROAD

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Pegay slide, Pachey, Pakyong-Linkey road	
3.	Location	Latitude	N 27° 14.818'
		Longitude	E 88° 35.542'
4.	Altitude	1441m	
5.	Geological Setting	Alternating Sericite & Quartzite dipping across the slope	
6.	Slide Type	Wedge type	
7.	Slide Material	Collapsed rock & soil debris	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	15000m^2	
13.	Failed Volume(M^3)	225000m^3	
14.	Damage Done	Pakyong-linkey road, Forest.	
15.	Age	About 30 years	
16.	Triggers	Joint failure, water(underground) Steep slope, Adverse geology	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Drainage, Slope dressing	

27. NAME OF THE SLIDE: - RANGCHANG KHOLA SLIDE (TUMIN)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	RANGCHANG KHOLA SLIDE(TUMIN)	
3.	Location	Latitude	N 27° 19.620'
		Longitude	E 88° 29.587'
4.	Altitude	860m	
5.	Geological Setting	Quartzite/phyllite interbanding	
6.	Slide Type	Rock fall	
7.	Slide Material	Rock boulders of various dimensions with debris	
8.	Average Depth (In Mts)		
9.	Maximum Depth (In Mts)		
10.	Length (In Mts)	60m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	3000m^2	
13.	Failed Volume(M^3)		
14.	Damage Done	Forest	
15.	Age	Recent	
16.	Triggers	Weak geology, Steep slope, Rainfall.	
17.	Likely Return Period	Recent	
18.	Coping Mechanism	No impact on habitation.	

28. NAME OF THE SLIDE: - TSOCHEN–PHERI SLIDE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Tsochen-Pheri slide	
3.	Location	Latitude	N 27° 15.745’
		Longitude	E 88° 41.689’
4.	Altitude	1464m	
5.	Geological Setting	Gneissic complex, sheared and rotated gneissic, suspected MCT	
6.	Slide Type	Complex	
7.	Slide Material	Boulder debris	
8.	Average Depth (In Mts)	70m	
9.	Maximum Depth (In Mts)	90m	
10.	Length (In Mts)	1500m	
11.	Width (In Mts)	1000m	
12.	Area (M^2)	1500000m^2	
13.	Failed Volume(M^3)	105000000m^3	
14.	Damage Done	Road cut off since 1997, Agriculture land, Habitation forest etc.	
15.	Age	1997	
16.	Triggers	Adverse geology, high water regime.	
17.	Likely Return Period	perennial	
18.	Coping Mechanism	Large scale effective, Drainage system, slope dressing, Bio-engineering, Effective civil retaining structures, Afforestation	

29. NAME OF THE SLIDE: - ZANG BUSTY SUBSIDENCE (NEAR DIKCHU)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Zang Busty Subsidence (Near Dikchu)	
3.	Location	Latitude	N 27° 23.748’
		Longitude	E 88° 31.022’
4.	Altitude	783m	
5.	Geological Setting	Quartzite with phyllite intercalation	
6.	Slide Type	Subsidence	
7.	Slide Material	Huge unstable boulders on steep slope and debris	
8.	Average Depth (In Mts)	100m	
9.	Maximum Depth (In Mts)	150m	
10.	Length (In Mts)	1000m	
11.	Width (In Mts)	1km (1000m)	
12.	Area (M^2)	1000000m^2	
13.	Failed Volume(M^3)	100000000m^3	
14.	Damage Done	Road, Agriculture, Settlement (un families) affected	
15.	Age	Old	
16.	Triggers	Unstable hope with deposit of boulders & debris ground water, lack of rim treatment at reservoir of Dikchu Dam	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Rim treatment at Dikchu Tista stage V dam site, effective drainage and retaining structures.	

30. NAME OF THE SLIDE: -7TH MILE GANGTOK – TSOMGO ROAD

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	7th mile Gangtok-Tsomgo Road	
3.	Location	Latitude	N 27° 22.124'
		Longitude	E 88° 40.409'
4.	Altitude	2630m	
5.	Geological Setting	High grade metamorphic terrain, highly disturbed banded geneis with quartz mica schist shear zone	
6.	Slide Type	Debris fall wedge type dominates	
7.	Slide Material	Mainly of boulders material with few	
8.	Average Depth (In Mts)	35m	
9.	Maximum Depth (In Mts)	40m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	120m	
12.	Area (M^2)	60000m^2	
13.	Failed Volume(M^3)	2100000m^3	
14.	Damage Done	Road	
15.	Age	Old, perennial	
16.	Triggers	Steep slope, Sheared rocks, water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Live with it or avoid it	

31. NAME OF THE SLIDE: -13TH MILE SLIDE ON J.N. ROAD

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	13th mile slide on JN Road	
3.	Location	Latitude	N 27° 22.51’
		Longitude	E 88° 41.24’
4.	Altitude	3110m	
5.	Geological Setting	Down slope dipping gneiss with thick cover of uniform size debris with boulders,	
6.	Slide Type	Complex, translational type dominating	
7.	Slide Material	Mainly of sheared gneiss almost uniform size	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	60m	
10.	Length (In Mts)	700m	
11.	Width (In Mts)	500m	
12.	Area (M^2)	350000m^2	
13.	Failed Volume(M^3)	17500000m^3	
14.	Damage Done	J.N. Road	
15.	Age	Old	
16.	Triggers	Steep slope, down slope dipping rock foliation Freeze & Thaw, Rain water	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Avoidance, Slope dressing, Rock bolting retaining structure, Geo-textile	

32. NAME OF THE SLIDE: - CANTEEN DARA, SAWA KHOLA NEAR RONGLI BRIDGE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Canteen Dara, Sawa khola near Rongli bridge	
3.	Location	Latitude	N 27^{o} 12.7’
		Longitude	E 88^{o} 41.35’
4.	Altitude	833m	
5.	Geological Setting	Thick slope forming material with active ground water.	
6.	Slide Type	Rotational	
7.	Slide Material	Slope forming material with boulders	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	200m	
12.	Area (M^2)	30000m^2	
13.	Failed Volume(M^3)	150000m^3	
14.	Damage Done	Road between Rongli & Rorathang/Rhenock forest	
15.	Age	About 50 years	
16.	Triggers	Adverse geology, High ground water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Drainage system, Retaining structures	

33. NAME OF THE SLIDE: -14TH MILE SLIDE ON J.N. ROAD

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	14th mile slide on JN Road	
3.	Location	Latitude	N 27° 22.50’
		Longitude	E 88° 41.60’
4.	Altitude	3146m	
5.	Geological Setting	Bounded with Garnetiferous gneiss & augen gneiss, highly jointed/sheared	
6.	Slide Type	Mainly wedge type	
7.	Slide Material	Huge boulders with 10-20% fires	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	300m	
11.	Width (In Mts)	110m	
12.	Area (M^2)	$33000m^2$	
13.	Failed Volume(M^3)	$330000m^3$	
14.	Damage Done	J.N. Road	
15.	Age	Old	
16.	Triggers	Steep slope, jointed nature of rock, vibration	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Rock bolting, Slope dressing, Drainage	

34. NAME OF THE SLIDE: - BHUTIA KHOLA, DALAPCHAND, REGLE

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Bhutia khola,Dalapchand, Regle	
3.	Location	Latitude	N 27° 11.58’
		Longitude	E 88° 40.53’
4.	Altitude	1040m	
5.	Geological Setting	Highly disturbed daling group of rocks.	
6.	Slide Type	Complex, translational dominating	
7.	Slide Material	Huge boulders with 10-20% fires	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)		
11.	Width (In Mts)	300m	
12.	Area (M^2)		
13.	Failed Volume(M^3)		
14.	Damage Done	Rongli-Dalapchand Road, Forest, Cardamom	
15.	Age	Old	
16.	Triggers	Adverse geology, High ground water	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Effective drainage system, retaining structures Afforestation.	

35. NAME OF THE SLIDE: - DOKSING ON RHENOCK – RONGLI ROAD

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Doksing on Rhenock-Rongli road	
3.	Location	Latitude	N 27^{o} 11.27’
		Longitude	E 88^{o} 8.10”
4.	Altitude	1172m	
5.	Geological Setting	Adverse geology of Daling groups of rocks	
6.	Slide Type	Mainly wedge type	
7.	Slide Material	Rock fragments with 10-20% fines	
8.	Average Depth (In Mts)	25m	
9.	Maximum Depth (In Mts)	30m	
10.	Length (In Mts)	2000m	
11.	Width (In Mts)	100-150m not the work portion	
12.	Area (M^2)	200000m^2	
13.	Failed Volume(M^3)	5000000m^3	
14.	Damage Done	Rongli-Rhenock Road	
15.	Age	5-6 years old	
16.	Triggers	Sleep slope, Fractured nature of rocks	
17.	Likely Return Period	Perennial	
18.	Coping Mechanism	Avoidance or with massive protective works	

36. NAME OF THE SLIDE: - KYONGSLA SLIDE ON JN ROAD (15th MILE)

SL NO	PARTICULARS	COMMENT	
1.	District	East Sikkim	
2.	Name Of The Slide	Kyongsla slide on JN Road (15th mile)	
3.	Location	Latitude	N 27° 22.136'
		Longitude	E 88° 42.36'
4.	Altitude	3173m	
5.	Geological Setting	Jointed gneisses within shear zone	
6.	Slide Type	Block & wedge failure type	
7.	Slide Material	Huge boulders with 10-20% fires	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	130m	
11.	Width (In Mts)	40m	
12.	Area (M^2)	5200m^2	
13.	Failed Volume(M^3)	52000m^3	
14.	Damage Done	JN Road	
15.	Age	Recent	
16.	Triggers	Steep slope, jointed/sheared rock vibrations.	
17.	Likely Return Period	Perennial unless corrected	
18.	Coping Mechanism	Trigger slide to stabilized it, Rock bolting, Retaining walls/in-set walls	

PART SIX
GSI MAPPING OF LANDSLIDE VULNERABLE AREAS OF WEST SIKKIM

INTRODUCTION

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 27^0 06’ 35” N – 27^0 36’ 58” N and longitude ranging from 88^0 12’ 47” E – 88^0 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 Bazar (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.

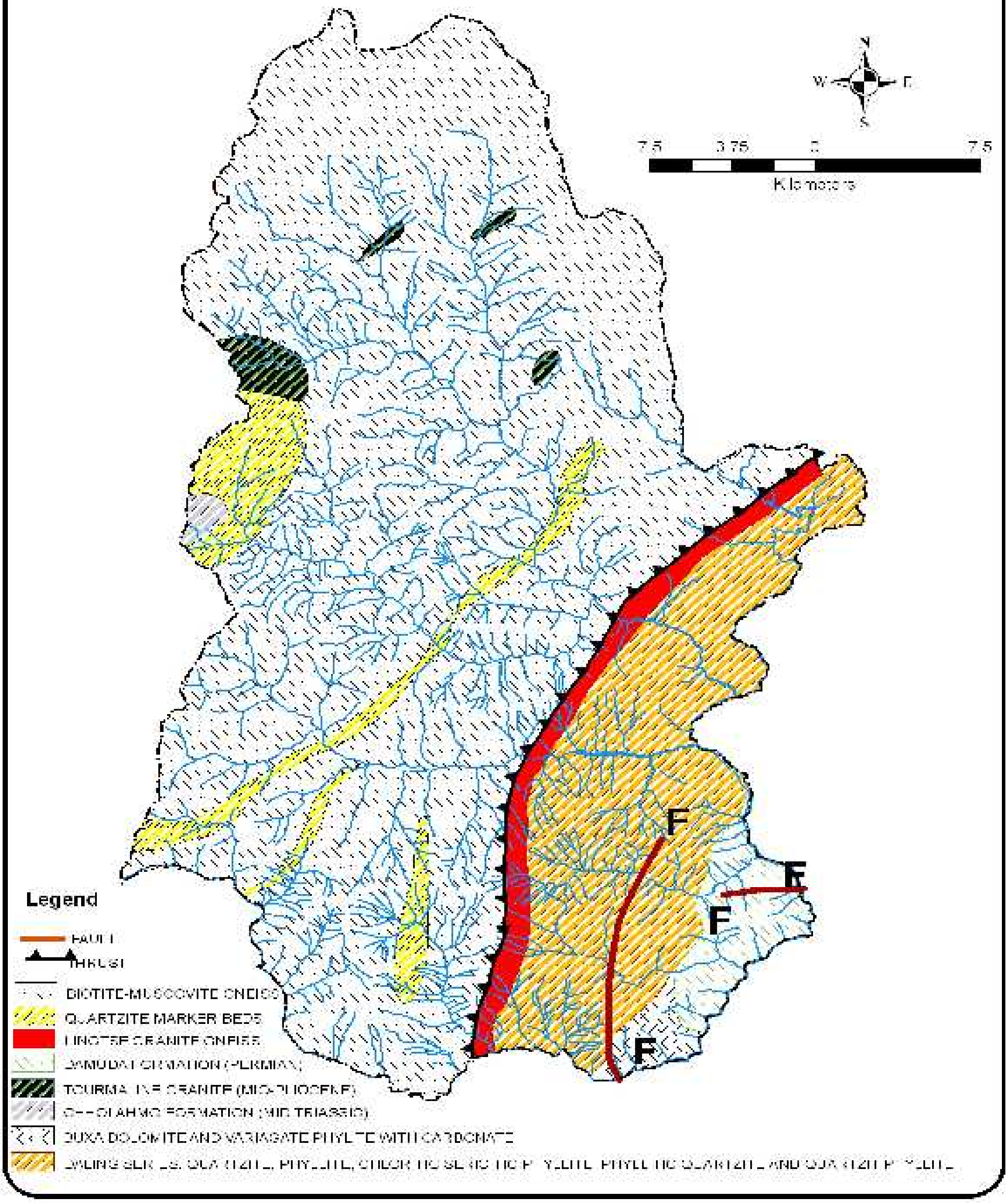
To assess the seriousness of the ground geo-environmental realities, a team of scientists and technical officers has attempted in making several interpretive thematic maps. The maps are the ultimate achievements of the team and made as credible and specific as possible. This report accompanying the maps contains replicable data, suggestions, and recommendations. Those are more of facts than myths, expressed in less technical terms. It is now up to the department to decide whether to act as recommended or wait for evidences or buy time for earth's social and natural constants/systems to adapt.

GEOLOGY

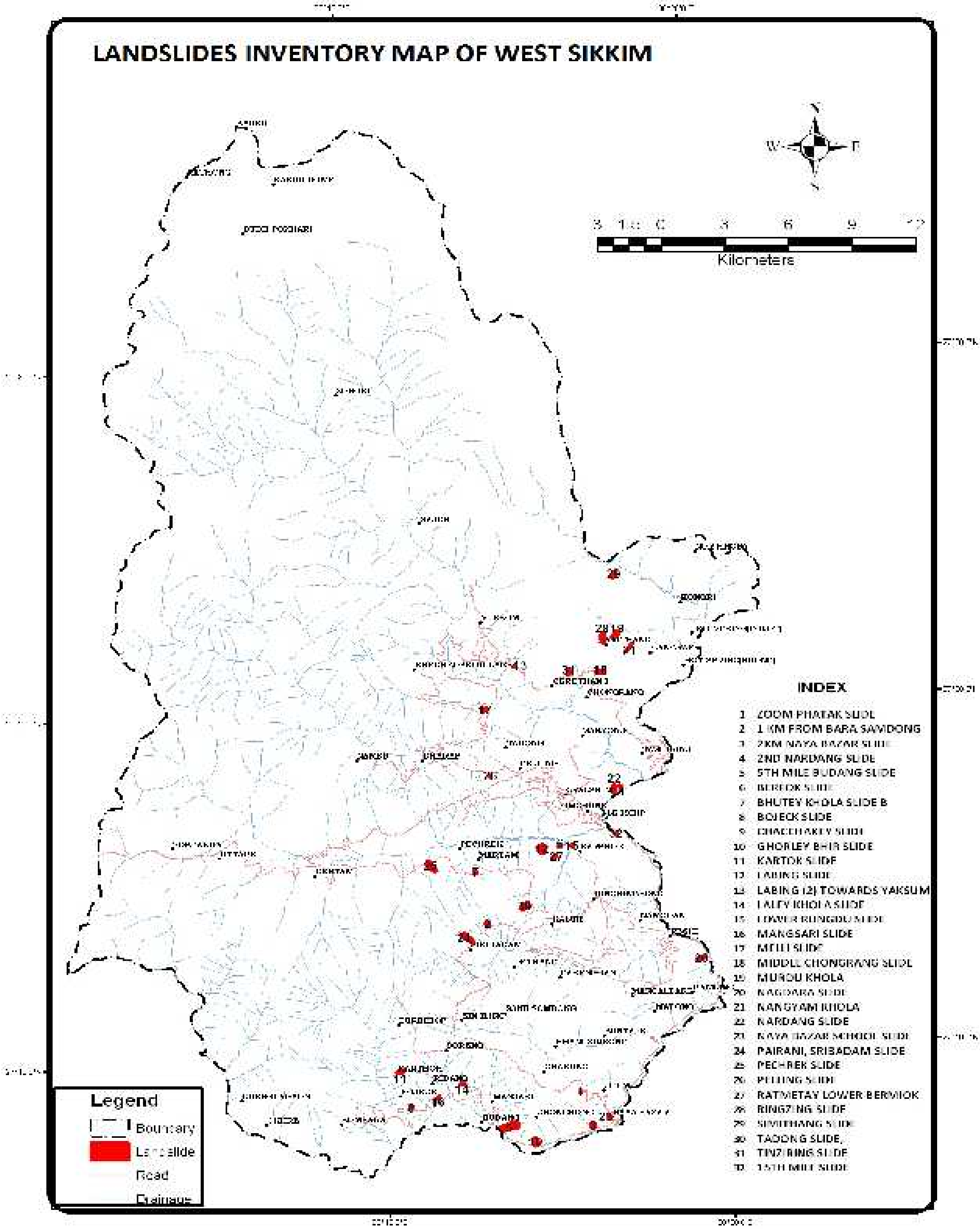
West District, the study area falls within the Lesser Himalaya which is made up of essentially of the Daling Group of rocks. The litho-units have been divided into categories based on their mineralogy, and their area of distribution is as shown in the map. The main litho-units are chlorite serecite phyllitic, 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 Quartz lens and rods. Few of Biotite-Serecite Litho-units show scattered 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.

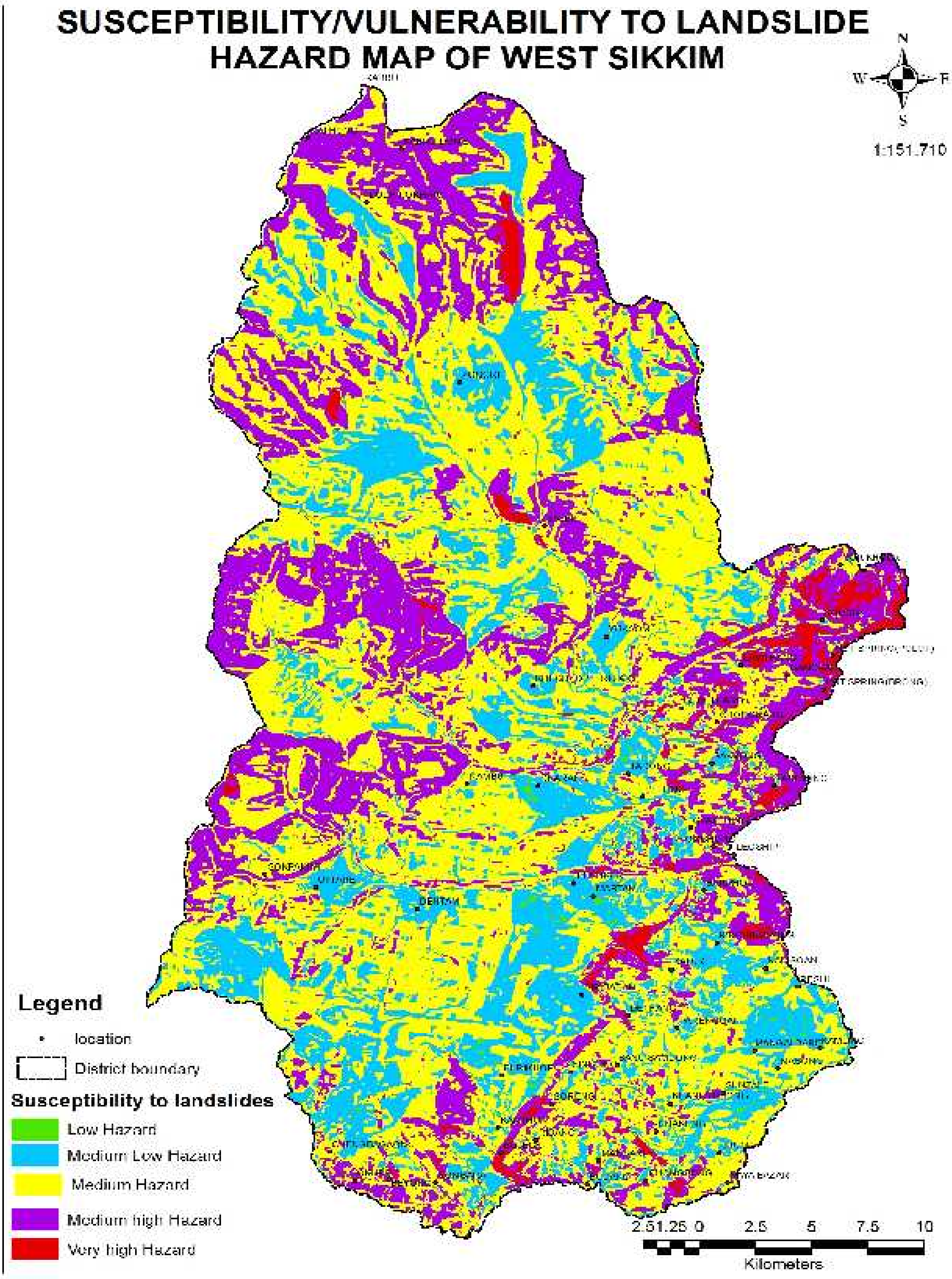
The remaining fifty percent is occupied by Quaternary deposits such as eluvial, colluvial, alluvial soils and debris. Mature soils with distinct horizons and high clay content are confined within reserve forests, ancient Landscape such as Pelling, Pemayangtse, Rabdentse, Chumbong, Baluthang, Sakyong,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

GEOLOGICAL MAP OF WEST SIKKIM



Map No 11


LANDSLIDES INVENTORY MAP OF WEST SIKKIM
W
E
Kilometers
INDEX
1 ZOOM PHATAK SLIDE
2 1 KM FROM BARA SAMDONG
3 2KM NAYA BAZAR SLIDE
4 2ND NARDANG SLIDE
5 5TH MILE BUDANG SLIDE
7 BHUTEY KHOLA SLIDE B
8 BOJECK SLIDE
10 GHORLEY BHIR SLIDE
11 KARTOK SLIDE
12 LABING SLIDE
13 LABING (2) TOWARDS YAKSUM
14 LALEY KHOLA SLIDE
16 MANGSARI SLIDE
17 MELLI SLIDE
18 MIDDLE CHONGRANG SLIDE
19 MURDU KHOLA
21 NANGYAM KHOLA
22 NARDANG SLIDE
23 NAYA BAZAR SCHOOL SLIDE
24 PAIRANI, SRIBADAM SLIDE
25 PECHREK SLIDE
26 PELLING SLIDE
27 RATMETAY LOWER BERMIOK
28 RINGZING SLIDE
30 TADONG SLIDE,
31 TINZIRING SLIDE
Legend
Boundary
Landslide
Road
Drainage



SUSCEPTIBILITY/VULNERABILITY TO LANDSLIDE
HAZARD MAP OF WEST SIKKIM
N
W
E
S
1:151,710
Legend
location
District boundary
Susceptibility to landslides
Low Hazard
Medium Low Hazard
Medium Hazard
Medium high Hazard
Very high Hazard
2.5 1.25 0 2.5 5 7.5 10
Kilometers

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 Bazar, 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, landslide etc. 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 Bazar 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 Bazar 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 Bazar 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. The slopes 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 (see maps) 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 west district 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. However, at local or individual Landowner scale some basic elements of Land-use plan seem to exist knowingly or otherwise- Present pattern of Land-use and Land-cover within west district has been assessed qualitatively as follows:-

Table No 11

Agricultural landuse Class		Area in sq meters	Area in ha.	% of Area
Forest	Forest	746751810	74675.18	64.04
Area under non agriculture uses	Settlement(point)	3300400	330.04	0.28
	Road (line)	11473774.16	1147.38	0.98
	Drainage (line)		0.00	0.00
	Mixed built up area	**941135**	94.11	0.08
	Public and Semipublic area	**494087**	49.41	0.04
Barren and unculturable land	Landslide	**721423**	72.14	0.06
Miscellaneous tree crops and groves not included in the area sown	Miscellaneous tree crops	**198923426**	19892.34	17.06
Culturable waste	Scrub land	**456946**	45.69	0.04
Fallow land	Fallow land and other then current fallow	**5134564**	513.46	0.44
	Current fallow	**188333**	18.83	0.02
Net sown area	Wet Land	**34401703**	3440.17	2.95
	Dry Land	**120156493**	12015.65	10.31
	Orange	**1021738**	102.17	0.09
	Cardamom	**37178112**	3717.81	3.19
Horticultural Crops	Green House	**30025**	3.00	0.00
	Potato	**4826031**	482.60	0.41
Total Net Sown area		197614102	19761.41	16.95
Geographical area of GPU west sikkim		**419248190**	41924.82	35.96
Geographical area of west sikkim		**1166000000**	116600.00	100.00

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, Soreng Bazar, Sombarya 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 Bazar 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 INCIDENCE

The landslides incidence map prepared for west district areas is an inventory of active and old landslides and other forms of slope instability. Almost the whole of west district is Landslide and instability prone and affected. The main causative factors of slope instability are weak geology, adverse planar structures in rocks, unstable slope materials, steep slopes or high relative relief, inappropriate Land-use and Land-cover, wayward water during monsoon and seismicity.

The term landslide is generally understood as downward and outward movement of slope forming materials or earth materials under the influence of gravity and causative factors as mentioned, either quickly or slowly, from one place to another. Landslides are quite complex in nature and no two slides are identical. Mountainous regions are generally home to mass wasting processes and Landslide is one of such processes, Sikkim in general and the study are in particular are no exceptions. The kinds of instability in west district are active slides, dormant slides, creep zones, slumps, mud and debris flow etc. Creeps and slumps graduate into either rotational slides or translational slides. Translational rock and debris slides under the influence of high water regime killed people and destroyed property two years ago around Gyalshing Bazar. The same area, parts of Gyalshing- Tashigang road section (see photos), Parbok-Daragoan-Lingchom area, East facing slope above Legship, parts of Sakyong- Baluthang are likely to experience destructive landslides, debris flows, debris avalanches etc. parts of Middle Gyalshing-Toyang, Kyongsa-Langang. St-Mary's school- Tikzak, Pemayangtse-Pelling area can expect benign as well as fairly destructive slope failures. Earthquake and unusual rain-storms are main triggers of major Landslides. The District Administration must, be aware of such events, and have contingency plans to face such eventualities. Destructive Landslides doesn't occur everyday. When they do, people and the Administration are caught unaware. Pessimism has no constructive value but in such cases it can save lives.

1. NAME OF SLIDE: - ZOOM PHATAK

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Zoom Phatak	
3.	Location	Latitude	N 27^0 08.733’
		Longitude	E 88^0 15.686’
4.	Altitude	1230 m amsl	
5.	Geological Setting	Sheared Phyllite/Quartzite interbands with rock/soil/mix overburden, Shear zone	
6.	Slide Type	Rotational	
7.	Slide Material	Rock soil mix materials.	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	150m	
12.	Area (M^2)	$22500m^2$	
13.	Failed Volume(M^3)	$675000m^3$	
14.	Damage Done	Agricultural land	
15.	Age	Since 1992	
16.	Triggers	Strike slip faulting, Weak geology, Ground water/rain water, vibration.	
17.	Likely Return Period	Active.	
18.	Coping Mechanism	Slope dressing, Geo-engineering.	

2. NAME OF SLIDE: - 1km FROM BARA SAMDONG TOWARDS SRIBADAM

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	1km from Bara Samdong towards Sribadam	
3.	Location	Latitude	N 27^0 13.695’
		Longitude	E 88^0 13.180’
4.	Altitude	1753 m amsl	
5.	Geological Setting	Gneissic rocks, Soil rock Mix cover, highly jointed rock-foliation N20 E-S20W, 30^{o}NW	
6.	Slide Type	Rotational	
7.	Slide Material	Rock soil mix	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	10000m^2	
13.	Failed Volume(M^3)	100000m^3	
14.	Damage Done	Cardamom field, Forest	
15.	Age	20 years	
16.	Triggers	Water movements, highly jointed rocks, soil cover.	
17.	Likely Return Period	Creep at present.	
18.	Coping Mechanism	Drainage, Geo-engineering and Afforestation.	

3. NAME OF SLIDE: - 2km NAYA BAZAR SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	2km Naya Bazar slide	
3.	Location	Latitude	N 27^{0} 07.782’
		Longitude	E 88^{0} 15.467’
4.	Altitude	405 m amsl	
5.	Geological Setting	Sheared, rocks due to thrust/fault environment, highly disturbed zone	
6.	Slide Type	Rotational	
7.	Slide Material	Mix of all types & sizes of rock frequents with hardly any soil	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	200m	
11.	Width (In Mts)	270m	
12.	Area (M^2)	$54000m^2$	
13.	Failed Volume(M^3)	$1080000m^3$	
14.	Damage Done	Road & forest cover	
15.	Age	Old (Dormant)	
16.	Triggers	Toe cutting, vibration	
17.	Likely Return Period		
18.	Coping Mechanism	River training, slope dressing.	

4. NAME OF SLIDE: - 2nd NARDANG SLIDE BETWEEN GUNRUKEY & NORDANG (100m DOWNSTREAM FROM RANGIT NHPC DAM)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	2nd Nardang slide between Gunrukey & Nordang (100m downstream from Rangit NHPC Dam)	
3.	Location	Latitude	N 27^0 17.464'
		Longitude	E 88^0 17.264'
4.	Altitude	658 m amsl	
5.	Geological Setting	Disturbed phyllite/quartzite sequence with soil overburden.	
6.	Slide Type	Rotational	
7.	Slide Material	Quartzite	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	150m	
12.	Area (M^2)	22500m^2	
13.	Failed Volume(M^3)	225000m^3	
14.	Damage Done	Road disruption, Agricultural land etc.	
15.	Age	NA	
16.	Triggers	Toe cutting, disturbed rock sequence, steep slope	
17.	Likely Return Period	Active above road and dormant below road.	
18.	Coping Mechanism	Toe protection, Sausages, Afforestation.	

5. NAME OF SLIDE: - 5th MILE BUDANG SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	5th mile Budang slide	
3.	Location	Latitude	N 27^0 07.697'
		Longitude	E 88^0 13.258'
4.	Altitude	476 m amsl	
5.	Geological Setting	Well layered quartzite & phyllites intercalation on either flanks of the slide. Right flanks-N15E-S15W, dip-38oNW	
6.	Slide Type	Mainly planner	
7.	Slide Material	Collapsed rock formations, rock fragments of all sizes, tilted trees.	
8.	Average Depth (In Mts)	>50m	
9.	Maximum Depth (In Mts)	>100m	
10.	Length (In Mts)	800m	
11.	Width (In Mts)	270m	
12.	Area (M^2)	216000m^2	
13.	Failed Volume(M^3)	10800000m^3	
14.	Damage Done	Road, forest	
15.	Age	Old (Dormant)	
16.	Triggers	Adverse geology, slope parallel to foliation plane, steep slope poor drainage, vibration	
17.	Likely Return Period	With 5-10 year-after construction of the dam, if no proactive works.	
18.	Coping Mechanism	Geo-eng, slope dressing, toe protection by hydel project developer at the slide.	

6. NAME OF SLIDE: - BERFOK SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Berfok slide	
3.	Location	Latitude	N 27^0 15.840’
		Longitude	E 88^0 15.440’
4.	Altitude	900 m amsl	
5.	Geological Setting	Phyllite/Quartzite interbanding sequence wedge failure N10 E-S 10 W (E 100 s) 45o amount	
6.	Slide Type	Wedge failure-Planner	
7.	Slide Material	Rock soil mix	
8.	Average Depth (In Mts)	3m	
9.	Maximum Depth (In Mts)	5m	
10.	Length (In Mts)	75m	
11.	Width (In Mts)	20m	
12.	Area (M^2)	1500m^2	
13.	Failed Volume(M^3)	4500m^3	
14.	Damage Done	Road	
15.	Age	Recent	
16.	Triggers	Sheared Rock with immature soil cover/surface run off	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Geo-engineering. Sausage, Gabbions etc.	

7. NAME OF SLIDE: - BHUTEY KHOLA SLIDE B

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Bhutey khola slide B	
3.	Location	Latitude	N 27^0 15.200’
		Longitude	E 88^0 12.950’
4.	Altitude	1436 m amsl	
5.	Geological Setting	Gneissic/Biotite rock sequence with soil cover.	
6.	Slide Type	Rotational	
7.	Slide Material	Gneissic rock boulders and transported, sandy soil.	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	30m	
10.	Length (In Mts)	75m	
11.	Width (In Mts)	50m along left abutment of Bhutey Khola.	
12.	Area (M^2)	$3750m^2$	
13.	Failed Volume(M^3)	$75000m^3$	
14.	Damage Done	Road blocked, Forest cover.	
15.	Age	15 years	
16.	Triggers	Water seepage, Toe Cutting by Bhutey Khola.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Toe protection, Low height sausage gabions Afforestation.	

8. NAME OF SLIDE: - BOJECK SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Bojeck slide	
3.	Location	Latitude	N 27^0 08.519’
		Longitude	E 88^0 10.751’
4.	Altitude	821 m amsl	
5.	Geological Setting	Highly foliated Chloride and Sericite, phyllite with their Quartzite layers, strike-N10E-S10W, dip-48NW, and faulted area. Rightflank-N15E-S15W, dip-24NW.	
6.	Slide Type	Wedge failure controlled by an active fault.	
7.	Slide Material	Sheared phyllites, ferruginous quartzite blocks & bands and failure traces deposits.	
8.	Average Depth (In Mts)	30m	
9.	Maximum Depth (In Mts)	50m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	150m	
12.	Area (M^2)	22500m^2	
13.	Failed Volume(M^3)	675000m^3	
14.	Damage Done	Agricultural land	
15.	Age	Since 1992	
16.	Triggers	Strike slip faulting, Weak geology, Ground water/rain water, vibration.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope dressing, Geo-engineering.	

9. NAME OF SLIDE: - CHACCHAKEY SLIDE (1st SLIDE NEAR LEGSHIP TOWARDS RESHI)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Chacchakey slide (1st slide near Legship Towards Reshi)	
3.	Location	Latitude	N 27^0 16.304’
		Longitude	E 88^0 16.855’
4.	Altitude	525 m amsl	
5.	Geological Setting	Favourably oriented Quartzites and phyllite interbanding sequence, strike-N20E-S20W, dip-44^0 NW	
6.	Slide Type	Planner, Rock toppling.	
7.	Slide Material	Quartzites and rock soil mix materials.	
8.	Average Depth (In Mts)	2m	
9.	Maximum Depth (In Mts)	5m	
10.	Length (In Mts)	25m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	2500m^2	
13.	Failed Volume(M^3)	5000m^3	
14.	Damage Done	Road traffic disruption for long period during monsoon.	
15.	Age	20years	
16.	Triggers	High degree slope, toe cutting by Rangit river.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope dressing, Geo-engineering.	

10. NAME OF SLIDE: - GHORLEY BHIR SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Ghorley bhir slide	
3.	Location	Latitude	N 27^{0} 07.302’
		Longitude	E 88^{0} 14.290’
4.	Altitude	440 m amsl	
5.	Geological Setting	Left slide/flank high sheared ferruginous quartzite with Carb phyllite, Sericite phyllite N 5 W-S 5 E Right flank fresh Quartize, Phyllite etc. N 20 E-S 20 W 750 N W	
6.	Slide Type	Complex with displaced rock formations in the slide body.	
7.	Slide Material	Sheared displaced Quartzite’s, Phyllites & slide material	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)		
10.	Length (In Mts)	400m	
11.	Width (In Mts)	330m	
12.	Area (M^2)	132000m^2	
13.	Failed Volume(M^3)	1980000m^3	
14.	Damage Done	Road, Forest	
15.	Age	Old (dormant)	
16.	Triggers	Adverse geology, steep slope, high rainfall vibration.	
17.	Likely Return Period	NA	
18.	Coping Mechanism	Geo-engineering work, drainage, afforestation.	

11. NAME OF SLIDE: - KARTOK SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Kartok slide	
3.	Location	Latitude	N 27^0 09.631’
		Longitude	E 88^0 10.251’
4.	Altitude	1450 m amsl	
5.	Geological Setting	Alternating layers of mica schist & Quartzite slope across the rock foliation	
6.	Slide Type	Planar due to failure of joint plane	
7.	Slide Material	Collapsed slope forming material	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	80m	
11.	Width (In Mts)	30m	
12.	Area (M^2)	2400m^2	
13.	Failed Volume(M^3)	24000m^3	
14.	Damage Done	Agricultural land, Forest	
15.	Age	>5 years	
16.	Triggers	Steep slope, brittle rocks	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Since slope doesn’t affect habitation or agriculture & slope being very steep, coping is not possible.	

12. NAME OF SLIDE: - LABING SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Labing slide morning	
3.	Location	Latitude	N 27^0 20.520’
		Longitude	E 88^0 14.730’
4.	Altitude	1456 m amsl	
5.	Geological Setting	Biotite schist/Gneiss, highly jointed rock slide, N40E-S40W, dip-36^0 NW.	
6.	Slide Type	Rock slide failure along joint.	
7.	Slide Material	Rock boulders with soil.	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	30m	
12.	Area (M^2)	15000m^2	
13.	Failed Volume(M^3)	75000m^3	
14.	Damage Done	Forest, Road	
15.	Age	15 years	
16.	Triggers	Highly jointed rocks, steep slope.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Sausages, Rock bolting, Afforestation.	

13. NAME OF SLIDE: - LABING SLIDE (2) TOWARDS YAKSUM FROM TASHIDING

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Labing slide (2) towards Yaksum from Tashiding	
3.	Location	Latitude	N 27^0 21.060’
		Longitude	E 88^0 14.342’
4.	Altitude	1368 m amsl	
5.	Geological Setting	Massive Gneissic bands with Biotite-schist intercalation with thin soil cover, strike-N20E-S20W, dip-55^0 NW.	
6.	Slide Type	A unique case of rock toppling or fall	
7.	Slide Material	Gneissic rock boulders with thin soil cover.	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	5m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	25m	
12.	Area (M^2)	$2500m^2$	
13.	Failed Volume(M^3)	$12500m^3$	
14.	Damage Done	Road disruption, trees.	
15.	Age	3 years	
16.	Triggers	Highly jointed rock.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Rock bolting, Low height retaining walls.	

14. NAME OF SLIDE: - LALEY KHOLA SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Laley khola slide	
3.	Location	Latitude	N 27^0 09.127’
		Longitude	E 88^0 12.312’
4.	Altitude	760 m amsl	
5.	Geological Setting	Left flank slope deposit Right flank pure quartzite underlain by Sericite and Chlorite phyllite N80W-S80E, dip-47^{0}NE	
6.	Slide Type	Rotational	
7.	Slide Material	Terrace material with boulders of all sizes	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	60m	
12.	Area (M^2)	6000m^2	
13.	Failed Volume(M^3)	60000m^3	
14.	Damage Done	Road, cultivated land, forest	
15.	Age	<15 years	
16.	Triggers	Weak geology, poor Drainage	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Engineering works, Toe protection.	

15. NAME OF SLIDE: - LOWER RUNGDU SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Lower Rungdu slide	
3.	Location	Latitude	N 27^0 15.857’
		Longitude	E 88^0 15.870’
4.	Altitude	850 m amsl	
5.	Geological Setting	Phyllite/Quartzite interbanding sequence soil over burden	
6.	Slide Type	Planner	
7.	Slide Material	Rock, Soil mix over burden	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	7500m^2	
13.	Failed Volume(M^3)	112500m^3	
14.	Damage Done	Agriculture land	
15.	Age	Recent	
16.	Triggers	Toe cutting, Seasonal surface run off	
17.	Likely Return Period		
18.	Coping Mechanism	Retaining structures, effective drainage, afforestation.	

16. NAME OF SLIDE: - MANGSARI SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Mangsari Slide	
3.	Location	Latitude	N 27^0 08.80’
		Longitude	E 88^0 11.575’
4.	Altitude	850 m amsl	
5.	Geological Setting	Chlorite and Sericite phyllite underlain by Quartzite, highly weather rocks.	
6.	Slide Type	Rotational	
7.	Slide Material	Pulverized Chlorite and Sericite phyllite with Quartzite boulders of all sizes.	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	50m	
12.	Area (M^2)	5000m^2	
13.	Failed Volume(M^3)	50000m^3	
14.	Damage Done	Agricultural land.	
15.	Age	10 years	
16.	Triggers	Weathered nature of slope material, foliation down dip, ground water.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Toe protection at Rani khola, slope dressing.	

17. NAME OF SLIDE: - MELLI SLIDE (BETWEEN YAKSUM & RIMBI)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Melli slide (between Yaksum & Rimbi)	
3.	Location	Latitude	N 27^0 19.878'
		Longitude	E 88^0 13.448'
4.	Altitude	1144 m amsl	
5.	Geological Setting	Fragile geological setting Quartzite/Phyllite interband with soil cover.	
6.	Slide Type	Complex	
7.	Slide Material	Rock soil mix	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	35m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	75m	
12.	Area (M^2)	$11250m^2$	
13.	Failed Volume(M^3)	$225000m^3$	
14.	Damage Done	Road destabilization, forest cover	
15.	Age	20 years	
16.	Triggers	Weak geological highly Jointed rocks	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Low height retaining walls, Rock bolting, effective drainage, afforestation.	

18. NAME OF SLIDE: - MIDDLE CHONGRANG SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Middle Chongrang Slide	
3.	Location	Latitude	N 27^0 20.791’
		Longitude	E 88^0 16.767’
4.	Altitude	1542 m amsl	
5.	Geological Setting	Gneiss with thin cover rock adversely foliated along slope.	
6.	Slide Type	Translational	
7.	Slide Material	Rock slip along with thin soil cover with trees.	
8.	Average Depth (In Mts)	2m	
9.	Maximum Depth (In Mts)	5m	
10.	Length (In Mts)	400m	
11.	Width (In Mts)	75m at road, but down below is 300m width	
12.	Area (M^2)	$30000m^2$	
13.	Failed Volume(M^3)	$60000m^3$	
14.	Damage Done	Road destabilization.	
15.	Age	Recent	
16.	Triggers	Water seepage/runoff, rock slip along foliation.	
17.	Likely Return Period	Dormant at present	
18.	Coping Mechanism	Low height walls, Drainage, rock bolting afforestation.	

19. NAME OF SLIDE: - MURDU KHOLA SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Murdu khola slide	
3.	Location	Latitude	N 27^0 21.760’
		Longitude	E 88^0 17.288’
4.	Altitude	1788 m amsl	
5.	Geological Setting	Phyllite & Quartzite, disturbed	
6.	Slide Type	Rotational	
7.	Slide Material	Failed rock & soil material	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	250m	
11.	Width (In Mts)	120m	
12.	Area (M^2)	30000m^2	
13.	Failed Volume(M^3)	300000m^3	
14.	Damage Done	Cardamom, Forest, Road	
15.	Age	10-20 years	
16.	Triggers	Adverse geology, Water, Road construction	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope dressing, drainage, afforestation.	

20. NAME OF SLIDE: - NAGDARA SLIDE (1km AHEAD OF SIKKIM ROAD JUNCTION TOWARDS RESHI)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Nagdara slide (1km ahead of Sikkim road junction towards Reshi)	
3.	Location	Latitude	N 27^0 12.429'
		Longitude	E 88^0 19.444'
4.	Altitude	538 m amsl	
5.	Geological Setting	Dolomitic terrain, dolomite with coal dolomitic boulders overburden.	
6.	Slide Type	Rotational.	
7.	Slide Material	Gondwana shales/phyllites, coal shale, dolomitic boulders.	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	75m	
12.	Area (M^2)	$7500m^2$	
13.	Failed Volume(M^3)	$75000m^3$	
14.	Damage Done	Frequent blocking of road traffic, Forest trees etc.	
15.	Age	NA	
16.	Triggers	Loose crushed materials, surface/subsurface water runoff	
17.	Likely Return Period	Active slide.	
18.	Coping Mechanism	Effective retaining structures, Afforestation.	

21. NAME OF SLIDE: - NANGYAM KHOLA SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Nangyam khola slide	
3.	Location	Latitude	N 27^0 21.559’
		Longitude	E 88^0 17.610’
4.	Altitude	1820 m amsl	
5.	Geological Setting	Phyllite with Quartzite well bedded------, rotated left side N40W-S40E towards 25^0NE, Right N70W-S70E, 14^0NNW	
6.	Slide Type	Fault controlled complex	
7.	Slide Material	Debris	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	60m	
12.	Area (M^2)	$6000m^2$	
13.	Failed Volume(M^3)	$30000m^3$	
14.	Damage Done	Road, Cardamom	
15.	Age	10 years	
16.	Triggers	Soil Collapse above the rock bed during rain fall	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope realignment, Afforestation.	

22. NAME OF SLIDE: - NAGDARA SLIDE (1st SLIDE ON HINGDAM-TASHIDING ROAD)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Nardang Slide (1st slide on Hingdam- Tashiding Road)	
3.	Location	Latitude	N 27^0 17.322’
		Longitude	E 88^0 17.150’
4.	Altitude	610 m amsl	
5.	Geological Setting	Phyllite/Quartzite disturbed tectonic zone	
6.	Slide Type	Rotational & Complex	
7.	Slide Material	Rock boulders & soil mix debris	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	200m	
12.	Area (M^2)	30000m^2	
13.	Failed Volume(M^3)	300000m^3	
14.	Damage Done	Road disruption, Agriculture land, trees	
15.	Age	5 years (more)	
16.	Triggers	Adverse geo setting, Toe cutting by Rangit river, road construction	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Toe protection, Sausages, Forest cover.	

23. NAME OF SLIDE: - NAYA BAZAR SCHOOL SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Naya Bazar School slide	
3.	Location	Latitude	N 27^0 7.945’
		Longitude	E 88^0 16.477’
4.	Altitude	394 m amsl	
5.	Geological Setting	Thrust zone, pulverized coal sand stone, limestone, phyllite, Quartzite	
6.	Slide Type	Rotational	
7.	Slide Material	Pulverized coal mixed with sheared rock fragments	
8.	Average Depth (In Mts)	25m	
9.	Maximum Depth (In Mts)	100m	
10.	Length (In Mts)	120m	
11.	Width (In Mts)	108m	
12.	Area (M^2)	12960m^2	
13.	Failed Volume(M^3)	324000m^3	
14.	Damage Done	Road, forest	
15.	Age	Old	
16.	Triggers	Thrusting, toe cutting, vehicular vibration, sheared nature of slope material	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Toe protection by river training, training walls.	

24. NAME OF SLIDE: - PAIRANI, SRIBADAM TOWARDS KALUK-2KM

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Pairani, Sribadam towards kaluk-2km	
3.	Location	Latitude	N 27^0 13.290’
		Longitude	E 88^0 12.589’
4.	Altitude	1790 m amsl	
5.	Geological Setting	Gneissic sequence and Fault zone.	
6.	Slide Type	Rotational as well as wedge failure	
7.	Slide Material	Rock/soil debris	
8.	Average Depth (In Mts)	15m	
9.	Maximum Depth (In Mts)	20m	
10.	Length (In Mts)	300m	
11.	Width (In Mts)	70m	
12.	Area (M^2)	$21000m^2$	
13.	Failed Volume(M^3)	$315000m^3$	
14.	Damage Done	Forest	
15.	Age	20 years	
16.	Triggers	Surface/sub-surface water movement, slide materials, Brittle rock, Toe cutting, vibration.	
17.	Likely Return Period	Active creep movement	
18.	Coping Mechanism	Water channelizing, geo-engineering measures, Afforestation.	

25. NAME OF SLIDE: - PECHEREK SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Pecherek Slide	
3.	Location	Latitude	N 27^0 15.609’
		Longitude	E 88^0 11.595’
4.	Altitude	1345 m amsl	
5.	Geological Setting	Gneissic rock sequence with Biotic schist intercalations/fault plane. N55W-S55E, Dip-23^0SE	
6.	Slide Type	Complex and rotational rock toppling.	
7.	Slide Material	Gneissic rocks boulders with soil cover.	
8.	Average Depth (In Mts)	40m	
9.	Maximum Depth (In Mts)	80m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	150m	
12.	Area (M^2)	75000m^2	
13.	Failed Volume(M^3)	3000000m^3	
14.	Damage Done	Road disruption, Forest cover and Agriculture land.	
15.	Age	30 years	
16.	Triggers	Weak Geology, surface/subsurface runoff, Toe cutting.	
17.	Likely Return Period	Active slide.	
18.	Coping Mechanism	Toe protection, Rock bolting, drainage, Effective drainage, in-set walls, Afforestation .	

26. NAME OF SLIDE: - PELLING SLIDE ALONG PELLING DENTAM ROAD (1/2km FROM PELLING RIDGE)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Pelling slide along Pelling Dentam road(1/2km from Pelling ridge)	
3.	Location	Latitude	N 27^0 17.935'
		Longitude	E 88^0 13.525'
4.	Altitude	1845 m amsl	
5.	Geological Setting	Jointed Gneissic rock sequence with the soil cover	
6.	Slide Type	Rock failure & planner	
7.	Slide Material	Gneissic boulders with soil	
8.	Average Depth (In Mts)	5m	
9.	Maximum Depth (In Mts)	10m	
10.	Length (In Mts)	175m	
11.	Width (In Mts)	25m	
12.	Area (M^2)	$4375m^2$	
13.	Failed Volume(M^3)	$21875m^3$	
14.	Damage Done	Vehicles & traffic disruption.	
15.	Age	5 years	
16.	Triggers	Highly jointed rock, steep slope, surface runoff	
17.	Likely Return Period	Active.	
18.	Coping Mechanism	Low height walls, sausage, Gabbions, Rock Bolting.	

27. NAME OF SLIDE: - RATMETAY SLIDE LOWER BERMIOK SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Ratmetay Slide Lower Bermiok slide	
3.	Location	Latitude	N 27^{0} 15.495’
		Longitude	E 88^{0} 15.178’
4.	Altitude	940 m amsl	
5.	Geological Setting	Phyllite with red soil over burden.	
6.	Slide Type	Planner	
7.	Slide Material	Soil with pebbles	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	100m	
11.	Width (In Mts)	25m	
12.	Area (M^2)	2500m^2	
13.	Failed Volume(M^3)	25000m^3	
14.	Damage Done	Trees, Road (Bermiok – Legship Road)	
15.	Age	NA	
16.	Triggers	Soil Collapse above the rock bed during rain fall	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Geo-engineering measures, Effective drainage.	

28. NAME OF SLIDE: - RINGZYANG SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Ringzyang slide	
3.	Location	Latitude	N 27^0 21.923’
		Longitude	E 88^0 16.929’
4.	Altitude	1763 m amsl	
5.	Geological Setting	Phyllite & Quartzite, disturbed Tectonic zone	
6.	Slide Type	Planner as well as Rotational	
7.	Slide Material	Residual debris	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)		
10.	Length (In Mts)	400m	
11.	Width (In Mts)	250m	
12.	Area (M^2)	100000m^2	
13.	Failed Volume(M^3)	1000000m^3	
14.	Damage Done	Habitation, cultivation, road.	
15.	Age	About 10 years after construction of road.	
16.	Triggers	Adverse geology, high ground, road construction. Toe cutting	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Slope dressing, realignment of road, drainage, Rock bolting	

29. NAME OF SLIDE: - SIMITHANG SLIDE

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Simithang slide	
3.	Location	Latitude	N 27^0 23.577’
		Longitude	E 88^0 17.220’
4.	Altitude	1800 m amsl	
5.	Geological Setting	Amphibolites, banded gneiss, Garnetiferous mica-schist, strike E-W, Dip Northerly.	
6.	Slide Type	Rotational	
7.	Slide Material	Debris/soil with boulders	
8.	Average Depth (In Mts)	50m	
9.	Maximum Depth (In Mts)	75m	
10.	Length (In Mts)	300m	
11.	Width (In Mts)	150m	
12.	Area (M^2)	$45000m^2$	
13.	Failed Volume(M^3)	$2250000m^3$	
14.	Damage Done	Simithang under impact, Cardamom field.	
15.	Age	50-60 years	
16.	Triggers	Adverse geology, poor Drainage.	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Toe protection, Drainage, Afforestation.	

30. NAME OF SLIDE: - TADONG SLIDE, 2km AHEAD OF KALUK TO DENTAM

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Tadong slide, 2km ahead of Kaluk to Dentam	
3.	Location	Latitude	N 27^0 14.243’
		Longitude	E 88^0 14.278’
4.	Altitude	1470 m amsl	
5.	Geological Setting	Quartzite/Phyllite interband sequence with soil cover, fault zone, contact of Quartzite with mica schist-mica schist towards BARMEK- N65 W-	
6.	Slide Type	Rotational S65E-15SE	
7.	Slide Material	Rock soil mix debris	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	30m	
10.	Length (In Mts)	500m	
11.	Width (In Mts)	100m	
12.	Area (M^2)	50000m^2	
13.	Failed Volume(M^3)	1000000m^3	
14.	Damage Done	Road, Forest, Agriculture	
15.	Age	50 years	
16.	Triggers	Fault Zone, Surface/subsurface water movement, steep slope	
17.	Likely Return Period	Active	
18.	Coping Mechanism	Effective drainage, correct retaining walls, Afforestation.	

31. NAME OF SLIDE: - TINZIRING SLIDE (AHEAD OF CHONGRAY BEFORE GERYTHANG)

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	Tinziring Slide (ahead of Chongray before Gerythang)	
3.	Location	Latitude	N 27^0 20.825’
		Longitude	E 88^0 15.900’
4.	Altitude	1425m amsl	
5.	Geological Setting	Sericite phyllite/Quartzite interbands, Jointed Strike-N20E-S20W,Dip-34^0NW	
6.	Slide Type	Rotational & Complex	
7.	Slide Material	Rock soil mix materials	
8.	Average Depth (In Mts)	10m	
9.	Maximum Depth (In Mts)	15m	
10.	Length (In Mts)	300m	
11.	Width (In Mts)	150m	
12.	Area (M^2)	45000m^2	
13.	Failed Volume(M^3)	450000m^3	
14.	Damage Done	Road sinking.	
15.	Age		
16.	Triggers	Geological formation, water runoff, Toe cutting.	
17.	Likely Return Period	Dormant at present with protective measures.	
18.	Coping Mechanism	Low height retaining walls, drainage, Toe protection.	

32. NAME OF SLIDE: - 15th MILE SLIDE (BETWEEN RESHI AND KALEJ KHOLA) 1km TO LEGSHIP

SL NO	PARTICULARS	COMMENTS	
1.	District	West Sikkim	
2.	Name Of The Slide	15th mile slide (Between Reshi and KALEJ khola) 1km to Legship	
3.	Location	Latitude	N 27^0 16.237’
		Longitude	E 88^0 17.127’
4.	Altitude	563 m amsl	
5.	Geological Setting	Quartzite/ Phyllite sequence with rock soil mix overburden.	
6.	Slide Type	Rotational (Creep)	
7.	Slide Material	Quartzite boulders, rock soil mix materials.	
8.	Average Depth (In Mts)	20m	
9.	Maximum Depth (In Mts)	25m	
10.	Length (In Mts)	150m	
11.	Width (In Mts)	200m	
12.	Area (M^2)	$30000m^2$	
13.	Failed Volume(M^3)	$600000m^3$	
14.	Damage Done	Sinking of road, Tilted trees.	
15.	Age	50 years	
16.	Triggers	Degraded slope materials, seasonal water runoff, Toe cutting.	
17.	Likely Return Period	NA	
18.	Coping Mechanism	Sausage, Gabbions, Bio-Engineering measures, Toe protection, Afforestation.	

PART SEVEN

INVENTORY AND GSI MAPPING OF LANDSLIDE VULNERABLE AREAS OF SOUTH DISTRICT

INTRODUCTION

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 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 Natural beauty.

GENERAL GEOLOGY AND STRUCTURE

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, slates, carbonaceous shale coal, sandstone and shale.

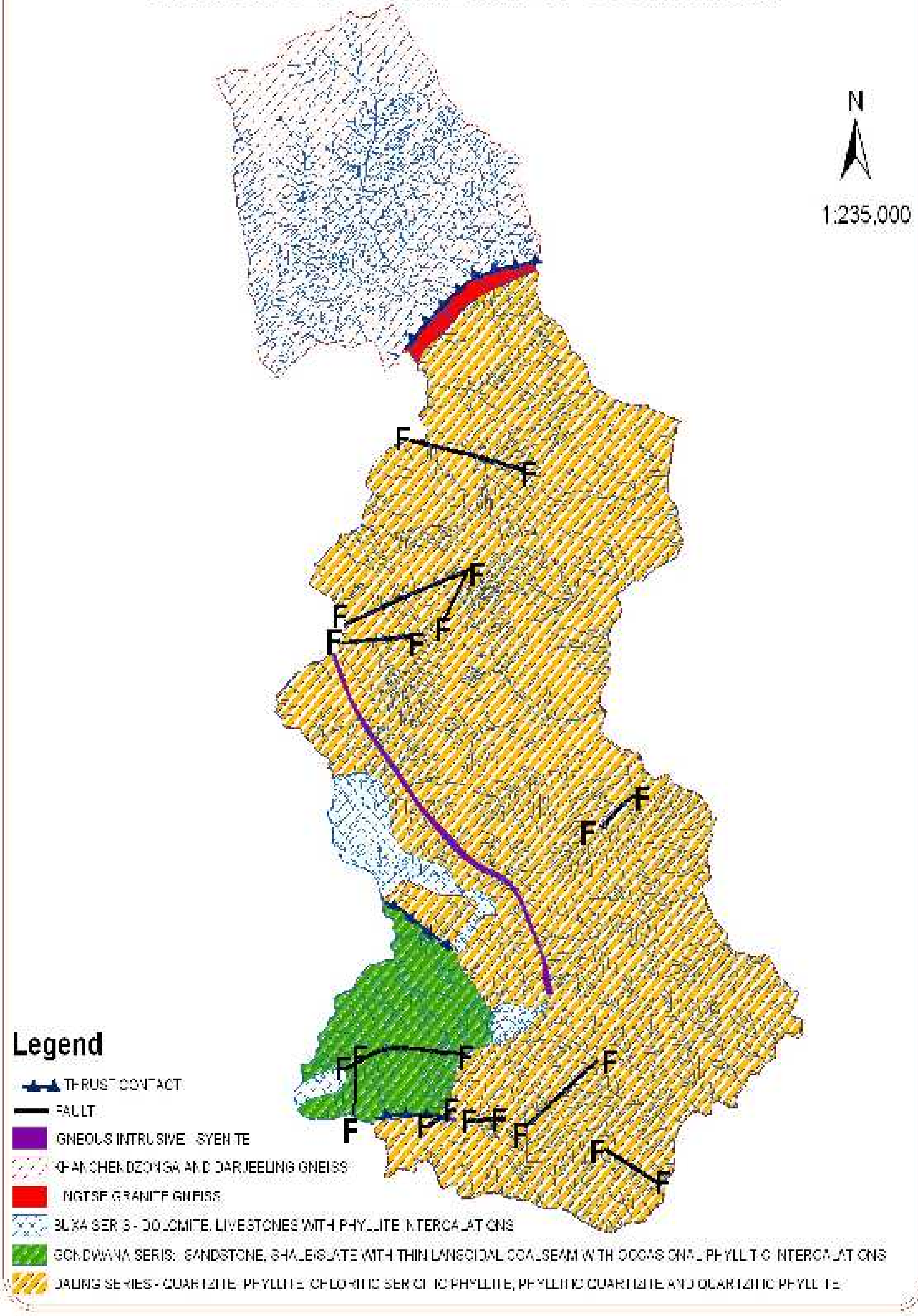
BUXA

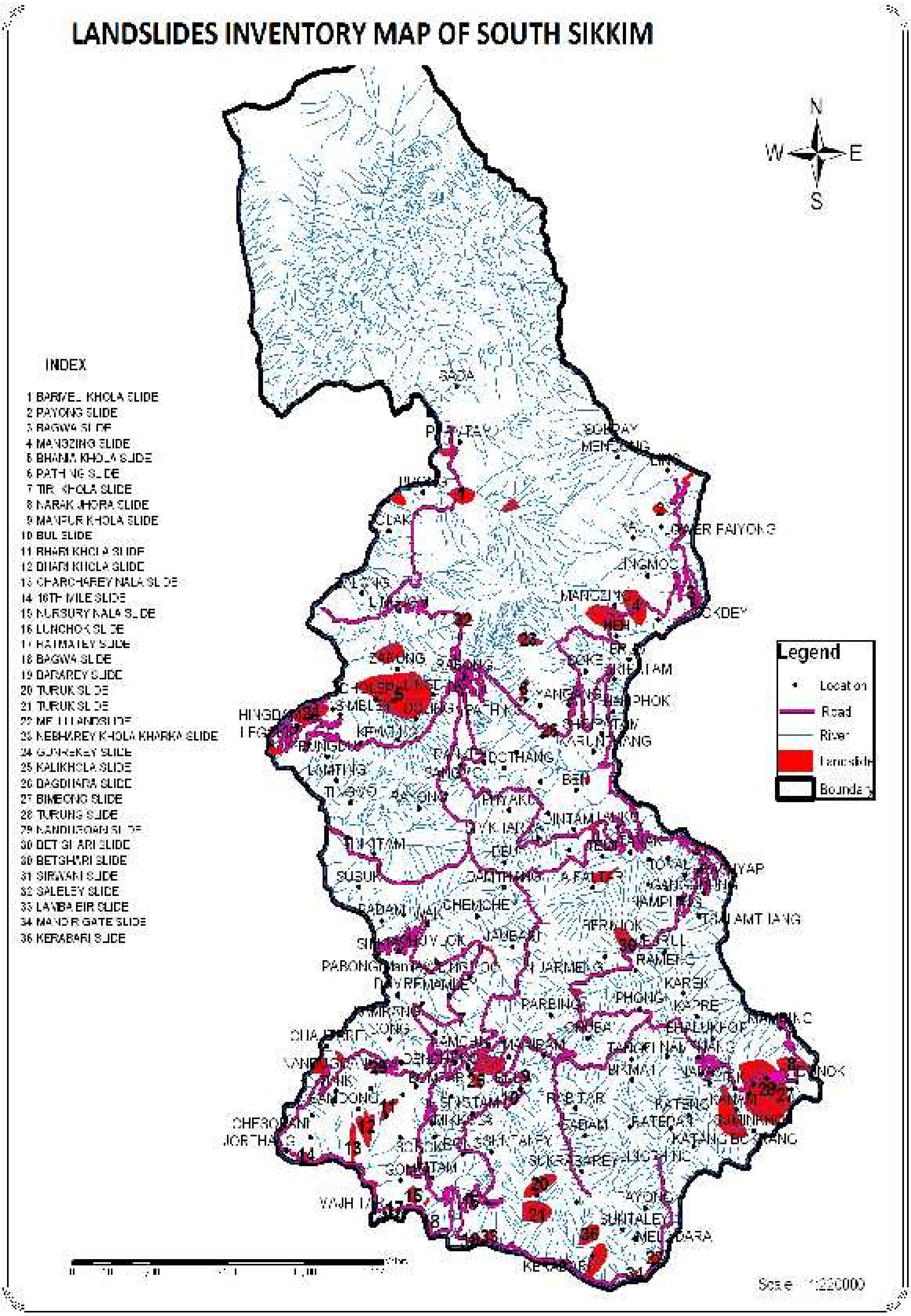
Carbon phyllites, slates, calc-phyllite, dolomite/limestone, purple phyllite, dark calcareous slates.

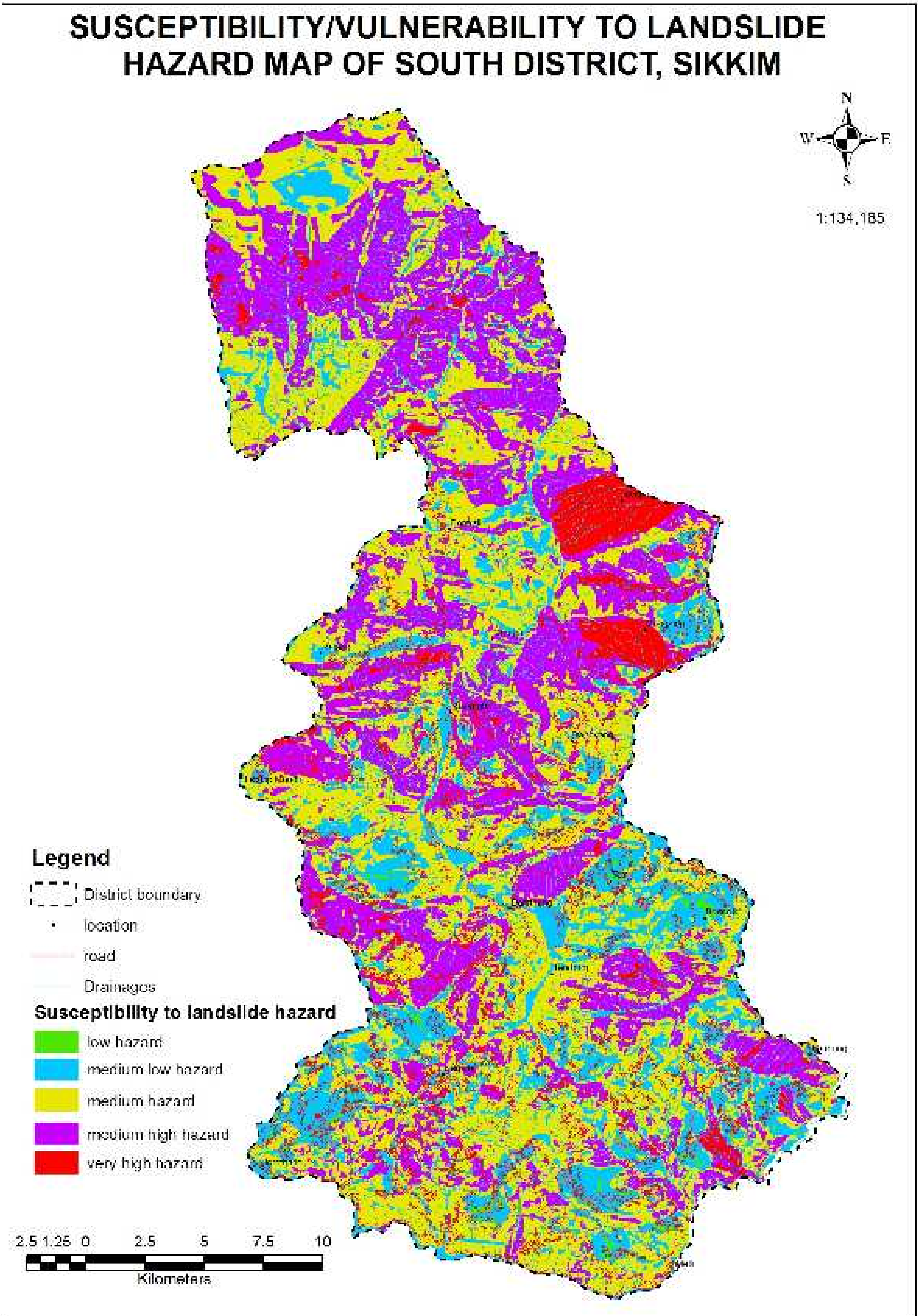
DALINGS

Phyllites, varved phyllite, basic instrusives, green quartzite (fuchsite) sericitic and chlonitic phyllite, massive and flaggy quartzite, quartz veins.

GENERAL GEOLOGICAL MAP OF SOUTH SIKKIM




LANDSLIDES INVENTORY MAP OF SOUTH SIKKIM
N
W
E
S
INDEX
1 BARMEL KHOLA SLIDE
2 PAYONG SLIDE
4 MANGZING SLIDE
5 BHANJA KHOLA SLIDE
7 TIRI KHOLA SLIDE
8 NARAK JHORA SLIDE
9 MANPUR KHOLA SLIDE
10 BUL SLIDE
11 BHARI KHOLA SLIDE
12 DHARI KHOLA SLIDE
13 CHARCHAREY NALA SLIDE
14 16TH MILE SLIDE
15 NURSURY NALA SLIDE
16 LUNCHOK SLIDE
18 BAGWA SLIDE
19 DARAREY SLIDE
20 TURUK SLIDE
21 TURUK SLIDE
23 NEBHAREY KHOLA KHARKA SLIDE
24 GUNRAKEY SLIDE
25 KALIKHOLA SLIDE
26 DAGDHARA SLIDE
27 BIMBONG SLIDE
28 TURUNG SLIDE
29 NANDUGOAN SLIDE
30 BETGHARI SLIDE
30 BETGHARI SLIDE
31 SIRWANI SLIDE
32 SALELEY SLIDE
33 LAMBA BIR SLIDE
34 MANDIR GATE SLIDE
36 KERABARI SLIDE
Legend
Location
Road
River
Landslide
Boundary



SUSCEPTIBILITY/VULNERABILITY TO LANDSLIDE HAZARD MAP OF SOUTH DISTRICT, SIKKIM
N
W
E
S
1:134,185
Legend
District boundary
location
road
Drainages
Susceptibility to landslide hazard
low hazard
medium low hazard
medium hazard
medium high hazard
very high hazard
2.5 1.25 0 2.5 5 7.5 10
Kilometers

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 'window zone' and the Dialing which are older form a sheet like structure enclosing the younger 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 FORMATION

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.

NARAK- JHORA- SLIDE

Located along Rangpo-Namthang-Namchi road 4kms (approx) from Rangpo towards Turung.

Location - 27^{o} 9.767'North latitude
88.31^{o}103'East longitude

Length = 300mts Breath =150mts.

Description

Area was initially inhabited by people with cluster of houses on the east facing slope. The extreme weathering event of October 1968 caused massive slides in the area. Geologically the area consists of monotonous meta-sedimentary sequence equivalent to the Dalings (Pre-cambrain). Well bedded Phyllites / quartzite followed by chlorite-sericite-phyllite with strike N 30^{o} E to N 40^{o} E. The rock sequences dip almost along the slope.

Contributing Factors

Bed rock structure and Inclination of slope
Reduction of sheer strength of rocks and soil
Extreme Precipitation event, occasionally concurrent with earthquakes
Destruction of Natural vegetation
Toe- cutting by high velocity streams
Other Human induced factors

TURUNG-BIMBONG SLIDE

Located around Turung and Bimbong village on valley side of Rangpo-Namthang-Namchi road.

Location- 27^{o} 05.258'North latitude
88º 25.886' East longitude

Description

Village of Turung is located on a east facing slope that has been undergoing slope instability for ages and still plague by slides beneath the unstable slope forming material is repetitive sequence of quartz – chlorite/sericite phyllite, quartzite, ortho – quartzite with greywacke intercalations within Turung slide Surface and sub surface water movement also plays major role for Triggering the landslide. The other slide named as ‘Bimbong slide’ at Bimbong village along the periphary of Turung area is characterised by the downward movement of thick soil overburden over the rock sequences as mentioned above. Turung and Bimbong slide together constitute one of the biggest active slides in Sikkim.

Localised failures are noticed along catchment area of Seti Khola towards east of Pamphok village.

KERABARI SLIDE

Located along Maniram - Sumbuk - Melli road Section at an altitude of 2073 ft (approx) and between

Location- 27^{o} 05.258’ North latitude
88^{o}25.886’ East longitude

Length = 100mts Breath =40mts.

Description

As a result of weak geological formation, Surface and sub surface water pressures, adverse slope condition etc the slide is active at Present, the peripheral area of the main slide consisting debris with boulders of various dimension with immature soil is found creeping.

Another section in this region which can categorized as unstable or slide occurring zone fall along Ratmatey, Turuk, Rong, singtham, Bul, Salibong, Bomter ,Kopche and Mikhola. In case of Bomtar, Kopche and Mikhola areas, the geological/geotechnical set up holds good but with the road development activity with in discriminate cutting of the steep slope under PMGSY scheme various location has started failing which may later developed into major slides. In other areas failures are less common but are noticed along nala abutments due to scouring activities by the water run-off.

LUNGCHOK SLIDE

Location- Along Manpur- Sumbuk road

27^{o} 06.636’ North latitude
88^{o} 21.905’ East longitude

Length = 100mts Breath =50mts (approx).

Description

Rotational type debris slide down a gentle slope, the slop failure is mainly due to presence of thick unstable overburden which is further unstabilized by surface and subsurface water flow, construction of PMGSY road over the unstable spot, random disposal of the road construction waste, lack of scientific and technical input in the road construction activity etc.

TURUK SLIDE

Located at Turuk village along the tributary nala Joining Manpur Khola from the eastern slopes.

Location- 27^{o}, 6.5’North latitude
88^{o} 24’East longitude

Length = 100mts Breath =800mts (approx).

Description

Slide along the slope to the west of Turuk village. The area comprises of sheared rock/soil mix sequence. The sheared rock consisting mainly of Sericite Phyllites is found overlain by red soil which failed over the steep slope under the triggering action of Nala water. The scouring action of the nala has made adverse impact over the slippery Sericitic – Phyllite rock sequence and the red soil overburden mass. The slide becomes active during rainy season when surface or subsurface water activities are maximum.

BUL SLIDE

Location- located to the south west of Bul village along Nala catchment between
27^{o}08, 697’ North latitude
88^{o} 23, 09’ East longitude

Description

It is a small slide at an altitude of 2500ft amsl and situated Southwest of Bul Village. The failure occured on the soil cover over the rock bed due to seasonal surface water run-off along the nala and scouring nala sides. The area consists of weak geological sequence comprising sheared Quartzite & Sericitic Phyllite rock sequence overlain by transported soil cover.

MANPUR KHOLA SLIDE

Location – Located along the tributory nala that join Manpur Khola North East of Bul and above Salibong- Namchi road section at an altitude of around 4300ft-(approx) amsl.

Length = 100mts Breath =20mts (approx).

Description

This is the fresh slide along the thrust/sheared zone between the Dalings and Gondwana. The material that has undergone failing consists of sheared rocks belonging to above two formations. Occurrence of coal seam in the area with spring water sources has added stress to the slope material and caused the failure. Similar failings are found at Bomtar village and Kali Khola banks. Cases of subsidence or surface failure are common in the specified locations due to existence of sheared coal pockets and presence of surface & sub-surface water action in the area.

Other areas plagued by landslides in parts of south Sikkim are around Kamrang, Mamley, Jaubari, Kholaghari, Pabong, Wak , Tinkitam, Rayong, Tingmo, Hingdam, Kewzing, Ravongla, Dolep, Barfung, Zarong, Ralang, Polot, Borung and Sada - Phamtam areas.

The geological sequence in these areas comprise of the rocks belonging to Daling, Buxa and Gondwana sequences as a part of Rangit valley window zone. Kamrang and Chamgaon areas near Namchi are represented in the area by phyllites and Quartzite rock sequences. Areas of Mamley, Pabong and Kholaghari comprise with the rocks of Buxa series represented in the area by Dolomtes with signs of current bedding and presence of earliest plant fossil of Cambrian age-the Stromatolites. The Buxa sequence rocks in these areas are underlain by the rocks of Gondwana series represented by Shale/Phyllites, Sandstones with occasional coal seam which are exposed in areas of Pakjor, Lower Kamrang & Lower Mamley. Cases of Subsidence, Soil overburden creep are common in these areas because of abundance of water. Jarong, Daling, Barfung Hingdam, Kewzing, Ralang, Polot, Borong, and Sada- Phamtam areas comprise of rock sequences belonging to daling series. The rocks are phyllites (ranging from Chloritic, Sericitic Phyllite to gritty phyllite), quartzite and higher grademetamorphic rocks comprising of gneisses and schists .The areas of Upper Phamtham and Sada village comprise of high grade metamorphites with presence of high grade Gneisses, Calc - Granulites, Schist and occasional Tourmaline bearing Pegmatites.

Kholaghari area experienced a massive flash flood in September 2003 and four people lost their lives due to unusual, unexpected cloudburst. Kholaghari Bridge was washed away. The areas close to Namchi are generally dry and as a result destructive landsides are few and far in between.
The landslides in the district of South Sikkim as mapped by the team are as below:-

TIRI KHOLA SLIDE

Location- Along Namchi- Kamrang-Mamley road at Tiri Khola between-:
27^o 11'North latitude
88^o 22'East longitude

Description

A small patch of mud flow, due to the movement of the sheared coal seam, with the overlying soil cover under the influence of surface, sub-surface water and scouring of khola banks by Tiri khola water. The process becomes active during monsoon rains and disrupts vehicular movements.

Failure along banks of Torikhola and flooding at Kholaghari area

Tori Khola water flowing down from Jaubari area at the upper reaches is overcharged during monsoon and causes flash floods and scours the banks of kholaghari khola during rainy seasons. Flashflood during the cloudburst of 2001 caused loss of human life and damage of properties.

BANIYA KHOLA SLIDE

Location - Along tributary& Main nala of Baniya Khola at Burfong -:
27^o 17.5, North latitude
88^{o}21'East longitude

Length = 300mts Breath =150mts (approx).

Description

Slide along main & tributary Nala of Baniya Khola. Initiated and triggered by the surfacial and Nala water movement over the weak geological condition of the area. Sericitic phyllites swell when saturated with water and tend to get loosened & degraded and the water acting as triggering mobilizes the movement of the degraded rock sequence along with soil cover. Areas around Barfung and Doling have come under the impact of this slide. Large parts of the lands are lost and become active during rainy seasons.

GUNDRUKEY NALA SLIDE

Location: - Located along Legship- Tashiding road near Rangit River between
27^{o} 17'North latitude
88^{o} 17'East longitude

Length = 50mts Breath =100mts (actual but impact area is large)
Description

A landslide located on steep slope with weak geological sequence and triggered by seasonal water run-off. The slide disrupts the Vehicular traffic during monsoon leading to Tashiding & Yuksom town. The weak geological sequence comprising of sheared Sericitic phyllites with medium thick soil overburden fails under the impact of excessive subsurface & surface water. The rock-soil mix debris debries is deposited over the road during the times of flash flood.

Other areas of landslides in parts of south Sikkim fall along Ravangla, Pathing, Yangyang, Niya-Brum, Manzing, lingmo and lingi-Payong areas. These areas are again prone to landslide basically due to adverse geology, steep sloop, presence of water etc. Further, slope condition along with human induced factors contributes for destabilization of the slope in these areas. The identified and important cases of slope failures in the area are as described below:-

PATHING SLIDE

Located along up-slope (hillside) of Ravangla -Yangyang road near Rangpo Khola at Pathing village

27^{o}18.5' North latitude
88^{o}23' East longitude

Description

Failure of overburden on steep slope comprising of conglomeratic rock soil mixture, failure occurred at a steep slope above (up slope) road section due to mobilisation of the rock-soil cover by surface water run-off during times of sudden cloud bursts at the upper reaches.

BAGDHARA SLIDE

Located along Ravangla-Yangyang road above Satam village at an altitude of 4720ft (approx)

27°16.920’North latitude
88°24.878’East longitude

Length = 150mts Breath =30mts

Description

The destructive slope failure at Baghdhara above Satam is not a true Slide. It is a typical debris avalanche. The competent rocks mainly of quartzites of the areas are highly brittle and subjected to shearing due to local active faults. The sheared rock fragments and debris overburden on steep slopes occasionally fail at times of high intensity rain. During June – July 2007, debris avalanche from Baghdhara buried several houses, paddy fields etc at Satam village. The location is likely to face such events in future also.

NEBHAREY KHOLA KHARKA SLIDE

Located above Rangang village near Yangyang at Nebharey-Khola Kharka at the head water of a tributary Nala of Brum Khola and is at 1520mts amsl (approx) & between.

27°18.425’ North latitude
88°24.921’ East longitude

Description

The spot is characterised by fragile geological set up consisting of highly jointed Quartzites and Phyllite rocks inter binding sequence with medium thick soil overburden cover. The slope material consisting of rock fragment of all sizes with small amount of fine materials fails even without the effect of excessive ground are surface water. The debris avalanche appeared to have been started off by an earthquake initially. Frequent avalanches are continuing because of fragility of the slope forming materials on a steep slope. The instability in the area regards detailed study soon.

MANZING SLIDE

Located along Yangyang-Lingmoo road at an altitude of 1520mts amsl and Covers almost the entire area of Manzing & Bande village. The slide killed 07 persons in 2005 during a sudden cloudburst. The location is about 22 kms from Ravangla at about one and half kilometer from Niyadara.

27°19.720'North latitude
88°27.764'East longitude

Description

Area is about one and half kms from Niyadara to lingmoo along Yangyang-Lingmoo road and is under the impact of an active slope failure. Major locations of failure are noticed along the Nalas. The whole parts of the area of Manging & Bande villages are under movement. Geologically, the area consists of quartzite and quartz chlorite/sericite phyllite interbanding rock sequences overlain by thick soil-rock mix cover. The topography is of an old landslide zone and the village stands over the earlier failed debris cover. The upper areas comprise of the rock exposure from where the overburden mass slided down and got deposited in the present village area. Scouring action by the existing tributary & main nala of Manzing Khola at time with heavy discharge of water during rainy season scoured its abutments and mobilised the whole overburden mass for movement towards down slope. As a result the whole village area is under the impact of creep movement, resulting houses in the vicinity. Cloudburst of 24th September 2005 created the debris avalanches and buried seven persons and 28 families were evacuated from the area.

BAGWA SLIDE

Located Along lingmoo-Makha road section at lower lingmoo village near Tista River just before reaching Makha Bazar.

N27°19.810'North latitude
E88o26.764'East longitude

Description

Area comprise of rocks belonging to Daling sequence represented by Quartzites and quartz chlorite/serecite phyllites. The medium thick rock-soil overburden in the area failed due to excessive surface & Subsurfarce water runoff and is deposited along the river terrace of Tista River.

LINGI PAYONG AREAS SLIDES

A major old landslide exists at Payong village which is presently dormant and few cases of surface failure are noticed along tributary Nala of Ranghap khola at lower Lingi areas which become active during rainy seasons. The area comprises of medium grade rocks of Daling sequence with soil over-burden, mobilizing agents like Nala water run-off scours khola abutments and after such failure the soil cover over the area starts failing downslope.

The final segment for the description of landslides in parts of south Sikkim can be explained along Namphing-Tokal-Bermeok-Rambang-Dong-Chuba-Parbing-Lingding-Phong village which is connected through a road section connecting Sirwani to Phong through Bermek-Tokal village. The major surface failure activities in these areas are as below:-

SIRWANI SLIDE

Located Just ahead of Sirwani Bridge towards Papung khola along Singtam-Sirwani-Papung road; (See Pic.No 38 & 39)

27^{o}14’North latitude
88^{o}28.5’East longitude

Description

This slide is a case of soil- debris failure over an area with weak geological conditions triggered by scouring by wayward nala water and abundance of underground water movement. The crown portion of the failing area is located along Sirwani-Papung-Bermeak road. The wayward Nala water and loose soil and debris as the slope forming material combined contributed to the failure. The debris cover was brought down-slope during an extreme rainfall event in 2007 and has damaged the roadside Café by consisting of huge boulders, rock fragments and other fine materials (photo no).

BETGHARI SLIDE

Along-Bermeok-Parbing-Phong road section near Rameng village between

27^{o}12.5’North latitude
88^{o}26’East longitude

Description

Medium grade rocks of Daling formation favourably oriented inside the slope with soil-overburden cover. The rocks have failed along their joint planes with soil overburden by the action of Nala water (Khola) . Frequent high intensity flash flood due to cloud-burst at upper reaches has made the area unstable. The slope movement process during rainy seasons in the area blocks the road for vehicular traffic for at least three months a year. Near Rameng village few instances of surface failure are noticed along banks of tributary nalas of Kalej khola along road section at around Parbing village.

MELLI - JORTHANG SALGHARI SECTION

One major stretch along south Sikkim covering the areas of lower reaches falls along the road section of 27km from Melli to Jorthang. Geologically, the area comprise of the rock belonging to low grade metamorphic rocks of Daling series along with rocks of Gondwana sequence exposed at certain areas. The daling sequence comprise of Quartzite-chlorite-sericite phyllite, phyllitic-quartzite or quartzitic-phyllite. The rocks belonging to Gondwana sequence which are exposed along Rangit valley window zone are sandstone, shale with thin & lansoidal coal seams. Chlorite-sericite-phyllite is the major unit of this section. The rocks containing sericite mica are slippery and hence slips or splits along foliation plane in strike-wise direction which has caused failure on rock formed slope material. Small patches of rock failure are common occurrence along this unit. Occasional quartz veins are noticed with presence of secondary mineralization (sulphide) in this unit. Quartzites are well exposed unit as interbanding sequence with the phyllites. Quartzites are present as massive, milky or grey unit to quartzitic- phyllite or phylitic quartzites. Massive well jointed milky quartzites unit are present near Manpur khola. Other area comprise of phyllite and quartzite interbanding sequence along Melli-Joethang road section. The area along Nalas of Bhari & Charchery shows exposures of Gondwana sequence due to erosion along these Nalas. The area ahead on upper portion of sixteen-mile slide is also exposed with coal belonging to Gondwana series.

As the area fall along contact zone of two stratigraphic units with presence of sikkip thrust and crushed lensoidal deposits of coal, surface failures are common in this section. Red soil cover exist in the area around Kitam Ratmatey and Majitar which fail downslope under water saturated condition .Nalas like Bhari kola has scoured its abutments and black colored water is seen flowing due to presence of pulverized coal sediments. Manpur Khola, Rabi khola etc. also scour its banks and surface failure in areas having sericitic phylitic dipping along slope direction is common. From Melli to Jorthang, major slop failure locations are as follows.

MELLI – ROLU KHOLA SECTION

Melli Slide: - Case of surface failure Near Melli.
Location: Near Melli Bazaar towards Jorethang

$27^0$5 North latitude
$88^0$27 ½ East longitude

Length = 50mts Breath =75mts

Description

The area comprise of quartz chlorite – quartz sericite phyllite and quartzite interbanding sequences. The rock are subjected to folding, faulting etc and most of the rock slops are overlain by varying thickness of soil or debris overburden. Melli slide is a complex slide triggered by weak geology, steep slope, depleting vegetation, active ground water regime, toe erosion by Teesta etc. The area is likely to be a perennial source of slop instability.

MANDIR GATE POINT

Location between:

27.06 North Latitude
88 025 ½ East Longitude

Description

Between Melli- Jorethang road for 100 mts (approx) and extending towards Karabari Slide in the North. Toe cutting action by Rangit River has initiated the slide.The other component for mobilasition is the seasonal water run-off. The weak geological formation comprising quartz chlorite/sericite-Phyllite with quartides with foliation planes down the slope with thick soil overburden cover is cause for instability. The road section comprise of highly jointed stated rock sequences with exposures in areas around Hui Khola and Champa Jhora. Wedge failures of rocks are common in these areas. The area between Champa Jhora and Mayalu Jhora has points of active instability. The overburden soils cover is under the impact of toe cutting action by Rongit River. The area ahead upto Rolu Khola in comparatively stable with few instances of wedge failures.

ROLU KHOLA MAJHITAR RIDGE POINT

Along the road section from Rolu Khola upto Majhitar instances of slope failure are encountered. This area comprise of rocks of Daling series and the rocks present here are quartz – Chlorite - Sericite Phyllite and Quartzites. The quartzites range from pure milky quartzite to grey quartzites. The areas with Sericite – Phyllite rock exposure facing towards slope are weak and fail under the impact of mobilising agents like surface run-off, weight of overbunde cover and by toe cutting action of Rangit River.

LAMBA VIR SLIDE

Located ahead of Rolu Khola forwards Manpur Glass Factory

$27^0$6½ 'North Latitude
$88^0$22½ East Longitude

Description

This landslide is extends for nearly 100 m along the road section. The area comprises of quartz – chlorite/Sericite Phyllite and quartzites rock sequences with grey & highly fractured quartzite interbands. The slope is of high degree and the fractured rocks slide down as avalanche as a result of wedge failure. The overburden soil cover also fails down-slope as triggered by surface run-off during monsoon period.

BARAREY SLIDE

Located approximately 75mts ahead of Lamba Vir Slide towards Manpur. This area comprises of quartz – chlorite/Sericite Phyllite and quartzites rocks with thin to medium thick soil cover. This area has lot of surface and surface water activity. The weathered and water saturated quartz – chlorite/Sericite Phyllite and quartzites rocks degrade and has moved down slope as creep movement. This slide is extends 150mts along slope and has extension towards lower Sumbuk Village in upper part.

BAGWA SLIDE

Location between:

$27^0$5.75' North Latitude
$88^0$21 East Longitudes

Length = 150mts Breath =75mts (approx)

Description

Landslide at Bagwa area characterised by thick rock – soil mix that slowly creeps down slope. The contributing factors are toe-cutting action of Rangit River at the base and the heavy water movement along the head area. Hence, with toe cutting action at the base of the slope and heavy seepages around the body of the slide the slope material is moving downwards. The rock exposures in the adjacent areas dip north to Northwesterly and the slope faces south – Westerly.

RATMATEY SLIDE

Located at Ratmatey area near Majitar

$27^0 5'$ North Latitude
$88^0 20'$ East Longitude

Description

Located at about ½ km ahead of Majhitar ridge point towards Melli along Jorethang-Melli road section, area comprises of thick red soil overburden over Quartzite / Phyllite interbanding sequence. In this case the failure of the overburden redsoil cover is due to faulty road cutting, sensitivity of the slope farming material, surface, sub-surface & atmospheric water regimes and steep slope condition in the area.

SURFACE FAILURES FROM MAJHITAR TO CHARCAREY AREA

The area between Majhitar to Jorethang comprises of the rocks belonging to Daling series overlain by the rocks of Gondwana series. The rock of Daling series comprise of quartz – chlorite/Sericite Phyllite and quartzites and highly jointed Quartzites. These rocks are well exposed along the road section. But from Charcharey area onwards, boulders of sandstone and crushed Coal/Shale sediments are seen hying along road. Failures of loose unconsolidated mass are noticed towards east of Bhari Khola. This is due to high surface and sub–surface water regime in the area with weak geological condition. Failures are noticed at Charcharey area where loose Coal/Shale bodies are scoured by Nalas and are deposited along its bank and road section. The stresses developed by the overburden Gondwana rock- cover add for failure in the area.

16th MILE SLIDE

Located at half kilometer (approx) from Jorethang towards Melli between

$27^0 75'$ North Latitude
88^0 17.3' East Longitude

Length = 150mts Breath =75mts (approx)

Description

Landslide located near Jorethang along road section. The area comprises of highly jointed quartzite with sheared Phlyllite intercalation of daling sequence. These rocks are overlain by rocks of Gondwana series represented by coal seam overlying the quartzite- Phyllite intercalation. The slide used to block the road for vehicular traffic prior to 1995 but the mitigative measures taken by the Mines, Minerals & Geology Department, Government of Sikkim has now controlled the failure.

Similar failures are common along Jorethang-Namchi road section with Coal Seams, influence of water and depending on the scope angle and so on.

Limitation

There has never been a systematic study of landslide problems in Sikkim. Most of the existing literatures on landslide of Sikkim are written by some fancy expert expatriate on a whirlwind visit to the Sate. Since no two landslides are identical in any given area, it is not always easy to know the ground realities of mechanism that triggers off landslides. The Sate Department of mines, Minerals & Geology, took up a number of landslide prone and affected areas for systematic study and so on, some planer type slides, controlled by joint, foliation and bedding planes were further subject to grouting and rock bolting , both tensioned and un-tensioned (see pics). Sikkim being a land locked state, disruption of road communication by landslide is an annual affairs. For every linear Kilometer of Sikkim's road there are atleast 10 minor to major slips.

CONCLUSION

Natural hazardous events such as earthquakes, landslides, floods etc. in the Himalayas are a reality. Man and man-made structure stand no chance against the awesome power and furry of such events when they strike. Therefore, a mechanism is needed to safeguard against massive and unwarranted loss of life and property in the event of a calamity. In August 2004, the Government of India came out with a detailed status report on Disaster Management in India. The report specifies various programs and strategies of the National to tackle and mitigates all forms of destructive natural events. Translations of some of the recommendations have already begun in Sikkim. Sikkim State Disaster Management Authority Government of Sikkim and UNDP have undertaken various initiatives in this direction. The general public is sensitized through awareness training / talk shows, mock drills, banners and so on. The North Eastern state including Sikkim being in high seismogenic domain, landslides and flood prone areas require special attention and constant vigilance. The on-going research by established institution in various fields of adverse event needs upgradation and monitoring by an apex authority for proper and effective coordination of long term research and dissemination of information to stake holders. The existing scenarios of haphazard and secretive study of natural event by all sorts of agencies need to be discouraged.

There are some reasons for optimism. Solutions to counter these trends exist and the knowledge and technology necessary to apply them are widely available. Disaster reduction is the sum of all the actions which can be undertaken to reduce the vulnerability of a society to natural hazards. The solutions include proper land-use planning, aided by vulnerability mapping, to locate people in safe areas, the adoption of proper building codes in support of disaster resilient engineering, based on local hazard risk assessments, as well as ensuring the control and enforcement of such plans and codes based on economic or other incentives. Sound information and political commitment are the basis of successful disaster reduction measures. This is an ongoing process, which is not limited to a singular disaster event. It motivates societies at risk to become engaged in conscious disaster management, beyond traditional response to the impact of natural phenomena. Disaster reduction is multi-sectoral and interdisciplinary in nature and involves a wide variety of interrelated activities at the local, national, regional and international level.

RECOMMENDATION

The study carried out has been exhaustive and specific under the given circumstances. All the landslides as enumerated in the format were measured physically as far as possible in the field and linked with GIS platform. Instability in the form of landslides is time dependent and, therefore, the attributes and variables of landslide are likely to change with time. For all purposes the description of a landslide may remain valid for upto five years at the most in a tropical and subtropical climatic setting as in Sikkim.

The coping mechanism or the mitigation measures which needs to be applied for a particular landslide areas has been provided in the study for the landslides cases in North, East and West Sikkim, whereas in case of the study carried out for Landslides in South Sikkim, the recommendation for mitigation for individual Landslides has not been made therefore the study needs to be taken up urgently. Various types of mitigation have been advices in Part Three of this publication. The landslides are to be priorities in term of their importance or vulnerability to life and property and accordingly the mitigation measures has to be taken up.

In the State of Sikkim, the most immediate and urgent requirement is establishment of a dedicated multi-disciplinary cell to study landslides and guide the Governments in all developmental activities. This cell will not only save money and time to the project developers but also act as a coordinator of landslide related researches in the State.

Landslide Photographs of North Sikkim

PIC NO 1

FAULT CONTROLLED RANG RANG LANDSLIDE, NORTH SIKKIM

PIC NO 2

DEBRI FLOW – LANTHEY KHOLA SLIDE, NORTH SIKKIM

PIC NO 3

FLASHFLOOD & LANDSLIDE AT LACHUNG: POST 18/9/2011 EARTHQUAKE

PIC NO 4

FLASH FLOOD AT LACHUNG: POST 18/9/2011 EARTHQUAKE

PIC NO 5

DEBRIS SLIDE AT NAMOK KHOLA-DIKCHU-MANGAN ROAD, NORTH SIKKIM

PIC NO 6

DEBRIS FALL-BAY-DZONGU, NORTH SIKKIM

Landslide Photographs of East Sikkim

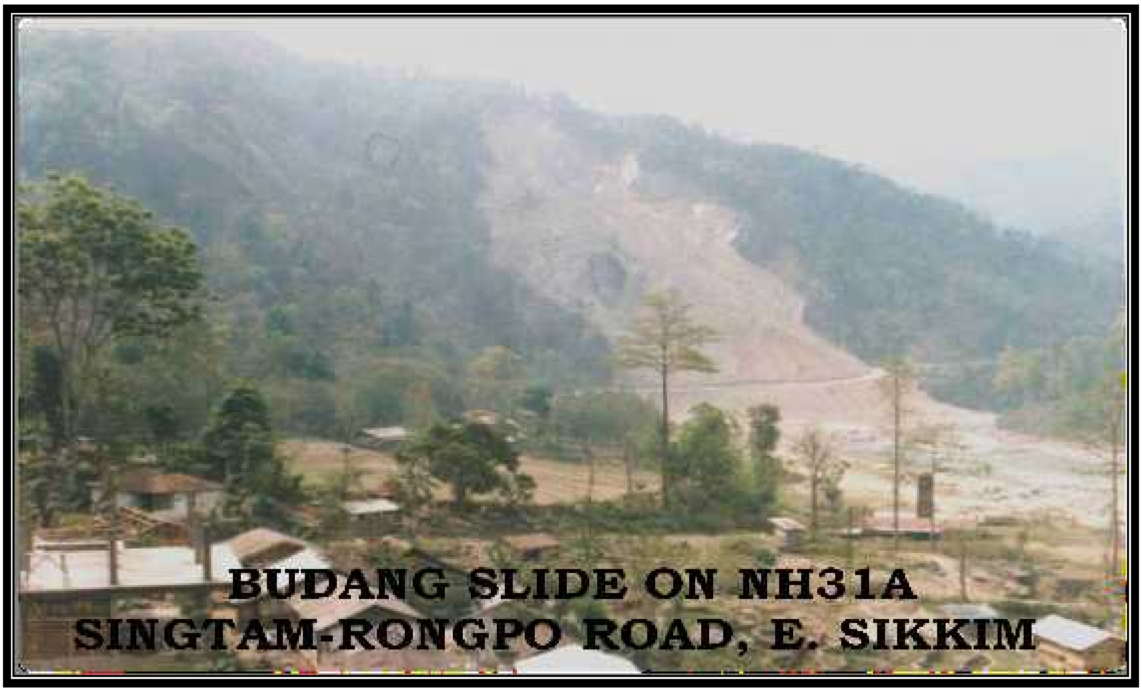
PIC NO 7

INSTABILITY ALONG RANIPOOL – PAKYONG ROAD-ANDHERI SLIDE

PIC NO 8

DEBRIS CHUTE/SKID TRAIL, VIEW FROM PAKYONG OF PACHE SAMSING

PIC NO 9



20TH MILE BORDANG SLIDE, EAST SIKKIM

PIC NO 10

ROCK FALL INDIRA BYE-PASS, GANGTOK, EAST SIKKIM

PIC NO 11

DEBRIS AVALANCHE, SUMIN-LINGZEY, EAST SIKKIM

PIC NO 12

FLASH FLOOD KHANI KHOLA, EAST SIKKIM

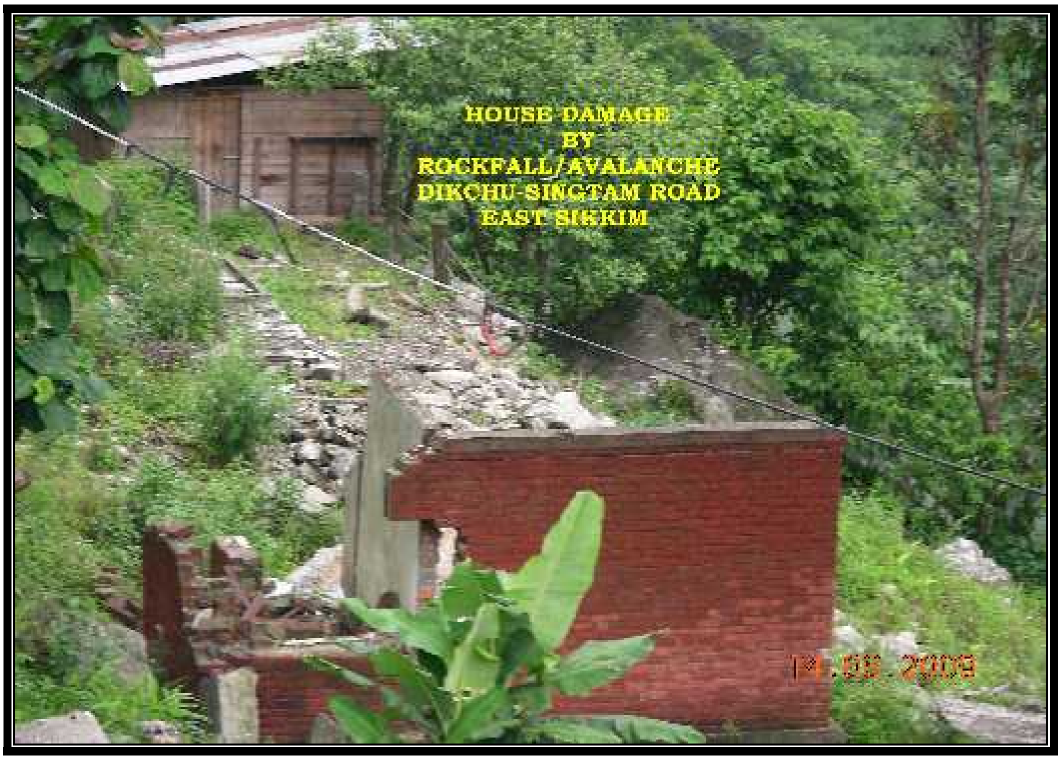
PIC NO 13

ROCK FALL / AVALANCHE DIKCHU-SINGTAM ROAD, EAST SIKKIM

PIC NO 14

DEBRIS FALL, TUMIN, EAST SIKKIM

PIC NO 15



HOUSE DAMAGED BY ROCK FALL/ AVALANCHE DIKCHU-SINGTAM ROAD, EAST SIKKIM

PIC NO 16

FLASH FLOOD NEAR MAKHA, EAST SIKKIM

PIC NO 17

P.M.G.S.Y ROAD CONSTRUCTION BHASMEY, EAST SIKKIM

PIC NO 18

SUBSIDENCE ZONE 13TH MILE, J.N ROAD, EAST SIKKIM

PIC NO 19

13TH MILE SUBSIDENCE ZONE, J.N ROAD, EAST SIKKIM

PIC NO 20

KOPCHE SLIDE, RENOCK-RONGLI ROAD, EAST SIKKIM

PIC NO 21

DEBRIS FLOW –CHISO PANI LANDSLIDE ALONG NH 31 A, NEAR SINGTAM, EAST SIKKIM

PIC NO 22

DEBRIS FALL/SLIDE, SIRWANI, SINGTAM-DIKCHU ROAD, EAST SIKKI,

Landslide Photographs of West Sikkim

PIC NO 23

FAULT CONTROLLED BOJECK SLIDE, WEST SIKKIM

PIC NO 24

SULDONG SUBSIDENCE ZONE, WEST SIKKIM

PIC NO 25

ROAD OVER DETACHED ROCK/DEBRIS, WEST SIKKIM

PIC NO 26

MUD & DEBRIS FLOW, SURGE SHAFT SITE, JAL POWER, ROATHAK KHOLA, WEST SIKKIM

PIC NO 27

SUBSIDENCE CASE-SUB-JAIL, OMCHUNG, WEST SIKKIM

PIC NO 28

ROCK & DEBRIS AVALANCHE, GERETHANG, WEST SIKKIM

Landslide Photographs of South Sikkim

PIC NO 29

NAMCHI, BOOMTAR, SUB-JAIL 2007, SOUTH SIKKIM

PIC NO 30

CHOKED CAUSEWAY AT NARAK JHORA SLIDE AREA, SOUTH SIKKIM

PIC NO 31

TURUNG SLIDE, CLOSE UP, SOUTH SIKKIM

PIC NO 32

BAGHDARA DEBRIS AVALANCHE, BURRIED SATAM VILLAGE, SOUTH SIKKIM

PIC NO 33

NEBHAREY KHOLA KHARGA SLIDE, SOUTH SIKKIM

PIC NO 34

CREEPING VILLAGE- MANZING, SOUTH SIKKIM

PIC NO 35

MANZING SLIDE, SOUTH SIKKIM

PIC NO 36

GABIONS OVER UNSTABLE SLOPE, DAM SITE, NHPC STAGE V, SOUTH SIKKIM

PIC NO 37

SLOPE FORMING MATERIAL ON DOWN DIP ROCK SLOPE, SOUTH SIKKIM

PIC NO 38

VIEW OF MANY SLIDE BAGHDARA, NEBAREY KHOLA KHARGA AND NEAR NHPC STAGE V POWER HOUSE SLIDE, SOUTH SIKKIM

PIC NO 39

SCOURING BY RIVER TEESTA WHEN IN SPADE, RONGPO IBM, EAST SIKKIM

PIC NO 40

COLLAPSED BRIDGE ON NAMCHI - BUL ROAD, NEAR SALEBONG, SOUTH SIKKIM

PIC NO 41

VIEW FROM MELLI BAZAAR (W.BENGAL) SLIDE BETWEEN MELLI & SIKKIM POLICE CHECK POST, SOUTH SIKKIM

PIC NO 42

ROAD CUTTING WASTE ON KITAM NAMCHI ROAD, SOUTH SIKKIM

PIC NO 43

FOLDED AND SHEARED ROCK FORMATION, SOUTH SIKKIM

PIC NO 44

TENSIONED ROCK BOLTING BY DMM&G AT LEFT BANK OF PABONG KHOLA SOUTH SIKKIM

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