

**GEOENVIRONMENT OF GANGTOK WITH SPECIAL  
REFERENCE TO GEOHAZARDS**

**ABSTRACT**

**KAMALESWAR KALITA**

**THESIS**

**SUBMITTED IN FULFILMENT OF THE REQUIREMENT OF THE  
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**DEPARTMENT OF GEOGRAPHY  
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## ABSTRACT

### Introduction

Geomorphology as an important branch of physical geography deals with the scientific study of origin and evolution of the landforms, the material with which they are composed of, and the processes that sculpture them. Among the various branches of geomorphology *applied geomorphology* is very important. Of late, within applied geomorphology has emerged *environmental geomorphology* and that is of great relevance today as the world is facing serious environmental problems. It deals with the application of geomorphological skill and tools to solve various environmental problems and go for environmental management. Of course, the main concern of the environmental geomorphologists is to deal with the *geohazards*- their occurrence, extent, intensity, frequency and mitigation- and this task has gained greater importance and significance in the wake of increasing intensity, frequency and extent of geohazards in the world nowadays. As a result, environmental geomorphology has gradually established itself as an independent branch of geomorphology.

Under the environmental geomorphology when those aspects of physical environment, which are related with land (including all attributes), water, soil, etc., are taken as a system to understand interrelations and interconnections among them and their total influence on man and environment, it is called *geoenviornment*. It particularly addresses the problem of geohazards. In fact, geohazards itself are part of the geoenvironment of an area. Moreover, today a new perspective is added to development

in which hazards are seen as an essential component of developmental planning. Now 'hazard and development' is the main theme of the planners and policy makers.

Man-induced changes in the geomorphic form and processes are also included in geoenvironmental studies, because most of the time such alterations create environmental problems and degradation. The sensitive ecosystems like the Himalaya Mountain are characterised by typical geoenvironment, which is quite often disturbed by frequent and irreversible human interferences causing geoenvironmental problems viz., landslides, sinking, scarcity of potable water, lack of space, pollution and many others. Such geoenvironmental problems are quite common in those settlements that are located on the hill slopes, and Gangtok is one of them. The growing problem of geohazards compels the geoscientists to apply the scientific geoenvironmental knowledge and skills for proper use of the hill ecosystem and to mitigate both natural and man-induced hazards. Therefore, in the present Ph.D. research, an attempt has been made to study '*Geoenvironment of Gangtok with special reference to Geohazards*'.

### **Objectives**

The main objectives of study are as follows:

1. to study the geoenvironment of Gangtok, and to delineate geoenvironmental units on the basis of parameters like slope, altitude, lithology, structure, soil, drainage and forest cover of Gangtok,
2. to find out the occurrence, extent and causes of geohazards in the study area as a whole and in the geoenvironmental units particularly, and
3. to suggest remedial measures for the geoenvironmental problems.

### **Research Questions**

To meet the requirements of the objectives, three research questions are formulated as stated below:

1. What are the potential and constraints of the geoenvironment of Gangtok?
2. What are the human interferences in the geoenvironment of Gangtok?
2. How to mitigate the geoenvironmental problems of Gangtok?

### **Data Base and Methodology**

Data for the study have been collected from both primary and secondary sources on various components of geoenvironment, which include physiography, slope, geology, soil, hydrology, and forest cover. For the preparation of base map, contour map, landforms, forests and drainage Toposheet Number 78 A/11 (1:50000), satellite imagery (IRS, LISS III, and 9th November 2002), and master plan of Gangtok have been used and interpreted. The angle of slopes was measured with the help of Abney's level. Discharge data on the two rivers of Gangtok was collected by the researcher. Field survey was done to record forest cover in the study area. Soil and water samples were collected for various tests in the laboratory. Secondary data on geology, seismicity, forests and soils have also been collected from published and unpublished reports of different departments. Population data was compiled from various census reports. Based on geoenvironmental elements, the study area has been divided into different geoenvironmental units for the purpose of micro-level study of Gangtok. Data on the geohazards, especially on the landslides, have been collected mainly through the fieldwork of the recent landslides and also from different secondary sources. Data on past landslides were also collected through personal interviews of elder people of the affected areas, and from the old Newspaper records. Different Websites were also used for the gathering information on

various aspects of the research. The study is based on empirical analytical method of investigation. The whole work was divided into three main stages.

The **first stage** consisted of the study of relevant books, journals, bulletins, souvenirs, articles, maps etc. and extraction of various types of information related to the topic of research.

In the **second stage** data have been collected from the primary and secondary sources. In this stage, researcher has collected data on physiography, geology, slope, soil, hydrology, climate and forest cover. Rock sample were collected and verified by the Sr. Geologist at Gangtok. Contours for the study area were derived from the Toposheet No.78/11 on 1: 50,000 scale having contour interval of 20 m. With the help of the contour map thematic maps on absolute relief, relative relief and average slope were prepared. Slope analysis was done with Wentworth's Method (1930) and Smith Method (1932). Apart from it slope angles were measured for the specific geoenvironmental units with the help of Abney's Level. Soil sample were collected from different parts of the study area and tested in Agriculture Department, Gangtok. Jackson's method was used for soil analysis. Hydrological data were collected from different sources of natural watercourses, mainly from the Rani Khola and Bhusuk Khola. Data on climate were collected from Indian Meteorology Department, Gangtok, and Spice Board, State Pollution Control Board, and Department of Agriculture, Gangtok. Land use map have been prepared through the field survey, satellite imagery and with the help of records from the Land and Revenue Department. Statistical techniques were applied while processing data on various components of geoenvironment. A set of thematic maps related to different geoenvironmental elements have been prepared for the authentic and

proper presentation of the same. Then these information layers have been merged (*i.e.*, Superimposed Method) to find out similar characteristics for the purpose of preparation of geoenvironmental units of Gangtok.

The data on geohazards, collected both from primary and secondary sources, have been processed with the help of different statistical techniques, and then presented through various cartographic methods. Data regarding frequency of landslides were correlated with various geoenvironmental elements using simple statistical techniques. Micro-landslide hazard zonation map has been prepared through composite method. Apart from it, Landslide Hazard Factor (LHF) has been used for determination of landslide susceptibility. Landslide susceptibility has been classified in to three categories as high, moderate and low according to the weightage and susceptibility values. Photograph coverage was made to show important geoenvironmental characteristics and geohazards.

Entire thesis has been organised in five chapters. The First Chapter is as introduction to the dissertation, containing statement of the problem, literature survey, objectives, research questions, data base and methodology. Chapter Second traces origin and development of Gangtok as a capital of Sikkim. The Third Chapter is devoted to detailed account of geoenvironment of Gangtok and delineation of geoenvironmental units. While Fourth Chapter is devoted to the study of landslide hazards, causes of their occurrence and preparation of landslide hazard zonation map. Remedial measures have also been suggested here. While Summary and Conclusion are given in the Fifth Chapter.

The present thesis pertains to an appraisal of geoenvironment of Gangtok, the capital of Sikkim state, with special reference to geohazards. Gangtok is a hill station perched on one of the many ridges of the Middle Himalaya Range. Alike most of the hill settlements Gangtok has typical mountain geoenvironment characterised by a long and narrow crest, steep slopes, forests, swift flowing streams interspersed with small spurs, presence of a number of geohazards, especially landslides, etc. Being in the Himalaya Mountain, the geoenvironment along with geohazards of Gangtok exhibit unique characteristics associated with the young folded mountain system of the world, particularly in the tropical belt. Proximity to the sea i.e., Bay of Bengal, has its own influence on the geoenvironment of Sikkim in general and Gangtok in particular, notably in terms of heavy rainfall from the southwest monsoon, making it a wetter part of the Himalaya in comparison to the western parts. The uninterrupted passage of the Bay of Bengal branch of southwest monsoon through the Malda gap results in the high rainfall, which is directly or indirectly related to the recurring problem of landslides in Sikkim. The Sikkim Himalaya, particularly Gangtok, has been experiencing a number of geohazards like earthquakes, landslides, avalanches, floods etc. Hence, a proper understudying of different types of geohazards is necessary to save lives and property, and to maintain the pace of development by managing and mitigating the natural hazards, particularly the geohazards. From the present research work the following major findings have been derived.

### **Major Findings**

1. Gangtok, the study area, has grown to present size and status from a tiny hamlet.
2. Main development and expansion started when Gangtok was made capital of the then kingdom in the year 1894, and the process got accelerated from 1975 when

Sikkim become the 22<sup>nd</sup> state of the Union of India. That is why exponential population growth of 207.13 per cent was recorded during the decade 1971 and 1981.

3. The growth of Gangtok have been identified in three phases, viz., 1894 to 1947, 1947 to 1975 and 1975 to 2005. During the last phase it has seen phenomenal expansion of area by 568 per cent, and it is spread over 40.81 sq km area today.
4. Land use/ land cover show that it still has 53.17 per cent area under forest cover, while built up area is 24.75 per cent. The later is mostly at the cost of forest cover, and that indicate the amount of deforestation in the study area.
5. Much of the development has caused alterations in the geoenvironment of Gangtok, and this human interference has led to emergence of number of geoenvironmental problems/ geohazards, including the landslides.
6. Gangtok is perched on a ridge, running northeast to southwest, of the Eastern Himalaya Mountain, hence its geoenvironment is characterised by all facets of mountain environment.
7. Eastern and northeastern slopes of the ridge are steeper than rest of the slopes, hence landslide prone. While most of the settlement has grown on the relatively less steep western slopes.
8. Geoenvironment of Gangtok is characterised by steep slopes of angle mostly  $40^{\circ}$  to  $60^{\circ}$ , weak rocks, structural discontinuities in the vicinity of MCT, MBT, ITSZ, and Gangtok fault right across the study area, part of seismically active zone IV, high drainage density and frequency, decreasing forest cover, sandy loam to sand clay loam soils with clay minerals, tropical to temperate climate with heavy

monsoon rainfall that is responsible for triggering landslides, and hydrological conditions with numerous rivers, streams and *jhoras* (small streams and springs).

9. Landslides occur in almost all the geoenvironmental units but they are most common in four units namely the Northeast Higher Steep Forested Ridge, Lower Central Deforested Ridge, Deforested Rani Valley and Southwest Deforested Moderate Slope, mainly due to steep slopes, construction works and deforestation.
10. Landslide is the most common geohazard of the area, occurrence of which has accelerated after 1950s. About 48 major landslides have occurred between 1960 and 2005.
11. Most landslide affected areas are Chandmari, Tathenchen, Deorali, Zero Point and Arithang, where geoenvironment is characterised by steep slopes, weak rocks, high drainage density and frequency, and open forest, while human factors are high number of RCC buildings, deforestation, and disturbance in slope stability due to different construction works.
12. Most of the landslides occur during the monsoon period, especially in June and September, when the southwest monsoon is strong.
13. Out of 48 landslides, 28 occurred in average slope category of  $18^{\circ}$  to  $24^{\circ}$ , and 15 in  $12^{\circ}$  to  $18^{\circ}$ . While 28 in coarse sandy loam porous soil, 17 in sandy loamy skeletal soil, and 10 in the built up area.
14. Undoubtedly, incessant rainfall is the main triggering factor in the landslides.
15. Over all main geoenvironmental causes of landslides are- steep slopes, considerable percentage of clay minerals in the sandy clay loam soils, weak lithology, geotechnical instability, excessive and heavy rainfall during short

duration, and human interference in the form of deforestation, construction works and slope alteration.

16. Alarmingly, more than half, i.e., 54.27 per cent of Gangtok falls in the High Hazard Zone, while another 25 per cent come under the Moderate Hazard Zone.
17. It can be said that Gangtok has been suffering from the recurring and chronic landslide geoenvironmental problem, and that invite attention of the geoscientists to understand the processes and mechanism involved in it to suggest remedial measures for checking frequent and devastating occurrence of landslides to save Gangtok and its inhabitants.
18. Taking care of the geoenvironment of Gangtok while developing it further, avoiding interference in the geoenvironmental system and planting of faster growing trees, bushes and grasses in the already landslide affected areas and will be the best solution of the problem.

## **Recommendations**

Though this research has been able to comprehend the geoenvironment of Gangtok with special reference to geohazards, still there is scope to carry out more detailed work on the following aspects of the research problem.

1. In-depth studies on the old and new landslides to find out site-specific geoenvironmental characteristics and reasons of landslides.

2. Such studies will include geomorphic features, processes and factors responsible for slope stability and its failure as well. Nuances, intricacies and complexities of mass movements are still not fully and truly understood, particularly on landslides, despite plethora of research, publication, and laboratory and computer simulations. This is because laboratory simulations can not create the natural conditions and processes, simply impossible. Field is the best and true laboratory of a geoscientist in general and geomorphologist in particular; and the results and findings of the only field based research should be accepted.
3. Though rainfall is considered the most accepted triggering factor of landslides through out the world, its actual role in the processes leading to break of the threshold on a stabilised slope are yet to be fully comprehended. No doubt the rainwater acts in many ways, like lubricating the plane of slide, increasing weight of the slope forming material through saturation of it leading weakening of shear strength etc., but all are happening every where wherever the same nature and amount of rainfall has taken place, but landslides occur at only a few sites and not in the entire area. This question has to be answered, why not at all places or why at only a few sites. Generally, the entire slope forming material gets wet under rainwater, which increases its weight, but slope does not fail as the balance between the downward stress/ gravity pull and vertical force is still maintained. The vertical force is responsible for slope stability, contrary to it the gravity generates downward mass movement causing slope instability. Therefore, it is interesting to investigate that when downward gravity pull will overwhelm the vertical force, leading to slope failure.

4. In studying slope stability slope should be taken as a system in which its different geoenvironmental components are working together harmoniously towards stability of slope. Hence, systems approach should be applied while studying slope instability and mass movement, especially the landslides.
5. As man has become dominant geomorphic agent at some places, human interference and alterations should also be examined thoroughly and critically. In this connection interface between natural and human systems must be studied to know the reality that who is responsible for landslides, nature or man, or both. Truth in this regard has to be searched and brought to the knowledge of the posterity.

These are the relevant research problems to be investigated to enrich the understanding of geoenviornment and geohazards, especially the landslides. It is very much possible with the tools and techniques available at the disposal of the geomorphologists and geoenvironmentalists. If required, more can be borrowed form other geosciences.

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## DECLARATION


I, Kamaleswar Kalita, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other university/institute.

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# CHAPTER- I

## INTRODUCTION

### 1.1 INTRODUCTION

The earth system comprises of lithosphere, hydrosphere, and atmosphere. Besides these, a fourth component that completes the earth system is the biosphere. Landforms constitute an important component of the lithosphere, and influence of landforms is profound on both man and environment. Hence, landform studies have remained the core business of the science of geography since its inception. However, the systematic study of the origin and evolution of landforms i.e., *geomorphology*, is of quite late in origin.

Geomorphology as an important branch of physical geography that deals mainly with the scientific study of origin and evolution of the landforms, the material with which they are composed of, and the processes that sculpture them. The scope of geomorphology has changed and expanded over the years, particularly in the recent times. As a result, various branches of geomorphology have come into existence, especially the *applied geomorphology*. Though geomorphology has always remained applied in nature right from its inception, in recent times applied geomorphology has emerged as a relevant branch of geomorphology. In fact, fundamental and applied aspects are complementary to each other in the growth of a discipline.

The practical application of geomorphological principles, knowledge, skills and tools while utilising the natural environment and in solving environmental problems, has given rise to applied geomorphology. Within the applied geomorphology when geomorphological skill is employed to solve various environmental problems faced by

humankind, the study is known as *environmental geomorphology*. In this context, the environmental geomorphology has emerged as an important branch of the applied geomorphology, which focuses primarily on application of geomorphological knowledge in environmental management. In fact, environmental geomorphology relates mainly to the environmental resource management and consists principally of analysing and monitoring landscape forming processes in relation to surface materials and evaluating landscape changes that may arise from human interference in the physical environment, particularly the landforms. Of course, the main concern of environmental geomorphologist is to deal with the *geohazards*- their occurrence, extent, intensity, frequency and mitigation- and this task has gained greater importance and significance in the wake of increasing intensity, frequency and extent of geohazards in the world nowadays. As a result, environmental geomorphology has gradually established itself as an independent and important branch of geomorphology.

Under the environmental geomorphology when those aspects of physical environment which are related with land (including all attributes), water, soil, etc. are taken as a system to understand interrelations and interconnections among them and their total influence on man and environment it is called *geoenvironment*. It particularly addresses the geohazard problem. In fact, geohazards itself are part of the geoenvironment of an area. In addition, as problem of geohazards is increasing day by day, which is a serious threat to man and environment both, geoscientists have become more and more interested in geoenvironmental studies, which have come to be recognised as an essential prerequisite for an integrated regional planning and

development. Moreover, today a new perspective is added to development in which hazards are seen as an essential component of developmental planning. Now 'hazard and development' is the main theme of the planners and policy makers.

Geoenvironment as a branch of the earth science is rather a new field that has grown out of an urgent social necessity to broaden and increase the capacity to solve many complex environmental problems, especially in the areas (including the urban centres) affected by geohazards. Man-induced changes in the geomorphic form and processes are included in geoenvironmental studies, because most of the time such alterations create environmental problems and degradation. The sensitive ecosystems like the mountains are characterised by typical geoenvironment, which is quite often disturbed by frequent and irreversible human interferences causing geoenvironmental problems viz., landslides, sinking, scarcity of potable water, lack of space, pollution and many others. Such geoenvironmental problems are quite common in the Himalaya Mountain, especially in those settlements that are located on the hill slopes. A few settlements affected by the geohazards to mention include Simla, Almora, Nainital, Mussoorie, Darjeeling etc. Even Gangtok, the recently developed capital of Sikkim, has been experiencing a number of geoenvironmental problems, including landslides, affecting life and property of its inhabitants. Most of the time geohazards are man-induced in such hill settlements. The growing problem of geohazards compels the geoscientists to apply the scientific geoenvironmental knowledge and skills for proper use of the hill ecosystem and to mitigate both natural and man induced hazards. Therefore, in the present Ph.D. research, an attempt has been made to study '*Geoenvironment of Gangtok with special reference to Geohazards*'.

## 1. 2 LITERATURE SURVEY

The study of environment and its relationship with development and planning is an important task of the geographers. The environment is the base of all life forms and source of all goods. Man contributes greatly to environmental changes and causes damage to environment, quite often leading to environmental degradation. However, to understand the significance and role of environment in planning and development it is necessary to know about the geoenvironment. Since geoenvironment is intimately related with the science of geomorphology, of late the geomorphologists have started taking keen interest in its appraisal, especially under applied geomorphology, and in that too particularly under environmental geomorphology.

**Applied geomorphology:** In recent decades, the geomorphologists all over the world have started taking keen interest in the application of geomorphological principles and findings to understand and to solve the practical environmental problems faced by mankind. In fact, both the fundamental and applied studies in geomorphology are of great relevance not only to the growth of the science of geomorphology but to man as well.

Although, the application of geomorphological knowledge and skill has been there right from the early times, major advances in this direction date from the 1950s. However, in the first half of the nineteenth century some applied geomorphological works were done by Glenn (1911), Bryan (1925), and Jacks and White (1939). Thornbury (1954) devoted entire chapter on applied geomorphology in his book *Principles of Geomorphology* and stressed the need for applying geomorphological knowledge to

mineral and oil exploration, hydrological studies, engineering projects etc. During the 1960s and 1970s, geomorphologists have given more attention to the resource surveys and mapping, undertaken in a number of developing countries. For example, by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Commission on Man and Environment, Geomorphological Survey and Mapping etc.

The book *Terrain Evaluation* by Mitchell (1973) was a milestone contribution in applied geomorphology in which techniques for evaluating the landscape for various purposes were given. Another important book entitled *Applied Geomorphology* was edited by Hail (1977), which included empirical contributions related to application of geomorphological knowledge and skills in various fields. According to Jones (1980) applied geomorphology may be defined as the application of geomorphic understanding to the analysis and solution of problems concerning land occupancy, resource exploitation, and environmental management and planning. Verstappen (1983) included the diverse applications of geomorphological ideas in the field of earth sciences, environmental studies, rural and urban development and planning and in the field of engineering. According to Chorley *et al.*, (1985) 'application of geomorphology is divided into two categories: i) man as a geographic agent, and ii) geomorphology as an aid to resource evaluation, engineering construction and planning'.

Hart (1986) has rightly said that 'pure and applied studies of geomorphology are like two wings of a bird, without which a perfect flight is impossible'. Singh and Ojha (1996) thought that 'the application of geomorphological techniques and the results of

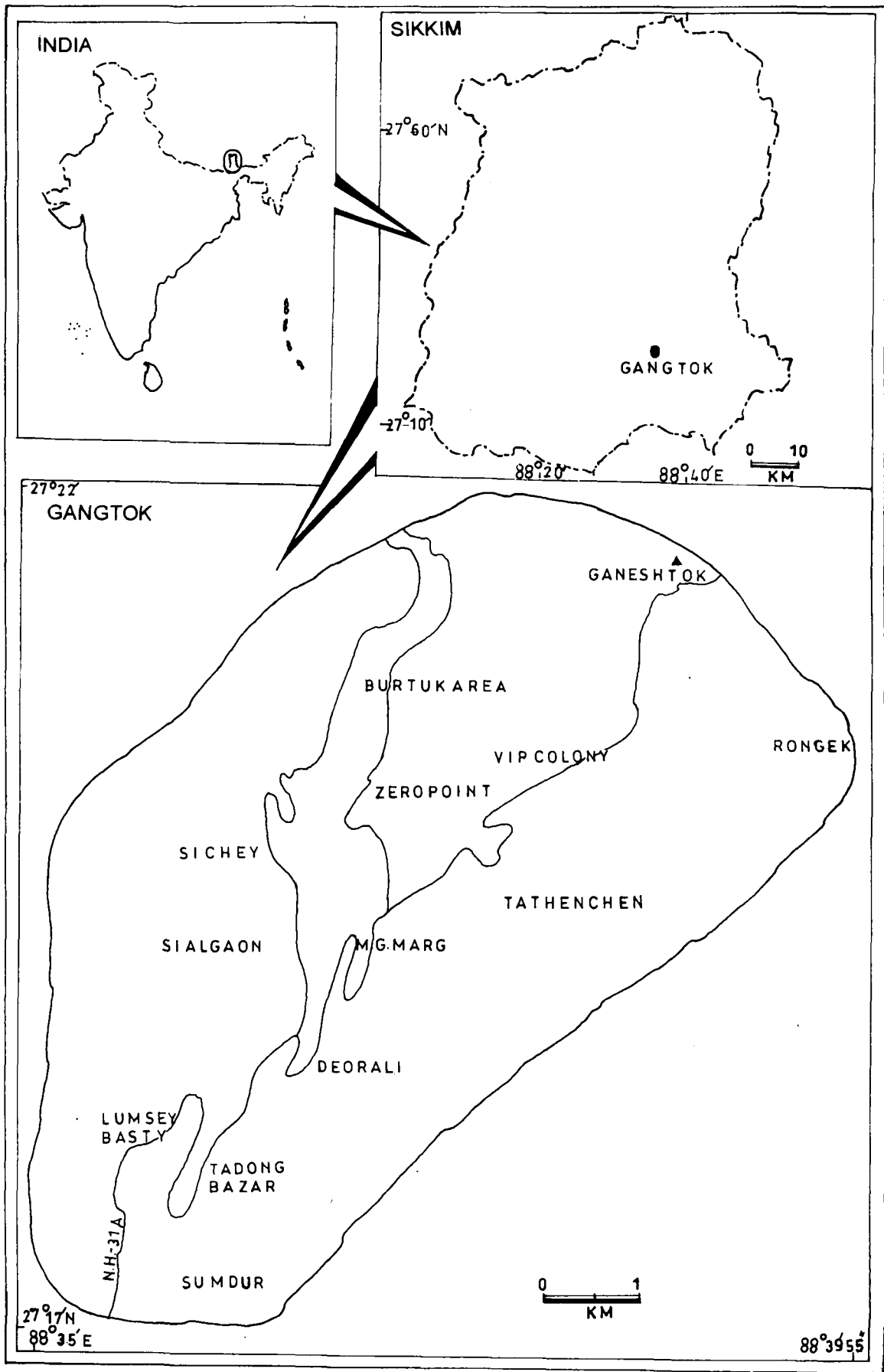


FIG.11 KEY MAP

geomorphological investigations for resource evaluation, socio-economic development and mitigation of natural hazards and disasters are significant aspects of applied geomorphology which should be taken into consideration by the geomorphologists'. As a result, some branches of applied geomorphology have emerged during the last few decades, viz., Environmental Geomorphology, Urban Geomorphology, etc.

Urban geomorphology is of recent origin as a branch of applied geomorphology, which mainly deals with the study of landforms and their related processes, materials, hazards management, development and planning in urban areas. Detwyler and Marcus (1972) wrote the famous book on *Urban Geomorphology* where role of geomorphology in urban development is highlighted.

**Environmental Geomorphology:** Environmental geomorphology is an important branch of applied geomorphology which is intimately associated with the environment and deals mainly with the impact of natural processes on human activities and application of geomorphological knowledge and skills to solve the current environmental problems and appraisal of geoenvironment. Development of environmental geomorphology as a branch of applied geomorphology has followed development in 'Environmental Geology' as geologists have pioneered the application of geological and geomorphological knowledge to the environmental management. In fact, it can be said that environmental geology and environmental geomorphology grew together, benefiting from each other's results and findings, and leading to development of almost common tools of research. Two edited volumes on *Environmental Geology* by Coates (1974) and a milestone

volume entitled *Geomorphology in Environmental Management: A New Introduction* by Cook and Doornkamp (1974) came out in the same year, which laid the foundation of and gave momentum to application of the earth sciences in environmental management. Various dimensions of application of the knowledge and skills of the earth sciences (geology and geomorphology) on environment (its characteristics, problems, hazards etc.) have been presented by Coates (1974), Ordway (1972), Cooke and Doornkamp (1974), Betz, Jr. (1975), Bolt *et al.*, (1975), Tank (1976), Lundgren (1986), Hart (1986) and others. Both environmental geology and environmental geomorphology as a young interdisciplinary branches of the earth science attempt to solve environmental problems, notably related with geohazards.

**Geoenvironment:** In fact, the term geoenvironment is of recent origin, though the holistic perspective to consider the physical environment as a system (single entity) is quite old. Geoenvironment includes the landforms (with all its attributes), rocks, soil, hydrology and vegetation (as manifestation of the first four elements, and climate). It is the environment directly created by the earth (*geo*) and its attributes or by the land bound elements of environment, hence appropriately called geoenvironment. Actually, the roots of the concept geoenvironment lie in the term landscape ecology – a concept introduced by the German geographer-ecologist Carl Troll (1968). This concept was further developed by him to suggest another well-known concept known as *geoecology* in which focus is placed on those geoenvironmental factors influencing environment and in turn man. Whereas, according to Bobrowsky (2001) the geoenvironment concept applies to i) the management of natural resources, and ii) the natural and anthropogenic processes that

affect the solid earth as a habitat of human beings. Geoenvironmental studies are being carried out in different disciplines including applied geomorphology, engineering geology, hydrology, geophysics, geochemistry, economic geology and geoecology. Dzhamalov and Safronov (1998) have explained various aspects of geoenvironment and geohazards in the '*Elsevier's Dictionary of Geoenvironment and Natural Disasters*'. Geoenvironmental study includes two aspects: 1) assessment, mapping and combating various geological and geomorphological hazards, and 2) conservation of landscape for optimum benefits. Not all these works can be accomplished unless the geoenvironment of a place is not taken into account, which actually gives a holistic dimension to study of natural landscape where landforms are the basic and most dominant component. According to the geologist Harsna (2002) the basic components of the geoenvironment are rocks, relief and ground water, and geodynamic phenomena. Geoenvironment is that part of the lithosphere that directly influences the condition of the existence and development of the society, which the man exploits and modifies.

Concisely, the concept of geoenvironment includes the physical landscape or terrain or land based environment. It means that part of the natural environment that is created by various attributes of the earth i.e., by its features (landforms), characteristics and properties. Geoenvironment is the base on which the rest of the physical environment rests, and together (i.e. both physical and biological) they influence the human beings and their activities (Husain, 2002:9). Further, geoenvironmental modelling is an important aspect of geoenvironmental study which provides a variety of information about different geoenvironmental behaviours of an area.

In the present context geoenvironment means those aspects of physical environment or landscape that are related with land (including all attributes), water, soil, etc. All these are taken as parts of a system to understand interrelations and interconnections among them and their total influence on man and environment, particularly addressing the geohazard problem. In fact, geohazards itself are part of geoenvironment of an area. Since the problem of geohazards is increasing day by day as a serious threat to man and environment both, it has invited the attention of the geoscientists to go for appraisal of the geoenvironment of the affected area. This is because development is seriously hampered by the increasing incidences of geohazards. Therefore, geoenvironmental studies have become an essential prerequisite for an integrated regional planning and development. Moreover, today a new perspective is added to development in which hazards are seen as an essential variable in developmental planning process. Now 'hazard and development' is the main theme of the planners and policy makers.

It is worth mentioning that geoenvironment is indeed an established concept today that has been accepted through out the world. A number of works have been done on geoenvironment with emphasis on geohazards by different departments of various universities, research organisations and institutions all over the world. A few to mention include the Geoenvironmental Research Centre (GRC), Cardiff University, Wessex, Institute of Technology, UK, University of Eduardo Mondlane, Mozambique, Aespoe Environmental Research Foundation, Sweden, Institute for Agro-biotechnology, Tulln, Austria, Gent University, Belgium, European Geoenvironmental Engineering

Infrastructure Cooperation Network, University of Ancona, Italy, Geodelft, Netherland, Ecole nationale des ponts et chaussées, French, Politecnico di Torino, Italy, Polish Geological Institute, Warsaw, Asian Institute of Technology, Thailand, Virginia Polytechnic Institute, Virginia, Illinois Institute and State University of Technology, Chicago, Florida Institute of Technology, Florida, Institute of Geosciences, Brazil, School of Earth and Ocean Sciences, Victoria, Swedish Geological Survey, Sweden, School of Environmental Studies, University of Alaska, Alaska, University of Athens, University of Kebangsaan, Malaysia, Geohazard International (GHI) etc. All the universities and institutes are engaged in detailed study of various aspects of geoenvironment, particularly geohazards. For example, China Institute of Geoenvironmental Monitoring in Beijing is directly engaged in monitoring, predicting and warning the geohazards throughout the country, in relevant survey and research work, and in providing hydrogeology, engineering geology and environmental geology information services. The International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, also carries out geoenvironmental studies in the Hindu Kush-Himalayan Mountain Region. Further, the Working Group of International Borders-Geoenvironmental Concern (IBC) is engaged in studying worldwide geoenvironment. According to the IBC the main aim of cross-border geoenvironmental study is to encourage and promote interdisciplinary cooperation across international borders for the efficient application of geoscientific information in environmental planning, ecosystem monitoring and environmental impact assessment in cross-border areas, thus ensuring sustainable use of resources, the quality of environment and mitigation of geohazards (Anonymous, 2004).

During the last few decades, a number of geoscientists in the world have made their valuable contributions in the field of geoenvironment, especially on geohazards. At national level geoscientists of a few institutions and University departments have contributed on different aspects of geoenvironment and geohazards, e.g., the Indian Institute of Technology, Rourkee, Indian Institute of Mines, Dhanbad, Geological Survey of India, Kolkata, Department of Civil Engineering, BHU, Department of Civil Engineering, IIT, Karagpur, G.B Pant Institute of Himalayan Environment and Development, Almora, Indian Institute of Geomorphology (IGI), Allahabad and others.

A few worth mentioning scholars who have made substantial contributions in the field of environmental geomorphology and geoenvironment at national and regional levels include- Wadia (1966), Valdiya K.S (1973), Bhandari (1974), Sinha (1975), Saxena et al., (1979), Windley (1983), Singh and Pandey (1983), Thakur (1986), Verma and Guha (1986), Chatterjee (1986), Gupta (1988), Gupta and Joshi (1990), Choubey and Litonia (1990), Gupta and Joshi (1990), Chandra (1992), Thakur (1992), Valdiya (1992), Pirazizy (1992), Mehrotra et al., (1992), Tashi (1993), Das (1993), Singanenjam (1993), Mehrotra et al., (1993), Arya et al., (1993), Mehrotra et al., (1994), Singh and Robotham (1995), Dubey (1995), Singh & Pandey (1996), Sengupta (1996), Prakash (1996), Mehrotra et al., (1996), Krishna (1997), Joshi (1997), Chatterjee and Choudhari (1988), Prakash (1996), Shrivastava (1998), Ghoshal (1998), Satyanarayan and Cheema (1998), Sharma and Kandpal (1998), Sarkar and Deb (1998), Singanenjam (1999), Acharya (1999), Gupta (1999), Sharma (1999), Nath (2000), Yudhbir (2000), Valdiya (2000), Shah (2001), Singh et al., (2001), Pandey (2001), Krishna and Kundu (2002), Pandey

(2002), Mukarjee (2002), Naithani et al., (2002), Joshi et al., (2003), Rawat et al., (2004), Rawat (2005), Basu and Dey (2003) and others.

Agarwal (1996) has done her Ph.D. on 'Geomorphology and Environmental Management of Umiam Basin, East Khasi Hills, Meghalaya'. Baseline geoenvironmental data (including geology, geomorphology, soil etc.) of East Khasi Hills District and Jaintia Hills District of Meghalaya was collected by Shukla and Chaurasia (2001) and on the basis of which four geoenvironmental zones were demarcated to be utilised by the planners for undertaking sustainable development. The zones are termed as- Most Suitable Land (MSL), Moderately Stable Land (Md SL), Poorly Stable Land (PSL) and Unstable Land (USL).

An in-depth and systematic study of geoenvironment of Gangtok is an immediate need to understand geohazards like landslides which pose great threat to the life and property of the people of Gangtok. No doubt earthquake is another major threat to life and property of the people of Gangtok, but as it occurs at regional level, not point or site specific as landslides, discussion of earthquake has been included as the seismic activity under geological component of geoenvironment.

### **1.3 STATEMENT OF THE PROBLEM**

Understanding of the geoenvironment of a place as a natural system and the processes operating there has become relevant now to have a better use of the land and its attributes, and also deal with the hazards. But the role of geoenvironment at a particular place for proper land use is much wider, involving the evaluation and mitigation of natural and man-induced hazards. Many of these hazards such as earthquakes, floods, landslides, subsidence, and related processes of geologic and geomorphic changes originate from the geodynamic events and exogenetic geomorphic processes, but some do occur due to human interference in the geoenvironment. Understanding of the earth's materials, attributes and dynamic processes is essential for comprehending geoenvironment of a particular place, especially in hilly region where large settlements like Gangtok have come up. It is equally important to study geoenvironment in context of geohazards occurring in such areas. In fact, the hill ecosystems have their own geoenvironmental potential and limitation for its utilisation and size and growth of human settlements.

Gangtok is situated on steep slopes of an almost north-south running ridge of the Middle Himalayan Range. Gangtok and its environs have experienced a number of geohazards like earthquakes and landslides, affecting life and property of the people. A number of landslides have occurred here mainly due to human interference in the geoenvironment. Further, the development of this hill settlement has reached to a dangerous level where slight tremor and sliding of land can cause severe damage to life

and property. It seems that geoenvironment has neither been given any due consideration up till now in the development of this settlement nor in the proposed master plan as well.

Landslides are the most common geohazards in and around Gangtok. A number of major and small landslides have occurred in the recent times affecting life and property. Construction of RCC buildings on steep slopes has increased the risk to life and property. Moreover, geoenvironment of Gangtok is characterised by such geological features which are conducive to occurrence of seismic activity causing severe earthquakes. It is a well known fact that earthquake not only damage life and property but trigger huge landslides also. In this context, the high-rise RCC buildings perched on the steep slopes are susceptible to greater damage. Hence, geoenvironmental appraisal is essential to understand and solve geohazard problems.

#### **1.4 OBJECTIVES**

The main objectives of study are as follows:

1. to study the geoenvironment of Gangtok, and to delineate geoenvironmental units on the basis of parameters like slope, altitude, lithology, structure, soil, drainage and forest cover of Gangtok,
2. to find out the occurrence, extent and causes of geohazards in the study area as a whole and in the geoenvironmental units particularly, and
3. to suggest remedial measures for the geoenvironmental problems.

## **1.5 RESEARCH QUESTIONS**

To meet the requirements of the objectives, three research questions are formulated as stated below:

1. What are the potential and constraints of the geoenvironment of Gangtok?
2. What are the human interferences in the geoenvironment of Gangtok?
2. How to mitigate the geoenvironmental problems of Gangtok?

## **1.6 STUDY AREA**

Gangtok, the capital of Sikkim, is situated in the western most part of the Eastern Himalaya at an altitude ranging from 900 to 2400 metres (Fig. 1.1, and Plate 1). The North Latitude of 27° 20' and East Longitude of 88° 40' passes through Gangtok. The total area of Gangtok is about 40.81 sq. km. As per the 2001 Census population of Gangtok was recorded as 75,112 persons. Gangtok extends from the Burtuk in the north to Sumdur in the south and from Lower Tathengchen in the east to Lower Sichey in the west. The Rani Khola (river) flows from north to south on the western side of the town, while the Bhusuk Khola flows in the east. A long, narrow and steep ridge dominates the landscape of Gangtok. From the crest of the ridge the slope declines in three directions, i.e., east, west and south. Towards the north the steepness reaches to the highest summit of the area known as Ganeshtok (2500m). Most of the Gangtok is spread over the western slope of the ridge.

## **1.7 DATA BASE AND METHODOLOGY**

Data for the study have been collected from both primary and secondary sources on various components of geoenvironment, which include physiography, slope, geology, soil, hydrology, and forest cover. For the preparation of base map, contour map, landforms, forests and drainage Toposheet Number 78 A/11 (1:50000), satellite imagery (IRS, LISS III, and 9th November 2002), and master plan of Gangtok have been used and interpreted. The angle of slopes was measured with the help of Abney's level. Discharge data on the two rivers of Gangtok was collected by the researcher. Field survey was done to record forest cover in the study area. Soil and water samples were collected for various tests in the laboratory. Secondary data on geology, seismicity, forests and soils have also been collected from published and unpublished reports of different departments. Population data was compiled from various Census reports. Data on climate were collected from Indian Meteorology Department, Gangtok, and Spice Board, State Pollution Control Board, and Department of Agriculture, Gangtok. Based on geoenvironmental elements, the study area has been divided into different geoenvironmental units for the purpose of micro-level study of Gangtok. Data on the geohazards, especially on the landslides, have been collected mainly through the fieldwork of the recent landslides and also from different secondary sources. Data on past landslides were also collected through personal interviews of elder people of the affected areas, and from the old Newspaper records. Different Websites were also used for the gathering information on various aspects of the research. The study is based on empirical analytical method of investigation. The whole work was divided into three main stages.

The **first stage** consisted of the study of relevant books, journals, bulletins, souvenirs, articles, maps etc. and extraction of various types of information related to the topic of research.

In the **second stage** data have been collected from the primary and secondary sources. In this stage, researcher has collected data on physiography, geology, slope, soil, hydrology, climate and forest cover. Rock sample were collected and verified by the Sr. Geologist at Gangtok. Contours for the study area were derived from the Toposheet No.78/11 on 1: 50,000 scale having contour interval of 20 m. With the help of the contour map thematic maps on absolute relief, relative relief and average slope were prepared. Slope analysis was done with Wentworth's Method (1930) and Smith Method (1932). Apart from it slope angles were measured for the specific geoenvironmental units with the help of Abney's Level. Soil sample were collected from different parts of the study area and tested in Agriculture Department, Gangtok. Jackson's method was used for soil analysis. Hydrological data were collected from different sources of natural watercourses, mainly from the Rani Khola and Bhusuk Khola. Land use map have been prepared through the field survey, satellite imagery and with the help of records from the Land and Revenue Department. Statistical techniques were applied while processing data on various components of geoenvironment. A set of thematic maps related to different geoenvironmental elements have been prepared for the authentic and proper presentation of the same. Then these information layers have been merged (*i.e.*, Superimposed Method) to find out similar characteristics for the purpose of preparation of geoenvironmental units of Gangtok.

The data on geohazards collected both from primary and secondary sources, have been processed with the help of different statistical techniques, and then presented through various cartographic methods. Data regarding frequency of landslides were correlated with various geoenvironmental elements using simple statistical techniques. Micro-landslide hazard zonation map has been prepared through composite method. Apart from it, Landslide Hazard Factor (LHF) has been used for determination of landslide susceptibility. Landslide susceptibility has been classified in to three categories as high, moderate and low according to the weightage and susceptibility values. Photograph coverage was made to show important geoenvironmental characteristics and geohazards.

## **1. 8 ORGANISATION OF THE DISSERTATION**

The whole dissertation on the topic *Geoenvironment of Gangtok with Special Reference to Geohazards* has been divided into five chapters. Chapter I deals with the introduction, literature survey, statement of the problem, objectives, research questions, data base and methodology. Chapter II is related to origin and development of Gangtok. Details of geoenvironment of Gangtok and geoenvironmental units have been discussed in Chapter III. While Chapter IV is devoted to Geohazards of Gangtok, which also includes discussion mitigation of hazards. Summary and major findings of the thesis have been given in Chapter V.

## CHAPTER- II

# ORIGIN AND DEVELOPMENT OF GANGTOK

Gangtok, the capital of Sikkim state, is perched on a ridge (Plate 3) of the Middle Himalaya Range of the Eastern Himalaya Mountain. The name Gangtok is amalgam of two Sikkimese words, viz., *Gang* means 'aptly enough' and *Tok* meaning 'hilltop', together it means 'aptly enough hilltop'. Another literary meaning of Gangtok is a 'hillock cut out to make flat land'. Origin and development of the settlement of Gangtok is closely related with the history and development of Sikkim, right from its inception as the independent kingdom in the distance past, ruled by different '*Chogyals*' (kings), to its merger with the Union of India in 1975, and its function as the fourth capital of the kingdom and then as the capital of the newly formed 22<sup>nd</sup> state of India. Over the years it has grown from a small settlement, comprising of a few houses and a monastery, to a relatively large settlement in the hills as a seat of administration during the kingdom and as one of the states of India too. Today it is a sprawling centre of administration, tourism, education and many other functions and services of national and international importance. The very sprawl of Gangtok over a large area (34.70 sq km in 2005) on the steep slopes (Plate 2) has become problematic, for most of the developmental works have caused interference in the geoenvironment leading to occurrence of a variety of geohazards, particularly landslides.

Before coming to the origin and development the hill settlement- known as Gangtok, it would be worth to describe in brief about the history of Sikkim state itself,

because Gangtok has served as the centre of administration, trade, religion and tourism both in the past and is serving in present as well. The discussion pertains to the period before and after the year 1975, a threshold year in the history of Sikkim and Gangtok as well. This is because origin and growth of Gangtok is closely associated with the developmental works undertaken during the earlier rulers and present administration under democracy. This Chapter not only reveals origin and development of Gangtok, but it also traces the human interference in the environment associated with the developmental activities. Not only that, it highlights the seriousness of geohazards in terms of their detrimental influence on the life and property of the people of Gangtok as it has grown haphazardly with out taking care of the geoenvironment. Therefore, on one hand the development of Gangtok is considered as a factor causing alterations in the geoenvironment, while on the other hand development is seen as the risk aspect that is affected in any unfortunate occurrence of geohazards.

## **2.1. A BRIEF HISTORY OF SIKKIM**

In prehistoric times, Sikkim Himalaya was inhabited by three tribes, viz., the Naong, the Chang and the Mon. Limbus and Mangars were also regarded as aborigines of Sikkim. The Mangars were the aborigines of Sikkim, but they were concentrated only a small part of Sikkim. The Lepcha entered Sikkim sometimes later and slowly absorbed them completely. Thus, now the Lepchas are considered to be the aboriginal inhabitants of Sikkim, and they call themselves '*rong-pa*' which means the 'squatter in' or 'caretaker' of the country of caves' (Sengupta, 1985).

The Tibetan apparently colonized Sikkim at some date prior to the beginnings of the 17<sup>th</sup> Century. Before the advent of the Tibetans on the scene of Sikkim, the Lepchas have had some kind of administrative organization headed by a 'Turve' i.e., Punu or King' but due to the frequent encounters with the 'Kirats' (Rias and Limbus) the Lepcha Kingship came to an end. Tubh Athak Punu was the last Lepcha chieftain. Somewhere in the 13<sup>th</sup> Century, Guru Tashi, a prince of Minyang dynasty in Tibet, came to Sikkim to get blessings for his issueless son Kheya Bumsa from Thekong Tek (a Lepcha chieftain). Luckily, Kheya Bumsa was blessed with three sons and he settled in the Chumbi valley and from there he used to maintain contacts with Thekong Tek. He visited Denzong (as Sikkim was called earlier) a number of times, as a result the treaty of brotherhood between the Lepchas and Bhutias was materialised at a place called Kabilongtso (situated at a distance of 38 km north of Gangtok). This led to the beginning of the influence of the Tibetans on the Sikkim Himalaya. Gradually the Lepchas broke into small clans and came under the protection of the descendants of Kheya Bumsa and after some time Tashi Phuntshong Namgyal became the first 'Chogyal' (King) of Sikkim. He was born in 1604 and passed his early life near Gangtok. The Namgyal dynasty ruled over Sikkim for about 332 years.

### **2.1.1. The capitals of Sikkim under the rule of Chogyals**

The Chogyals had ruled over Sikkim from four capitals, viz., Yuksum, Rabdentse, Tumlung and Gangtok. 'Yuksam' (in west Sikkim) was the first capital of Chogyal dynasty, whereas Gangtok was selected as capital in 1894. Tashi Phuntshong Namgyal ruled over a vast territory, which was many times in size of the present Sikkim. He was

succeeded his only son Tensung Namgyal in 1670. Tensung Namgyal shifted the capital to 'Rabdentse' (near Gyalshing in the western part of Sikkim). Chakdor Namgyal, son of Tensung Namgyal, became the third Chogyal of Sikkim in 1700. His son Gyurmed Namgyal succeeded him in 1717. His reign was uneventful. 'He was at all events eccentric if not actually weak in intellect' (Risley, 1989). In his time '*Limbuana*' (original home of Limbus) was lost to Nepal and the boundary dispute with Bhutan also arose.

In 1733, Phuntshong Namgyal II became the fifth Chogyal of Sikkim. During his reign the Lepchas and the Bhutias occupied important positions in the Sikkimese court, but the Limbus slowly lost their position, even '*Limbuana*' also merged with Nepal at that time. During Phuntshong II rule, a number of polemic developments took place in Sikkim, for example, the planned invasion of Sikkim by Mangars and Gorkhas, and the treaty of Nepal-Sikkim in 1775 regarding boundary dispute. Bhutan also invaded Sikkim and had captured almost all the eastern part of the Teesta River Basin. However, Phuntshong II repulsed all the attacks on Sikkim by different forces. Further, in his time the gap between Bhutias and Lepchas had increased in many folds. He had three wives and only son- Tenzing Namgyal.

Prince Tenzing Namgyal succeeded his father in 1780, and when the Nepali forces attacked the capital Rabdentse he had to flee to Tibet. "Unable to bare the hard life, Tenzing Namgyal sought asylum in Tibet in 1790 and died at Lhasa in the year 1793 (Basnet, 1974). Then his son Tsugphud Namgyal, merely eight years old, was made the

ruler in 1793. During his reign the capital Rabdentse was shifted to Tumlong (situated 30 km north of Gangtok), as Rabdentse was considered insecure due to its proximity to Nepal. His reign was the longest in the history of Namgyal Dynasty. He ruled over Sikkim for almost 70 years lasting from 1793 to 1863. Sikkim came into contact with the British India in his time. "Having mastered India, British power ambitiously sought to penetrate the Himalaya in their urge to establish an overland trade route to Lhasa in Tibet and then towards Peking in China" (Joshi, 2004). During his reign, two important treaties namely '*Treaty of Segauli*' 1815 and '*Treaty of Titalia*' 1817 were signed among Nepal, Sikkim and British India. According to the Segauli Treaty the territory lying between the Machi and Teesta Rivers, which was captured by Nepal earlier, was returned to the British India. On the other hand, the British India i.e., East India Company, was to return territory occupied by them to the Sikkim through the Treaty of Titalia. The boundary between Nepal and Sikkim had also been drawn along the Singilela range, Michi and Mahanadi Rivers. This treaty established the supremacy of the British East India Company on Sikkim and paved the way of playing its predominant role in the state (Sengupta, 1985).

Later, in 1861, British forces captured the capital of Sikkim i.e., Tumlung. Again a new treaty- *Tumlung Treaty*, consisting of 23 articles, was signed between the Ashley Eden and the Sidkeong Namgyal (son of Tsugphud Namgyal) on 28<sup>th</sup> March 1861. This treaty declared Sikkim a princely state under the British rule, and that led to increase of supremacy of the British authority over Sikkim. After his father's death in 1863 Sidkeong Namgyal was made ruler of Sikkim. He always kept the good relations with British

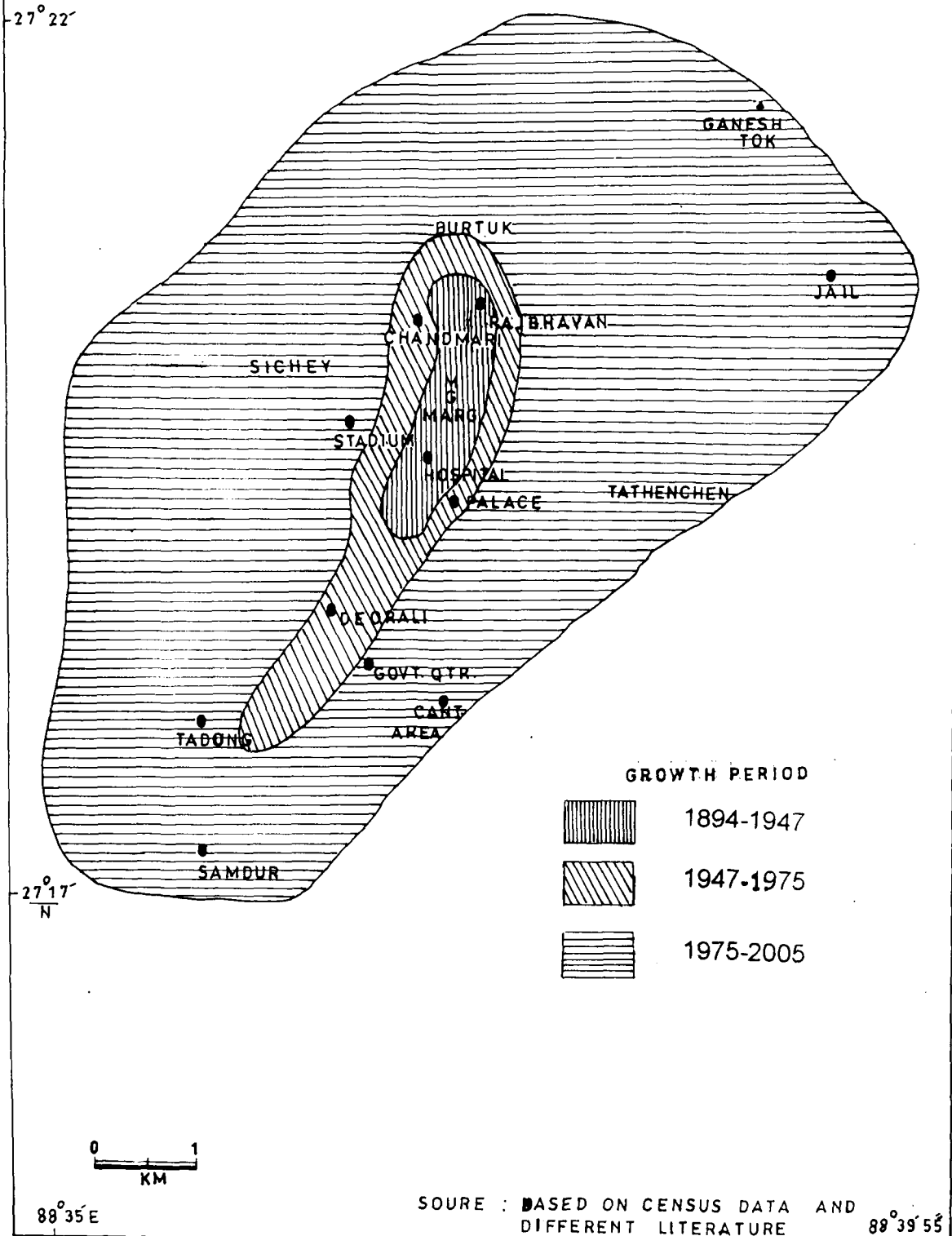
authority. His brother Thutob Namgyal succeeded Sidkeong Namgyal, having no child, in 1874. In the time of Thutob Namgyal a serious conflict between the original inhabitants of Sikkim and the Nepali settlers broke out, which ultimately led to direct British intervention. History of Sikkim of later times is now discussed in direct context of development of Gangtok, which has been divided under three periods.

## **2.2. DEVELOPMENT OF GANGTOK**

Development of Gangtok can be seen in three phases, viz., from 1894 to 1947, 1947 to 1975, and 1975 to 2005. All the three time brackets are related with specific political, administrative, and socio-economic developments in Gangtok. For example, the first phase started with the shifting of capital to Gangtok and ending with the Independence of India when Sikkim secured a 'protectorate' status from India. This set the beginning of the second time bracket that culminated in the final merger of Sikkim with the Union of India as its 22<sup>nd</sup> state. Moreover, with this the latest phase of development started in which Sikkim and its capital- Gangtok have seen an all round faster, dominating, eventful development, especially transformation from autocracy to democracy, definitely an important change.

Figure 2.1 depicts spatial growth of Gangtok over the three time periods. Up to 1947 it was spread over 2.10 sq km area, which doubled to 6.11 sq km by 1975. However, after 1975 it has seen a tremendous growth and now it covers 40.81 sq km area. It means an area of 34.70 sq km was added to Gangtok after 1975 and it shows that during the last phase there was an increase of about 568 per cent area. This happened

# GROWTH OF GANGTOK



SOURCE : BASED ON CENSUS DATA AND DIFFERENT LITERATURE

FIG. 21

definitely due to various developmental activities after Sikkim turned to a democratic state in which its capital became nodal point of development for the state in general and Gangtok in particular.

### **2.2.1. Development between 1894 and 1947**

In 1894, Chogyal Thutob Namgyal shifted the capital from Tumlong to Gangtok. The Sir Thutob Namgyal Memorial Hospital (S.T.N.M.H) at Gangtok was built in his memory in 1917. Thudob Namgyal distributed the responsibility of administration among several ministers and set up a Secretariat. It was during his time, the first English Medium School was set up at Gangtok in 1906.

Sidekong Tulku succeeded his father Chogyal Thutob Namgyal in 1914, but unfortunately died in the same year. As a result his brother Tashi Namgyal became Chogyal in 1914. During his long 50 years of rule Chogyal Tashi Namgyal made a number of socio-economic reforms and all round development of Sikkim in general and Gangtok in particular. A modern Court, designated as Chief Court, was set up in 1916 and a full time judge was also appointed, there by bringing the judicial function of the landlords under the command of a Superior Court (Sikkim Herald, 1975). 'Until the mid-1960's Gangtok was a major staging point for mule caravans travelling on the ancient trade route to Lhasa. The road climbed over Nathu La (Pass) before entering Tibet' (Lepcha, 2003).

### **2.2.2. Development between 1947 and 1975**

On 15<sup>th</sup> August 1947, when India became independent, Chogyal Tashi Namgyal was successful in getting a special status of 'protectorate' for Sikkim. A Treaty was signed between India and Sikkim, which ratified the status of Sikkim as a protectorate with Chogyal as the king. The magisterial and judicial powers of the landlords were completely abolished by 1948. A Charter set up a High Court at Gangtok in April 1955. Public gambling as well as the use of unpaid labour was prohibited in Sikkim. Chogyal Tashi Namgyal also made land reforms rules. Executive and judicial powers were also decentralized. He died on 22<sup>nd</sup> December 1962 and was succeeded by his son Palden Thondub Namgyal.

In the year 1973 started a widespread agitation in Sikkim against the Sikkim Durbar. The growing agitation led to the complete collapse of administration in Sikkim. Hence, Sikkim was accorded status of an 'Associate state' in place of a 'protectorate'. Then Kazi Lendup Dorjee, a leader of Congress, was elected as the first Chief Minister of Sikkim on 4<sup>th</sup> September 1974. However, in the new set up also the Chogyal remained the constitutional head of the state of Sikkim. On 16<sup>th</sup> May 1975 Sikkim was merged in the Union of India as its 22<sup>nd</sup> state. The institution of Chogyal was subsequently abolished. In this way Sikkim state passed from Autocracy to Democracy. This paved the way for the emergence of a number of political parties who have fought number of elections to form democratically elected government, committed to social justice and overall development of Sikkim. Democratically elected governments have been engaged in various developmental activities and it can be said that now Sikkim is one of the developing states of India.

### **2.2.3. Development between 1975 and 2005**

It is important to mention here that until the merger of Sikkim with the Indian Union, a Bazaar Committee which was constituted in 1918 governed Gangtok, but after 1975 the state had introduced the municipal form of local self-government. After the formation of municipality a rapid change has been seen in the Gangtok and its suburbs. As mentioned above, it is evident from an exponential 568 per cent growth in terms of area during this phase. It clearly speaks about the rapid spread of the settlement. Without doubt, this spatial expansion has been at the cost of forest area, which has direct or indirect influence on occurrence of landslides in the study area, apart from degradation of geoenvironment of Gangtok.

It has been mentioned earlier that until 1894, the capital of Sikkim was Tumlong. When the capital of Sikkim was shifted to Gangtok in the regime of Thudob Namgyal, it was a small village in the midst of the natural forests. Of course, there were a few hamlets nearby such as Lingding, Syari, Tadong, Burtuk, Deorali, and Damdikyoung etc. As early as 1776 a monastery was built on the upper crest of the spur on which Gangtok is situated today. It shows that a monastery, a few houses and a palace was already there when the capital of Sikkim was shifted here from Tumlung in 1894.

Gangtok is the youngest Class III hill town in India. Infrastructure development in Gangtok had started in the beginning of the 20<sup>th</sup> century, i.e., during the reign of Thutob Namgyal. That time the total population of Sikkim was very less. According to a Census report, which was conducted in Sikkim in the year 1891, the total population of Sikkim

was only 30,458, hence, one can easily imagine about the total population of Gangtok at that time. However, with the passes of time the population of Gangtok has increased many folds. Table 2.1 shows the growth of population of Gangtok since 1951.

**Table 2.1. Total population of Gangtok, 1951-2001**

Year	Population (in persons)	Percentage Growth
1951	2,744	-
1961	6,848	+149.56
1971	13,308	+94.33
1981	40,873	+207.13
1991	67,330	+64.73
2001	75,112	+11.56

Source: Different Census of India Reports.

Table 2.1 and Figure 2.2 clearly shows that population growth of Gangtok has not been uniform. The highest percentage growth of 207.13 was recorded during the decade of 1971 and 1981. This phenomenal growth of population again validates the point that Gangtok has experienced a faster growth after merger of Sikkim with the Union of India. However, the second highest percentage of 149.56 of population growth was between 1951 and 1961, the main reason for this can be attributed to culmination of the rule of Chogyal Tashi Namgyal during which a number of socio-economic developments took place. After 1981 Census population growth has been on decline, and coming to as low as 11.56 per cent during 1991 and 2001.

Table 2.2 shows density of population in Gangtok. As the total area of Gangtok was 6.11 sq km up to 1975, the population density persons per sq km increased from 449 to 1121 and 2179 in 1951, 1961 and 1971, respectively. However, with the increase of

### Population Growth of Gangtok (1951- 2001)

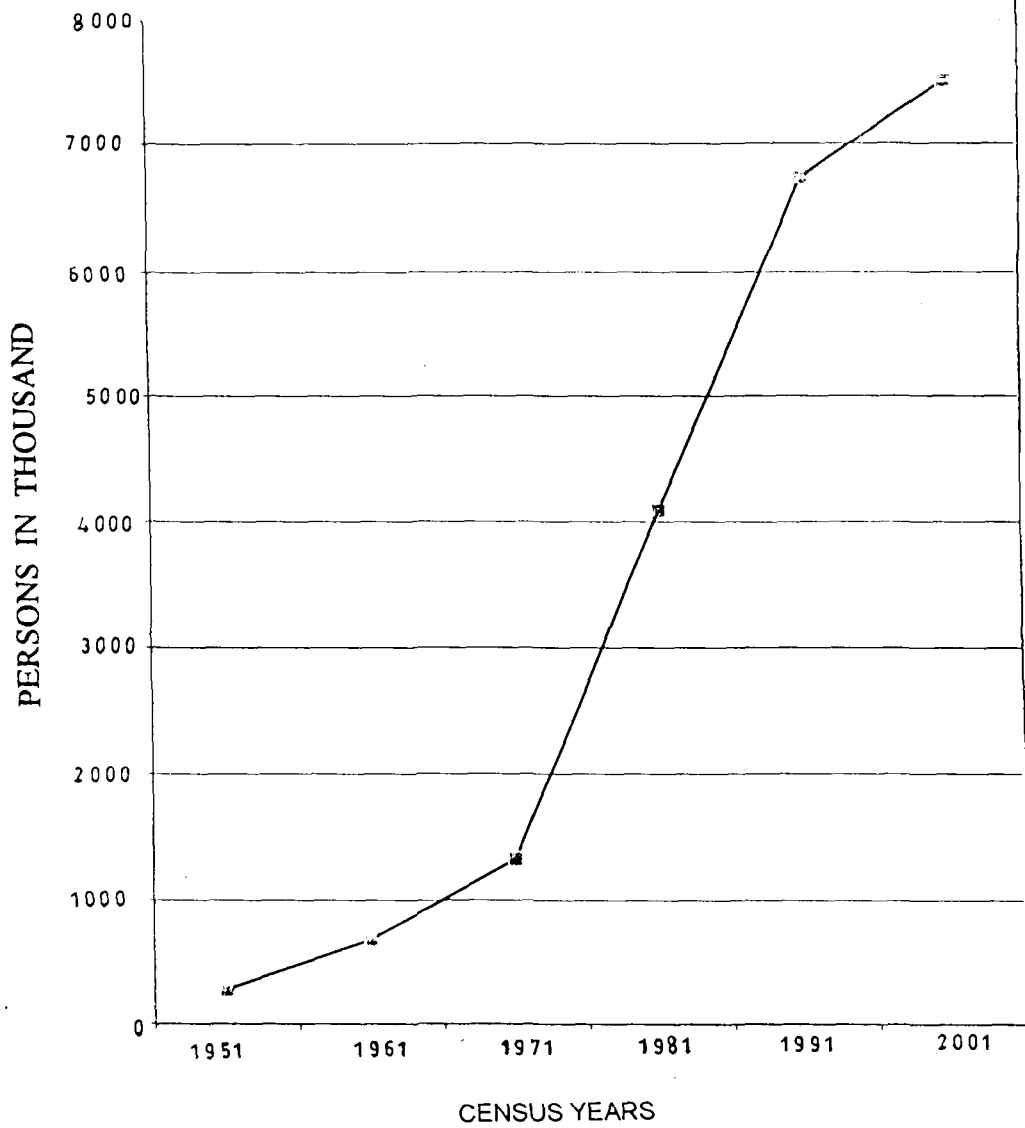


FIG. 2.2

area to 40.81 sq km the density of population came down to 1002 persons per sq km in 1981 Census, despite Gangtok experiencing the highest growth of population during 1971-1981, and having 40,873 persons in 1981. But again population density increased to 1650 persons per sq km in 1991 and 1841 persons per sq km in 2001, simply due to increase in total population.

**Table 2.2. Density of population in Gangtok, 1951- 2001**

Census year	Total population (in persons)	Total area (in sq km)	Density of population (persons per sq km)
1951	2744	6.11	449
1961	6848	6.11	1121
1971	13308	6.11	2179
1981	40873	40.81	1002
1991	67330	40.81	1650
2001	75112	40.81	1841

Source: Different Census of India Reports

As early as 1950, almost 90 per cent shops and official buildings were concentrated near the White Memorial Hall. The Ridge Road, leading to the Royal Palace, was the main commercial hub of Gangtok, while the Lall Bazaar, Mahatma Gandhi Marg and Sikkim Guards Ground (the most developed area of today) were cultivated fields only. In 1951, Gangtok appeared as a town on a map of the Sikkim with a population of 2744, when it was connected with Siliguri by motor service. During the 1<sup>st</sup> Five Year Plan (1954-61), a number of government institutions were established for the workers mainly in the tertiary sector coming from the surrounding states. On the other hand, during the Indo-China war (1962) a large number of Tibetan refugees settled down in Chandmari, Tathengchen and in the area lying around the main market (Boot, 1991). However, in the successive five-year plan periods the scenario of Gangtok has markedly

changed. New settlements in the different parts viz., Sichey Area, near Tashi Namgyal Senior Secondary School, Development Area, Tibet Road, Deorali, Tadong Dargaon, 5<sup>th</sup> Mile, Indira Bye-pass etc. have appeared. The old Lall Bazaar was built in the 1950s' so that the villagers could sell their own products easily. This market is named after J.S. Lall, the first Dewan of Sikkim. However, by the end of the 19<sup>th</sup> Century all the major roads of the state including the Indo-Tibetan trade route used to converge at Gangtok and very soon a trade registration office opened at this emerging nodal point. In this way, a tiny settlement has gradually turned into a trade centre, flourishing with numerous trading activities (Boot, 1991). Construction of the present M.G. Marg market started as early in 1925. Today National Building Construction Corporation has developed Lall Market to a multi-storied modern shopping complex. A rapid development of Gangtok has taken place after the 1980s'. Present government of Sikkim Democratic Front (SDF) has taken number of initiatives for the development of Sikkim in general and Gangtok and suburbs in particular.

As Gangtok has developed on an elongated narrow ridge, the settlement pattern of Gangtok has been determined mainly by length and width of crest and slopes. The important buildings of the capital are situated on the narrow crest of the ridge. From the point of view of geohazards more significant is its development on steep slopes, which exhibits high risk in the event of earthquakes and landslides. On the other hand, the main settlement of Gangtok is like a cluster with compact pattern except the areas like 5<sup>th</sup> Mile, Tadong, Indira-by-Pass, and Burtuk etc. where linear type settlement is seen.

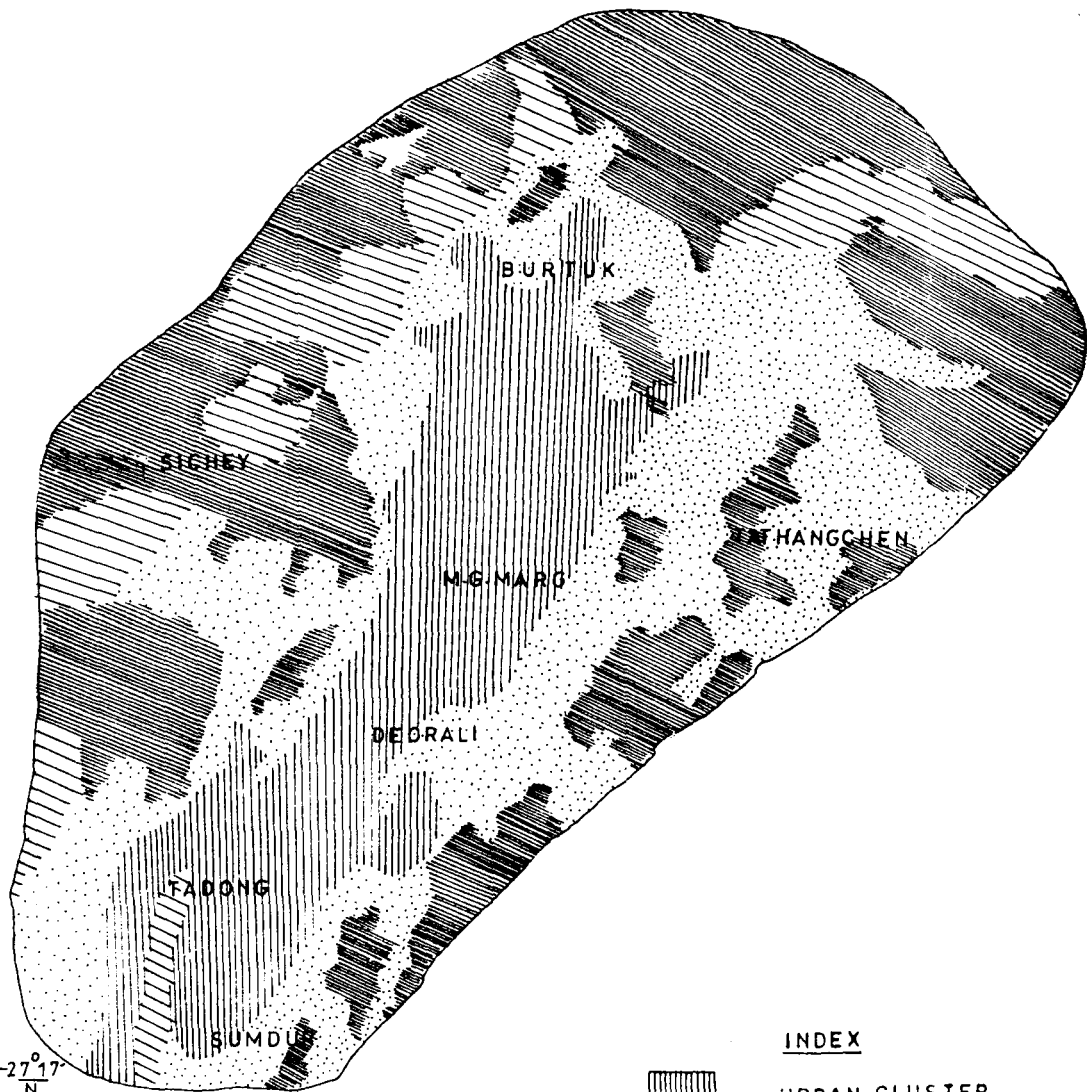
In the Census of 1941 Gangtok was accorded the urban status and up to 1971 Census it was the only census town in entire Sikkim. However, in the Census of 1971, seven new towns of Singtam, Rangpo, Mangan, Gyalshing, Jorethang, Nayabazaar and Namchi emerged (Chib, 1977). In real sense, Gangtok is still the only urban centre in the state. Though of a very moderate size, it has accommodated the largest number of state's urban population. It also has a variety of people in terms of religion, race, language and socio-economic classes and it is the only town where urban character is discernible in true sense of the term (Boot, 1991).

During the Chief Ministership of Kazi Lhendup Dorji Khangsarpa (i.e., from 1974 to 1979) various types of developmental activities took place in and around Gangtok. For example, a number of offices, centres and services were established including that of the Anti-Corruption Branch, Frontier Railway Passenger Out Agency at Sikkim Nationalized Transport Office, Temi Tea Factory, Water Treatment Plant at Selep, Gangtok-Chungthang Bus Service, Divisional Telegraph Office at Gangtok, Industrial Training Institute at Rangpo, Tashilling Secretariat (Plate 4), Kendriya Vidhalaya at Libing etc.

Present land use/ land cover of Gangtok include four categories, viz., urban cluster, dense forest, open forest and crop land including open spaces (Fig. 2.3), covering an area of 10.10, 16.80, 4.90 and 9.01 sq km, respectively. Percentage wise maximum area (41.17) is under dense forest, and if open forest percentage (12.00) is added to it then about 53.17 per cent area is still under different types of forest cover. But it should not be taken as rosy picture because the 24.75 per cent area of Gangtok shown under urban

GANGTOK  
LAND USE/LAND COVER

27° 22'







27° 17'  
N



88° 35' E

INDEX

-  URBAN CLUSTER
-  DENSE FOREST
-  OPEN FOREST
-  CROPLAND AND OPEN SPACE

SOURCE : FIELD WORK , 2004-05  
AND DIFFERENT LITERATURE

FIG. 23

cluster has definitely come up after removing the forest cover, and that is point of concern because such deforestation has altered geoenvironment, which has contributed to occurrence of landslide hazards in the area. Interestingly, 22.08 per cent area is as open space and cropland.

Gangtok has now been proposed to be built into a model city. Master Plan of Gangtok has been prepared by the Department of Urban Development and Housing Development (UD&HD), Sikkim. Nowadays, the Government of Sikkim has launched new schemes, plans and projects for Gangtok to develop it as a modern tourist spot on the Eastern Himalaya Mountain. In short, it may be said that within 100 years of time period, the scene of Gangtok has changed very rapidly. However, the faster urbanization has to be matched with the equal development of the infrastructure facilities in Gangtok in near future. It has already been facing pressure from all corners due to rise in population, and it has little scope for infrastructure development due to lack of space. Moreover, geoenvironment of Gangtok has degraded and it experiences number geoenvironmental problems, including recurring landslides and sometimes earthquakes also. A conflict seems imminent between the development and geoenvironment, but it has to be avoided for better future. From the above discussion it can be easily shows development and expansion of Gangtok from a tiny hamlet to a sprawling capital of Sikkim.

## **CHAPTER- III**

# **GEOENVIRONMENT OF GANGTOK**

As mentioned earlier, appraisal of geoenvironment is essential for the development of the area. Geohazards form an important part of the geoenvironment, hence their frequency of occurrence, intensity, extent and causes are also studied in details to have total understanding of geoenvironment of an area. The holistic understanding of geoenvironment not only helps to mitigate and predict occurrence of geohazards but also facilitates development of the area. This is because hazards on one hand destroy the development that has already taken place while on the other hazards hamper development on an area as well. Moreover, from another point of view, most of the developmental activities cause interference in geoenvironment leading to occurrence of geohazards. From this perspective, geoenvironment of Gangtok has been discussed and analysed in this Chapter.

As mentioned earlier that Gangtok is located on steep slopes of a ridge, and the way it has grown from a settlement comprising of a few wooden houses to a large settlement having a number of RCC buildings, it appears that the entire settlement is at great risk, particularly in the event of any earthquake or landslide. That is why the understanding of geoenvironment of Gangtok with special reference to geohazards is of great relevance to its development and safety. Any development in and around Gangtok has to take into consideration its geoenvironment not only to ensure success of the development but also to see that development do not have negative influence on the

geoenvironment, for changes in the geoenvironment mostly lead to degradation of geoenvironment and occurrence of man-induced geohazards.

Geoenvironment is a holistic study of landforms, geology, water, soil, and forests. Of course, climate is also included as it governs other elements of geoenvironment. In fact, it is study of those elements of physical environment, which are related to the earth and its various attributes. Moreover, geoenvironment is taken as a system to understand interrelations and interconnections among different elements and their total influence on man and environment. Geohazards are addressed specifically in geoenvironmental studies, because as extreme events of natural environment they create havoc for man. In the following lines, geoenvironment of Gangtok has been discussed. The different components of the geoenvironment included here are- physiography (landforms, altitude, slope, and drainage), geology, soil, hydrology, and forests. Climate has also been taken in to consideration as it is directly or indirectly related to occurrence of landslide geohazards (discussed in Chapter IV). Before discussing each component individually and then demarcating geoenvironmental units by taking in to consideration various geoenvironmental components together, it would be relevant to mention location and extent of the study area. In dealing with the discussion on the geoenvironment from whole to the part approach has been adopted in which nature and a characteristic of geoenvironment of Gangtok is given in the background of Sikkim as a whole.

### **Location and Extent**

Sikkim, the small enchanting mountain state of India, is lying in the Eastern Himalaya Mountain. The bowl like mountain-girdled state is bounded by Nepal in the west, Tibet and Bhutan in the east, Tibet in the north and Darjeeling district of West Bengal in the south. Sikkim lies between the  $27^{\circ} 04'$  and  $28^{\circ} 07'$  north latitudes and  $88^{\circ} 01'$  to  $30^{\circ} 55'$  east longitudes, means it falls in the tropical belt that influences its climate, vegetation etc. Whereas due to its location in the Eastern Himalaya north of the Bay of Bengal and Malda Gap (through which the Ganga-Brahmaputra Rivers drain towards the Bay of Bengal) it has proximity to the sea that influences its climate, particularly rainfall that in turn has its own direct or indirect influence on various elements of geoenvironment and occurrence of landslides as well.

The state has a total area of 7,096 sq km. Maximum length of the state from north to south is about 113 km, whereas the maximum width from east to west is only 64 km. The altitude varies from 213 m in the south to over 8,500 m in the northwest culminating in the Kanchendzonga peak at 8698 m. With the increase of altitude a great variations of climate and vegetation are found here also. As a result of different pedogenesis factors, a large variety of soils have developed in this Himalayan state. It has a population of 5,40,493 as per 2001 Census.

Gangtok is situated on a steep mountain slope. It lies at  $88^{\circ} 7'$  east longitude and  $27^{\circ} 3'$  north latitude in the East District of Sikkim. It is spread over altitudinal range of 900 to 2400 m covering an area of 40.81 sq km (Fig. 3.1). Gangtok extends from the Burtuk in the north to Sundur (6th Mile) in the south and from Lower Tathenchen in the

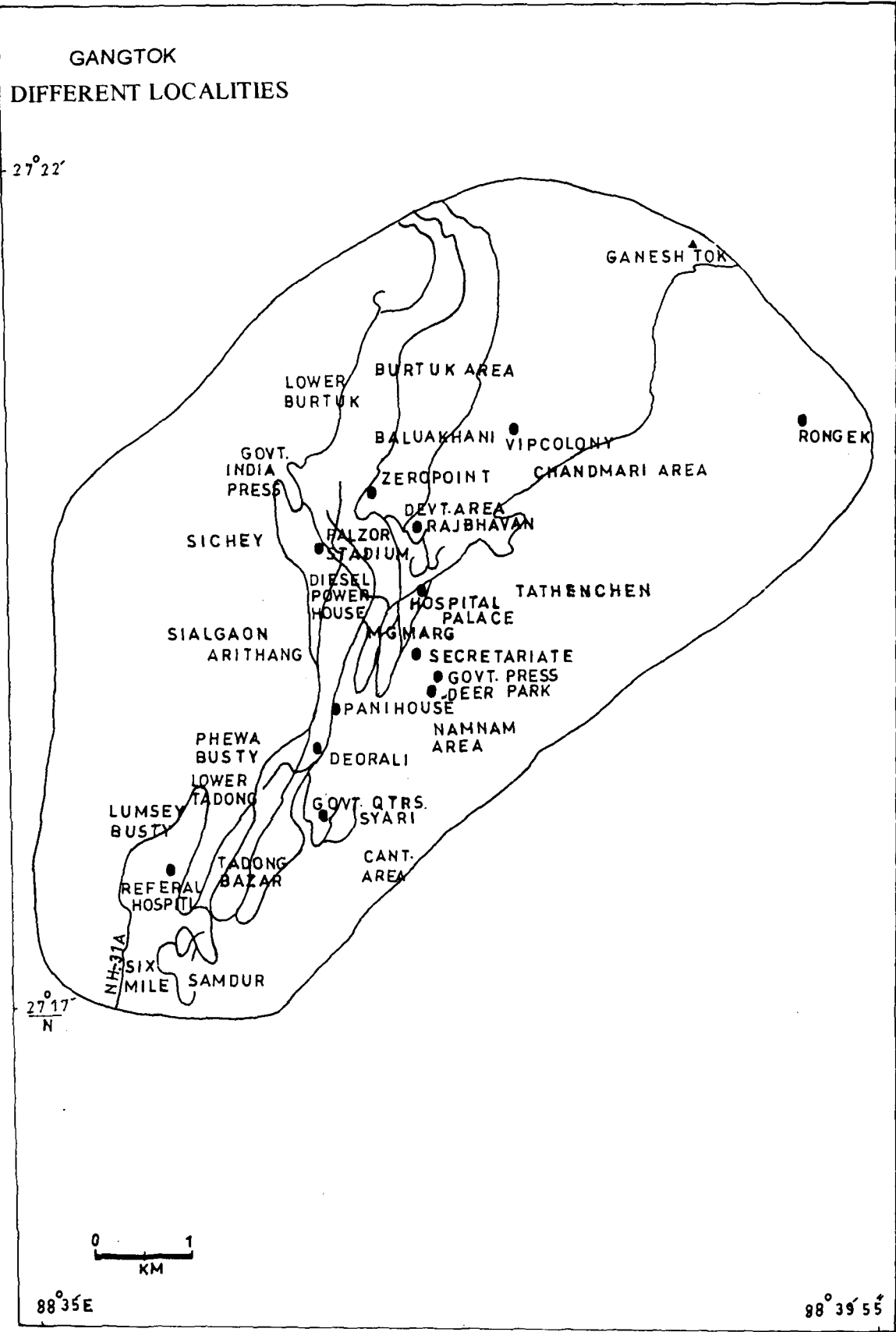


FIG. 3.1

east to Lower Sichey in the west. The swift Rani Khola flows from north to south on the western side of Gangtok, while the Bhusuk Khola flows on the eastern side. In the following lines various components of geoenvironment of Gangtok have been discussed separately first, then they have been taken together to delineate geoenvironmental units where totality of the geoenvironment of Gangtok has been comprehended.

### **3.1 PHYSIOGRAPHY**

The physiography of Gangtok can be understood with help of parameters like landforms, relief, and slope. It need not be emphasised here that physiography is basic component of geoenvironment of a place, particularly in the mountains it is an imposing feature of the geoenvironment.

#### **3.1.1. Landforms**

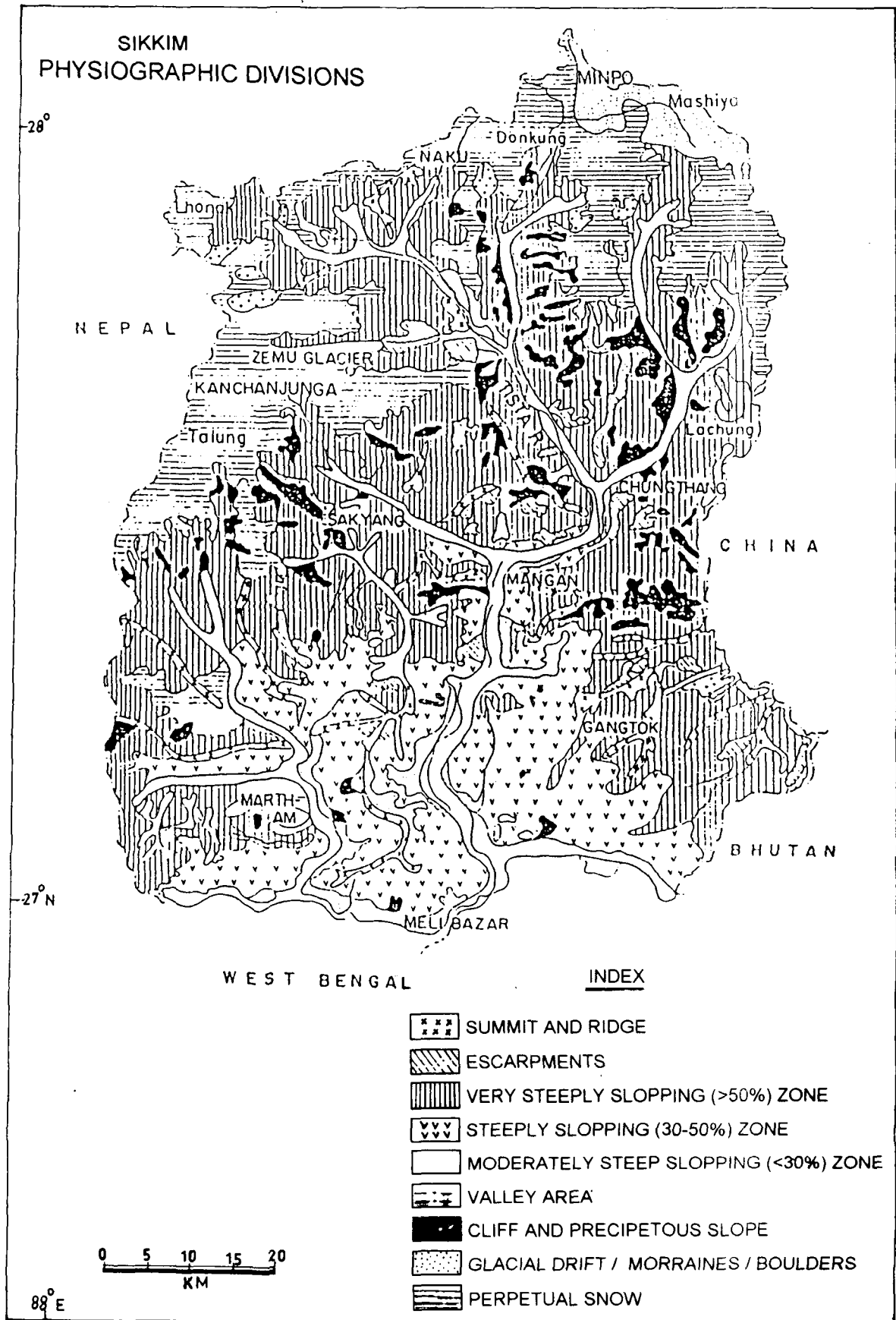
Landforms are basic component of geoenvironment of an area as these are most dominant feature of the physical landscape. As a part of the great Himalaya Mountain Sikkim has highly rugged terrain with sharp peaks and crests, gorges, and steep slopes, glaciers and river valleys. Flat land is rare to found here. That is why Risley (1989) mentioned that 'Sikkim is essentially a mountainous country without a flat piece of land of any extent anywhere'. The parallelism of three longitudinal ranges is broken here as it is found in Kumaon and Kameng Himalaya regions (Chaudhury, 1981, Husain, 2002). Of course, almost east-west running two ranges of the Greater and Outer Himalaya exist here, but the Middle Himalaya Range is conspicuous by absence of its parallelism to the above two ranges. In fact, it is a chaotic pattern of orientation of hill ranges in the Middle Himalaya where even north south extending ranges are seen. In fact, a chequered pattern

of main ranges has been observed in Sikkim Himalaya. 'A number of peaks comprising of crystalline rocks accentuate the demarcation between Tibet and Sikkim. The longitudinal Chola range separates the state from Tibet in the eastern side. While the Singalila range, another longitudinal offshoot of the Greater Himalayan Range, marks the boundary between Sikkim and Nepal in the west (Choudhary, 1998).

Major landforms of Sikkim are crests and ridges, escarpments, hill slopes, 'V' shaped and 'U' shaped valleys, lakes, and perpetual snow fields, glacial drifts, moraines, and boulders in the higher altitude. In the northwest, north and northeast Sikkim is marked by high peaks, the highest being Kanchendzongha at 8698 m in the northwest. In the East District of the state, where Gangtok is located, the elevation gradually rises from 350 m near Rangpo in the south to 5278 near Chhumpu in the northeastern part of the district. The famous pass Nathu La (4728 m) is only 56 km northeast of Gangtok.

Figure 3.2 depicts major physiographic divisions of Sikkim as prepared by the scientists of the National Bureau of soil Survey and Land Use Planning (NBSS and LUP, 1993). Most of the area in the northwest, north and northeast lies under perpetual snow from where originate a number of glaciers carving 'U' shaped valleys and depositing moraines and boulders down stream. The glaciers of Sikkim are Pauhunri (source of Teesta), Zemu, Simvu, and Talung etc. Apart from these landforms, there are summits and ridges, escarpments, cliffs, moderate to steep slopes, river valleys, terraces and hot springs.

Interesting to note that on geomorphology of Sikkim Himalaya significant works have done by geomorphologist-ecologist Mukhopadhyay (1978, 1980, 1982 and 1998). According to him assemblage of the distinct landform features of Sikkim comprise of-



SOURCE : AFTER NATIONAL BUREAU OF SOIL SURVEY AND LAND USE PLANNING, NAGPUR

FIG. 32

peaks, snow fields, glaciers, moraines, high altitude lakes, gorges, river terraces, hill slopes, landslide slopes, narrow belt of flood plains along the main rivers etc. Landforms sculptured by glacial, peri-glacial, fluvio-glacial, fluvial and tectonic processes are found here. 'The diversity in litho-techno landform units of Sikkim Himalaya is greater than any other sub-basins of the physiographic or geologic terrains within the Eastern Himalaya....' (Mukhopadhyay, 1998:1). While dealing with the physical landscape of Sikkim, Choudhury (1998) has described about its glaciers, rivers, cirques, arêtes, glacial troughs, moraines, lakes, rivers, hot springs etc. The famous peaks of Sikkim Himalaya are- Kanchendzonga (8595 m), Siniolchu (6895 m), Pandim (6708 m) etc. The famous passes are Nathu La (4728 m), Jelep La (4040 m) etc. The placid high altitude lakes include- Chho Lhamo (5099 m), Gurudongmar (5176 m) etc.

Coming to Gangtok it has been observed that a long, narrow, and steep ridge extending from northeast to southwest direction dominates physiography of Gangtok. This ridge radiates in southwest direction from the highest point (Ganeshtok peak- 2500 m) and terminates at the confluence of the rivers- Rani Khola and Bhusuk Khola, just two km away from the southwestern end (900 m) of the study area. Northeast to southwest schematic profile (Fig. 3.3) shows four distinct sections of the Gangtok ridge. First is the higher altitude steep slope area from Ganeshtok to White Hall. Second is the slightly level surface of the crest of the ridge extending from the White Hall to Tashilling (Secretariat). From here starts the third section which is characterised by steep slope up to the base of the Deorali hillock, where is found a saddle. The fourth section belongs to the Deorali hillock and spurs radiating from it in three directions- the west, south and east, the last two are steep slopes. Whereas, from east to west the slope rises sharply from the

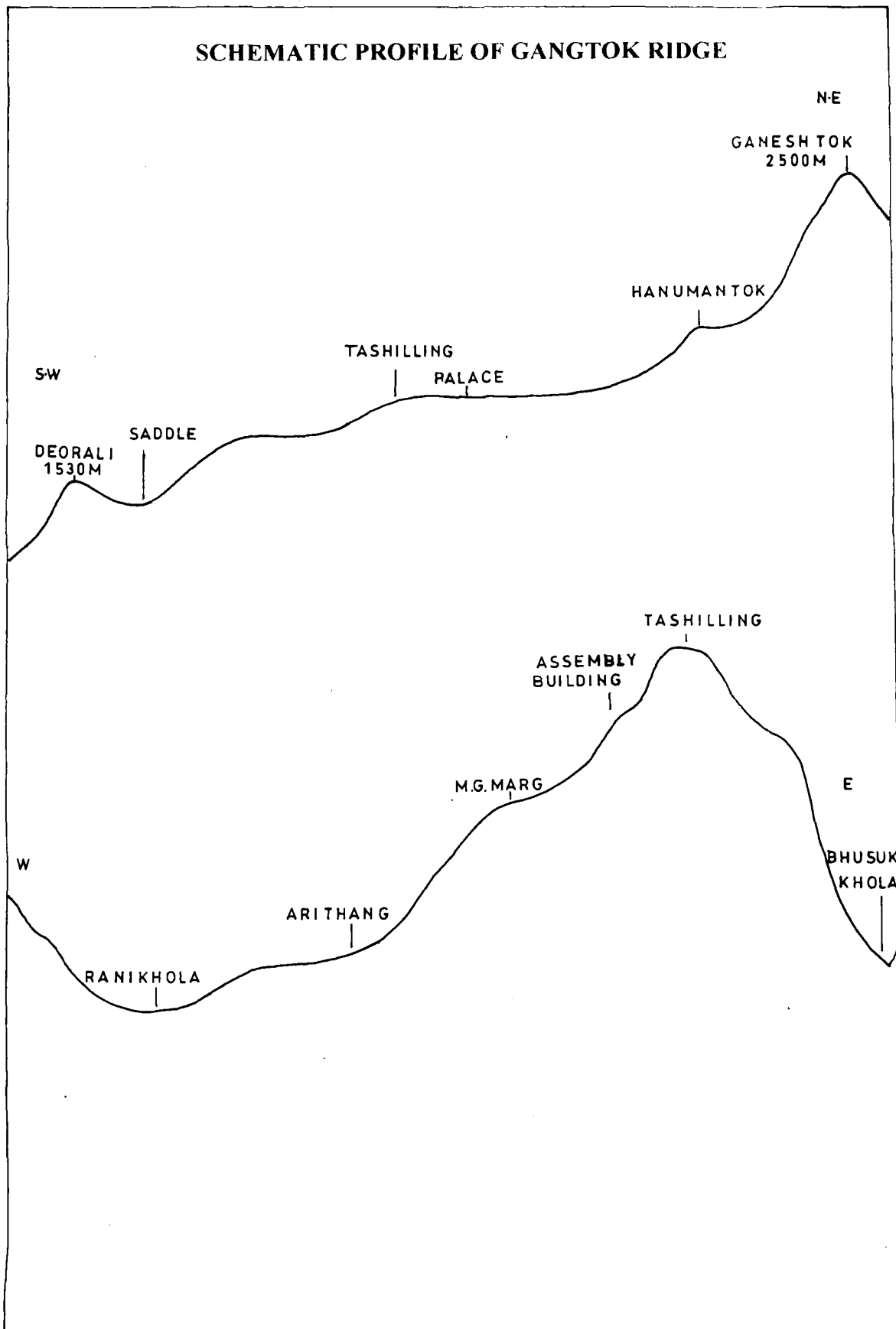


FIG. 33

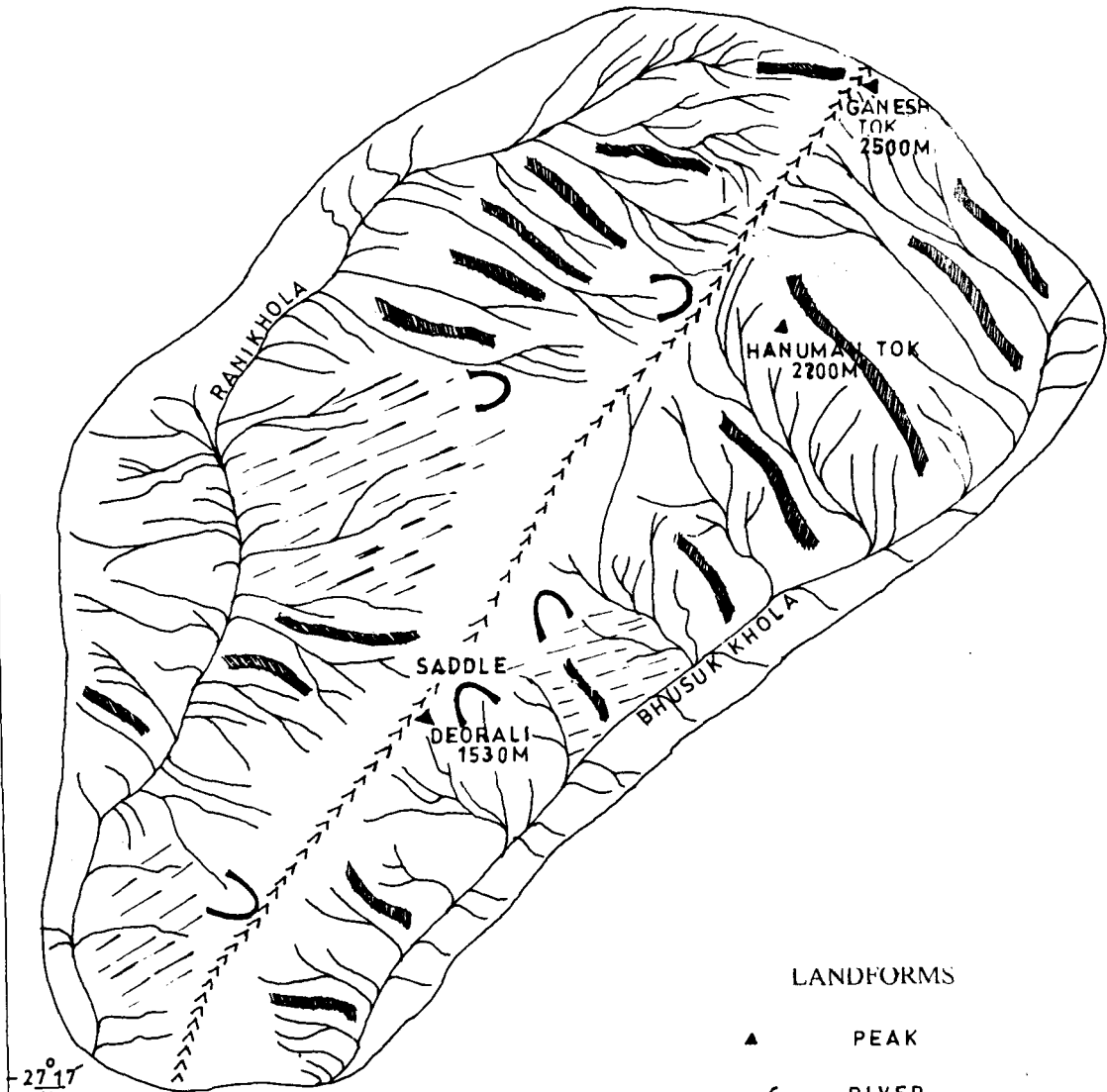
bed of the Bhusuk Khola and it touches the Tashilling point in the crest of the ridge. Then start the steep western slopes where the main settlement is precariously located. Midway the slope becomes moderate, followed by steepness, which continues up to the Rani Khola.

Need not mention that detailed study of landforms and its various aspects is the main task of geoscientists. It is very important to know the various landforms in an area to understand its geoenvironment. This because various features and aspects of landforms dominate geoenvironment, particularly in a hilly terrain like that of the study area. In fact, uniqueness of geoenvironment is determined by landforms that play an important role in demarcation of geoenvironmental units as a whole. Broadly, the ridge on which the settlement is located dominates the landscape of Gangtok, however there are different types of micro landforms are present in the study area. Landforms of Gangtok like peak, crest, Deorali ridge, small spurs, steep valley (Bhusuk), gentle valley (Rani), escarpment, saddle etc. have been depicted in Figure 3.4.

There are three important peaks in Gangtok. Ganeshtok peak (2500 m) is the highest point of the area, which is located in the northeast of Gangtok. Another important peak is Hanumantok (2200 m), located near the Chandmari area. Deorali hillock (1530 m) is comparatively low in height and it is located in the south central part of Gangtok. Between the Deorali hillock and the main ridge or Palace ridge or Gangtok ridge there is small and narrow saddle. Thus, it can be said that with a little break the main ridge runs in northeast to southwest direction, starting from steep slopes of Ganeshtok peak, and

# GANGTOK LANDFORMS

27° 22'



27° 17' N

## LANDFORMS

- ▲ PEAK
- RIVER
- RIDGE
- ESCARPMENT
- VALLEY



88° 35'E

SOURCE : FIELD WORK, 2004-05

88° 39' 55"E

FIG. 34

ending at the confluence of the Rani Khola and Bhusuk Khola. The ridge is kernel of the landscape. Its general slope is from northeast to southwest.

The crest line of Gangtok ridge is running from the Palace in the northeast to Deorali hillock in the southwest. Because of relatively flat and wide surface on the western side, the settlement of Gangtok has been developed here. On the other hand, eastern flank of the ridge is very steep ( $>60^{\circ}$ ), that is why, retarded the growth of settlement on this side. Another important ridge is located in the southern part of Gangtok known as Tadong-Amdogolai ridge. In the eastern flank of the ridge, the military cantonment has been established. A small By-Pass Arithang ridge is located in the central part of Gangtok, which starts from Amdogolai and ends below Palzor Stadium. Western side of the ridge has been thickly occupied, in spite of comparatively steep slope.

A number of escarpments are also seen in Gangtok. The main escarpments, dominating the landscape, are, Phatek escarpment (near the Tashi viewpoint), Amdogolai escarpment (located at the starting point of Indira by-pass), Arithang escarpment (near the Court), Lower Tadong escarpment (near Metro Point), and the 5<sup>th</sup> Mile escarpment (near Manipal University Campus). Apart from it, there are few small valleys, e.g., Arithang valley (below the Indira by-pass and extend up to east bank of Rani Khola), Lower Sichey valley (near Burtuk), and Phewabasti valley (below Arithang). Slope of the valleys is comparatively gentle, ranging from  $20^{\circ}$  to  $40^{\circ}$ . Terrace cultivation is done in some of these valleys. A concave-convex valley is seen in the eastern part of the main ridge which starts from Lower Syari and ends below the Government Press. The angle of slope of this valley is comparatively higher ( $40^{\circ}$ - $75^{\circ}$ ) compared to other valleys. Except

small patches of lower Syari, this valley has not been used for any agricultural activities. Another small but important valley is seen below the Development area, which is known as Palzor Stadium valley. As name implies the well-known stadium of Gangtok is situated in this valley. The angle of slope of this valley is ranging from 20<sup>o</sup>- 40<sup>o</sup>. Below 5<sup>th</sup> Mile area another valley is located, which is known as Linding-Lumsey Basti valley. This valley is also comparatively gentle with slope angle ranging from 20<sup>o</sup>-40<sup>o</sup>. Another small valley is found in the western side of the upper Burtuk. A number of spurs are also present in the area. Major spurs observed are- Deer Park spur, Tathenchen spur, Rongek spur, Arithang spur, Phatek spur, Burtuk spur and Bojogary spur. Actually, these spurs are micro level water divide between streams of the area.

### 3.1.2. Relief

The physiography of Sikkim is characterized by great variations in elevation ranging from 250 m in south to 8,566 m above mean sea level in the northwest. The altitude increases from south to north. Based on Oxford University Atlas (1990) Sikkim Himalaya can be divided in to seven altitudinal zones (Table 3.1). It clearly shows that a large part of Sikkim lies in the higher altitude zone, i.e., above 3000 m covering 57.10 per cent area. While 36.66 per cent area falls between 900 to 3000 m altitude, and a very small percentage of 4.7 lies between 200 to 900 m altitudes.

**Table 3.1. Altitudinal zones of Sikkim**

Sl. No.	Altitudinal Zones	Area	Percentage (%)
1	200-600	38.03 sq km	0.53
2	600-900	299.75 sq km	04.2
3	900-1350	785.85 sq km	11.00
4	1350-1800	824.87 sq km	11.56
5	1800-3000	1014.00 sq km	14.10
6	3000-4500	1922.00 sq km	26.94
7	4500-6000	2185.97 sq km	30.26

Source: Oxford University Atlas, 1990.

Relief aspects of Gangtok have been analysed on the basis a contour map (Fig. 3.5) prepared from the toposheet of 1:50,000, with a contour interval of 20 metres. It clearly depicts general relief of the area. The steepness of slope is evident generally in the northeastern and eastern parts, while an escarpment can be seen in the northwestern corner and central part as well. Towards the west openness of contours is associated with the Rani Khola valley.

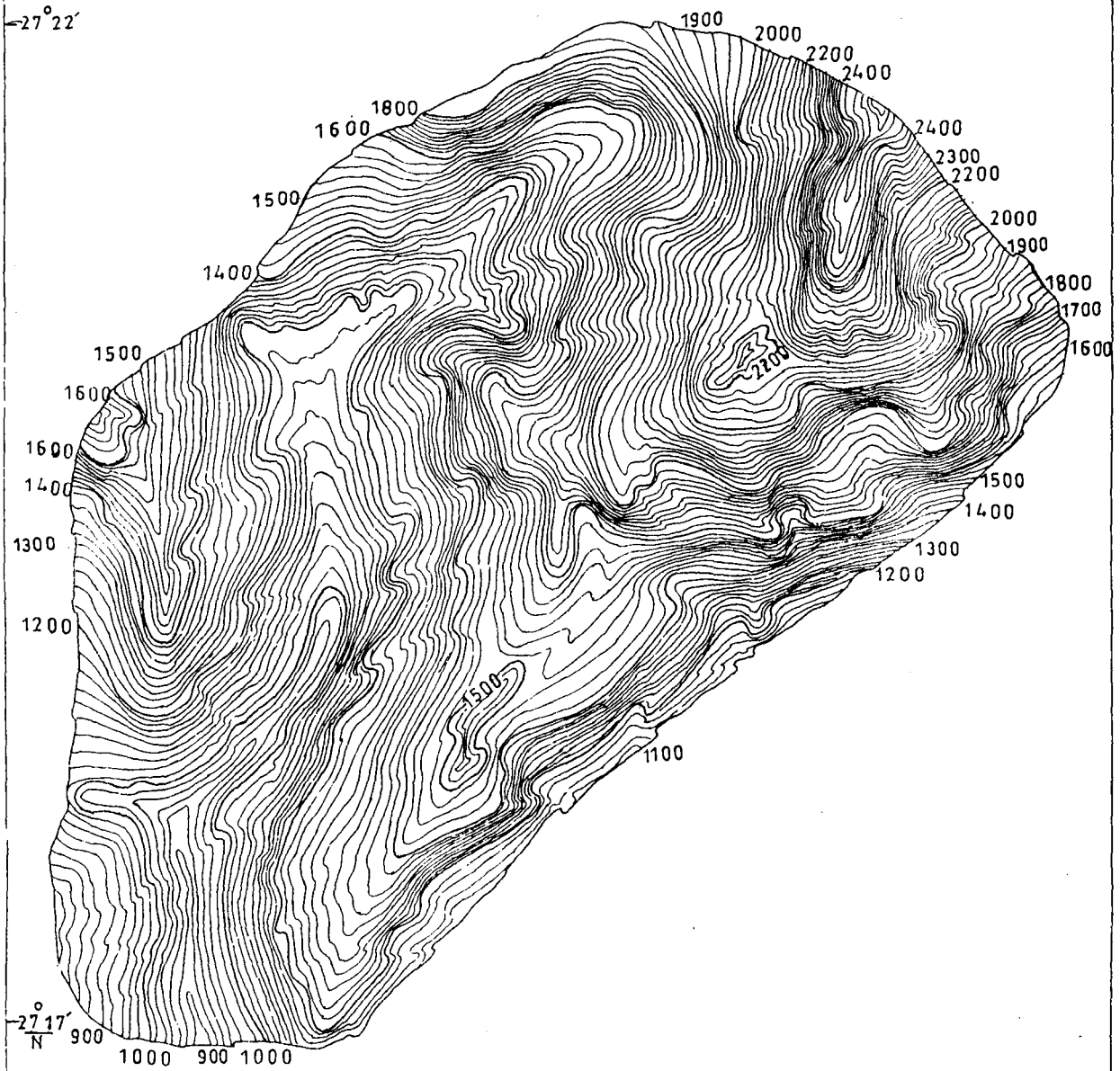
The absolute relief (Fig. 3.6) has been shown in nine categories, starting from below 1000 m to ending with above 2400 m altitude. Important to mention that the highest area of 9.21 sq km falls between 1200 to 1400 m, and the lowest area of 0.40 sq km is above 2400 m. However, it is relevant to mention that the main part of settlement lies between 1400 – 2000 m altitudes.

The relative relief map (Figure 3.7) shows that maximum relative relief of more than 600 metres is again associated with the steepness of the northeastern corner of the study area, which covers merely 1.05 sq km. It is also observed that highest area of 8.95 sq km falls between 500 – 600 m altitudes. Only 4.21 sq km area is under relative relief of below 100 m.

### **3.1.3. Slope**

Slope is very important element of geoenvironment, especially in the hilly areas. Slope also plays a crucial role in the occurrence of landslides. Therefore, it is relevant to analyse slope of the study area. It is seen that from the crest of the Gangtok ridge the

GANGTOK  
CONTOURS



CONTOUR INTERVAL 20 METRE



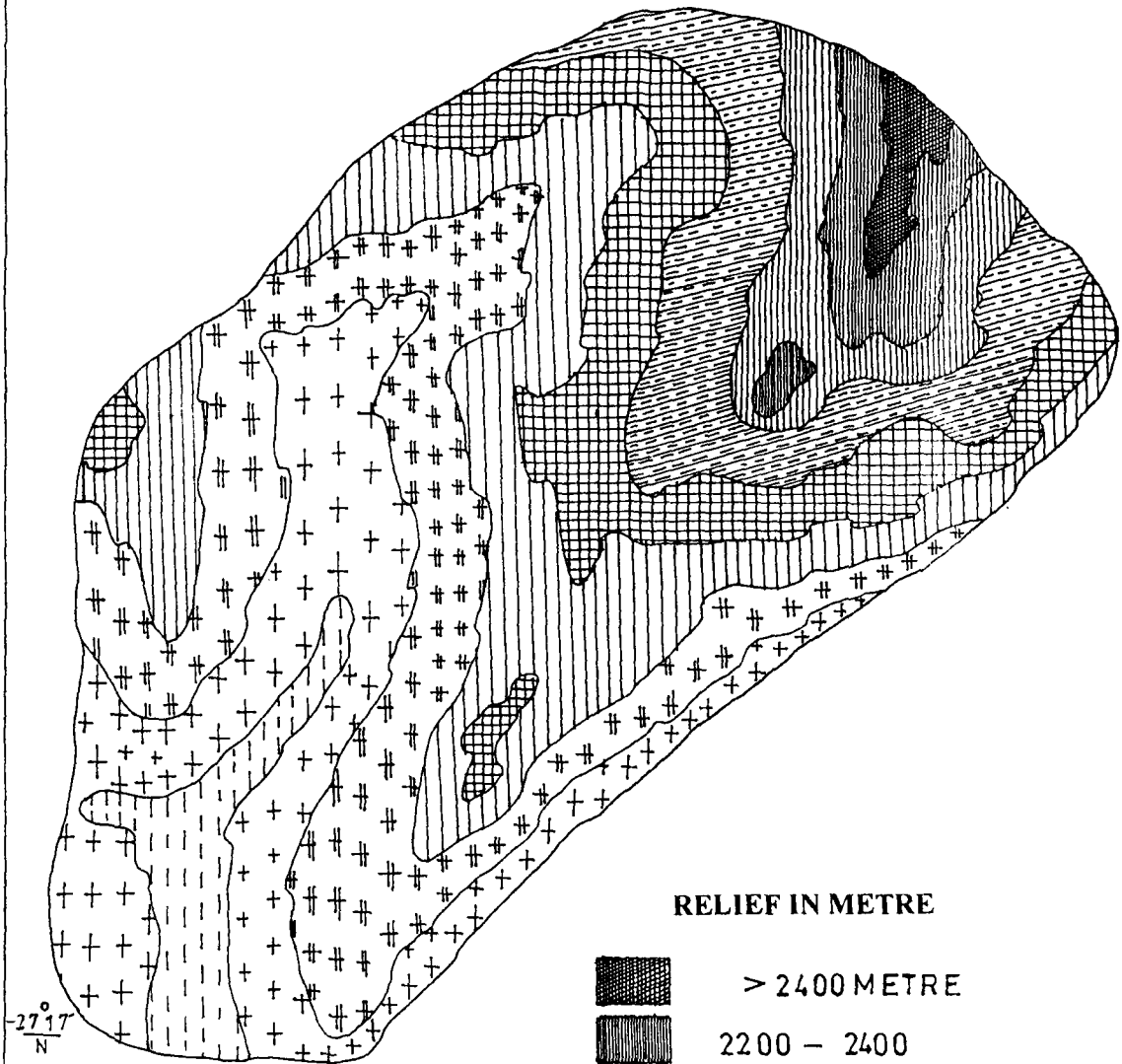
88° 35' E

SOURCE : 78 A/11 88° 39' 55"

FIG. 3.5

# GANGTOK ABSOLUTE RELIEF

$27^{\circ} 22'$



$27^{\circ} 17'$   
N

## RELIEF IN METRE

	> 2400 METRE
	2200 - 2400
	2000 - 2200
	1800 - 2000
	1600 - 1800
	1400 - 1600
	1200 - 1400
	1000 - 1200
	< 1000



$88^{\circ} 35'E$

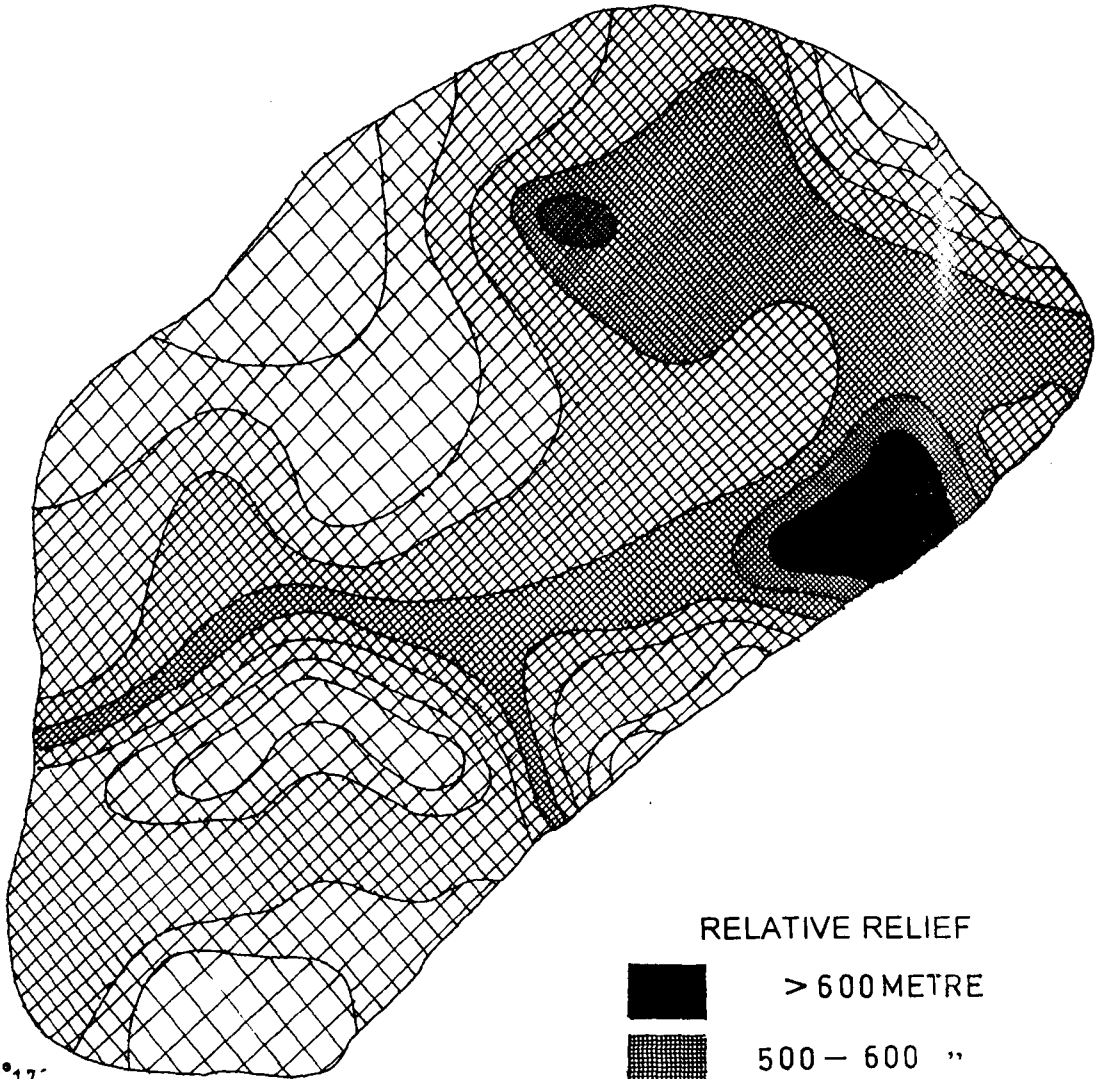
$88^{\circ} 39' 55''$

FIG. 3.6

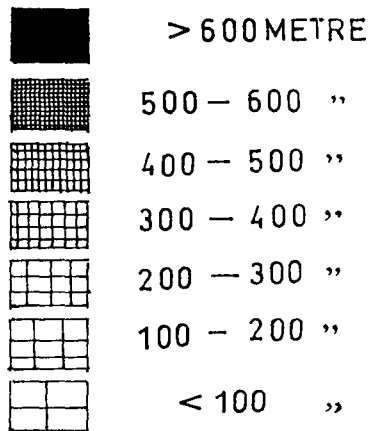
GANGTOK  
RELATIVE RELIEF

27°22'

27°17'  
N



RELATIVE RELIEF



88° 35' E

88° 39' 55" E

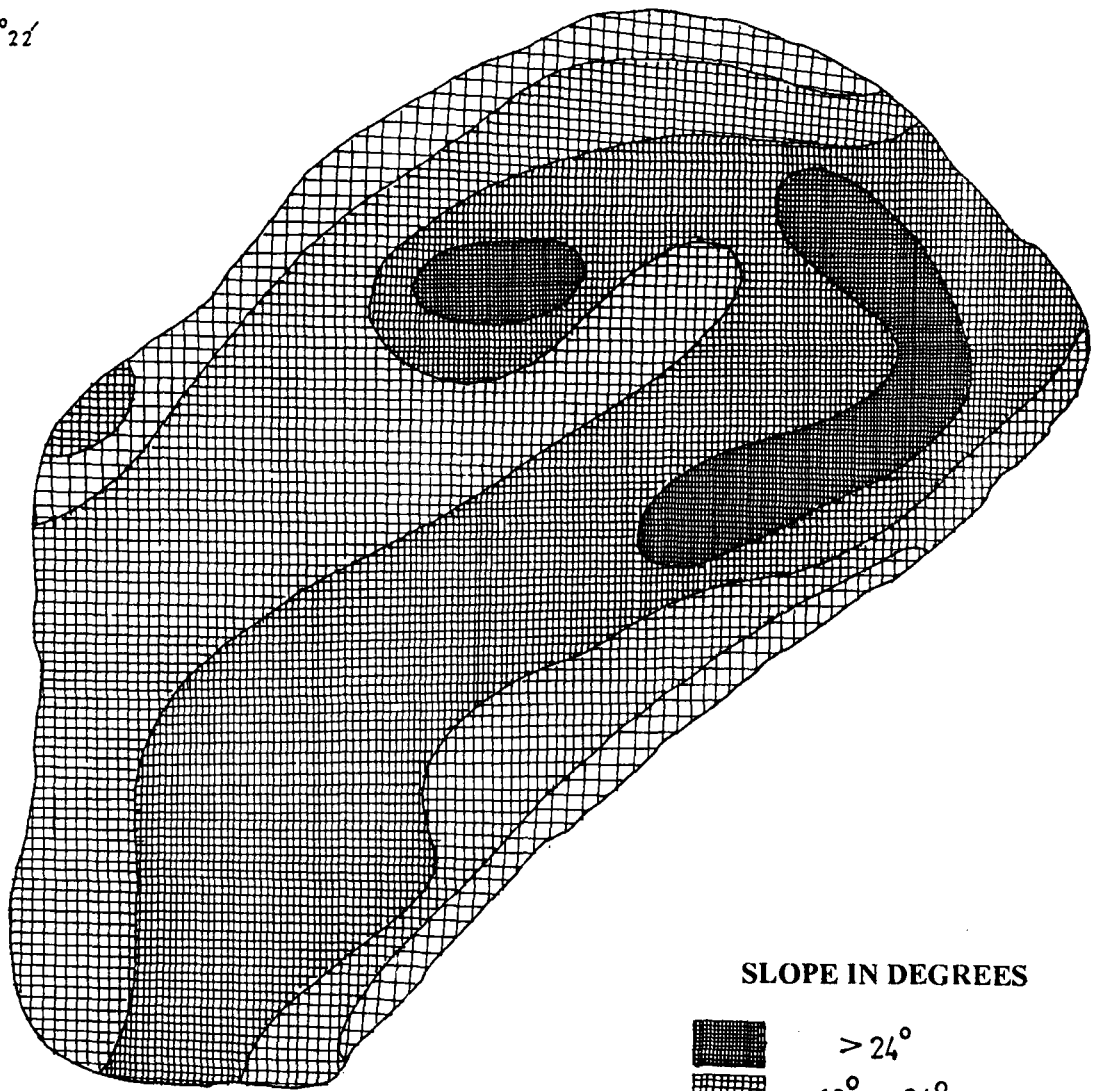
FIG.37

slope declines in three directions i.e. east, west and south. Whereas, towards the north steepness reaches to the highest summit of the area, known as Geneshtok (2500 m). Surprisingly, the western slopes of the spur have been chosen for the location of the settlement and most of the Gangtok is spread over this western slope. Broadly, this slope forms the eastern catchment of the Rani river. The geometric forms of the eastern and western slopes of Gangtok ridge are highly complex. The east facing slopes from 6<sup>th</sup> Mile to Bhusuk locality can be classified as Linear Convex (6<sup>th</sup> mile to Lower Syari); Collinear (Syari to Tathenchen), Linear Concave (Chandmari) and Linear Convex and Linear Concave (Bhusuk). Similarly western face of the slopes from 6<sup>th</sup> mile to Burtuk (Bojogari) can be classified as Concave Linear (6<sup>th</sup> mile to Amdo Golai); Collinear (Amdo Golai to Lower Sichey), Concave-Convex (Lower Sichey to Tashi Namgyal Senior Secondary School area), Linear Convex (Tashi Namgyal Senior Secondary School area to Lower Burtuk) and Linear Concave (Lower Burtuk to Bojogari). The amount of the slope in absolute terms varies from one slope aspect to another. Leaving sheer rock cliffs aside, the general slope in degrees vary from 20 to 40 degrees in case of the eastern slopes of Gangtok ridge, whereas the west facing slopes from 6<sup>th</sup> mile to Bojogari (Development area) are gentler. 'Certain stretches around Adampool, below Amdo Golai and Rani Khola areas of Sichey show slopes of 10<sup>0</sup> to 15<sup>0</sup> while in other areas it varies from 30<sup>0</sup> to 42<sup>0</sup>' (Tashi, 1993). The eastern slopes of the Gangtok ridge, from Syari to Tathenchen area, show a concave valley. In Tathenchen valley area, slopes are steep to very steep, i.e., 20<sup>0</sup> to 70<sup>0</sup>.

Average slope (Figure 3.8) of the study area clearly shows that the northeastern part, where steep slope is found near the higher part of the ridge, has more than 24<sup>0</sup> of

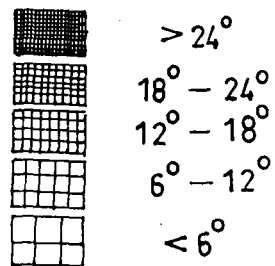
GANGTOK  
AVERAGE SLOPE

$27^{\circ} 22'$



$27^{\circ} 17'$   
N

SLOPE IN DEGREES



$88^{\circ} 35' E$

$88^{\circ} 39' 55''$

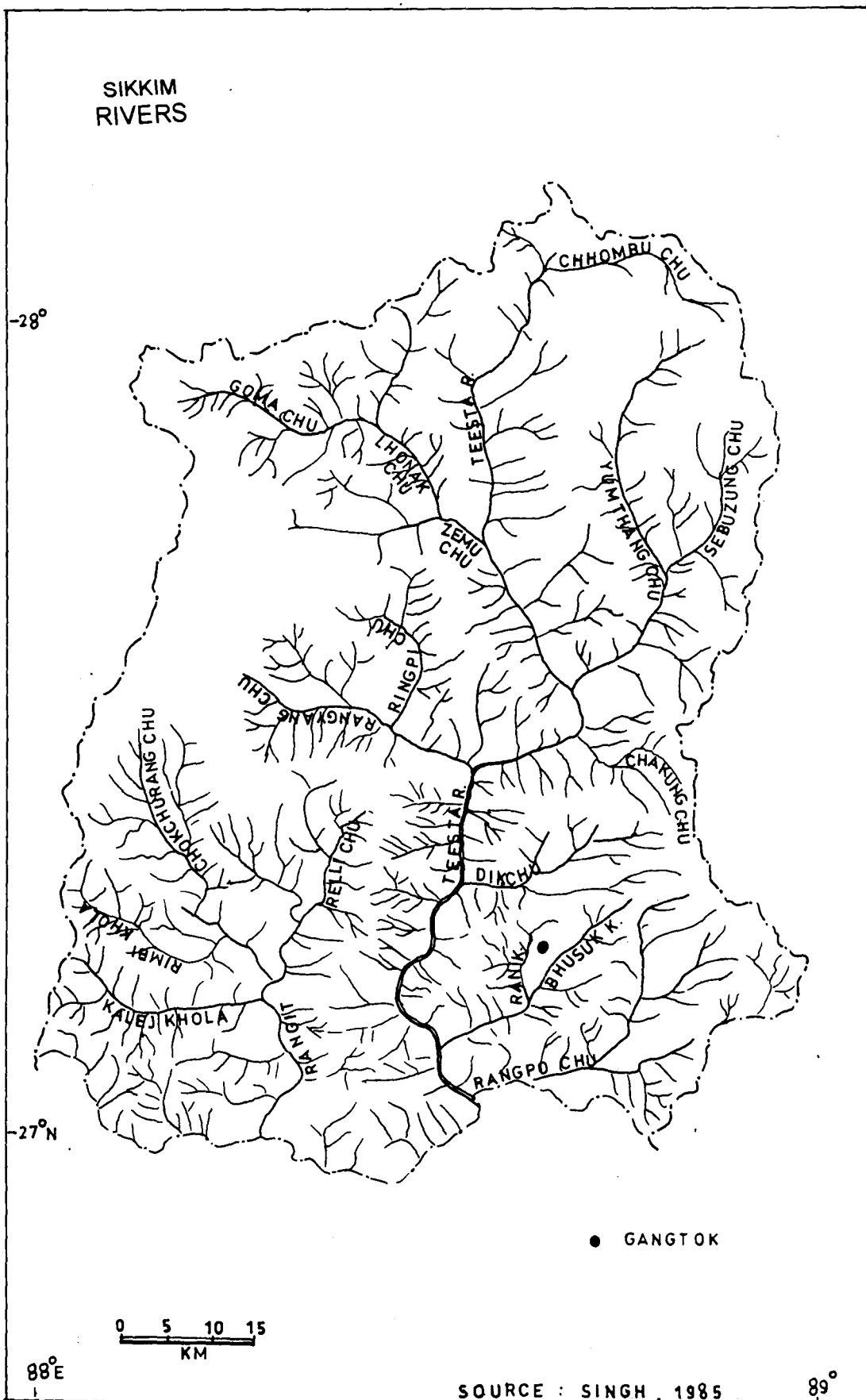
FIG. 38

slope. A small pocket of similar average slope lies in the north central part where an escarpment exits. Both the areas cover a very small area (3.2 sq km) of Gangtok. However, the maximum area of 16.60 sq km (40.68 per cent) falls under 18-24 degrees of slope. Interestingly, the settlement is spread over this category of average slope. Next to it is 16.30 sq km area (39.94 per cent) coming under 12 – 18 degrees.

#### **3.1.4. Drainage**

Sikkim Himalaya forms the upper basin of the Teesta River and numerous tributaries that dominate physiography of the area. The Teesta River flows in almost north-south direction almost in the central part of Sikkim Himalaya (Fig. 3.9, and Table 3.2). The Rangit River is a major right bank tributary of the Teesta River, which comes from the Southwest and joins the Teesta near Melli. Rangit rises from Talung Glacier on the southeastern slopes of the Kanchendzonga massif. The upper catchment of this river has been carved by the action of glaciers. The middle and the lower course of this river flow along valleys carved by the action of running water (Negi, 1991). The Rangit River has a total length of nearly 200 km, out of which 30 km in the North and 170 km in the South District. This river in the higher reaches flows through gorges until it joins the Rothang Chu, which originates from the Tothang glacier. After joining Ramam Chhu and Little Rangit near Naya Bazaar, the Rangit debouches into plains and widens out until it meets the Teesta River.

SIKKIM RIVERS



● GANGTOK

0 5 10 15  
KM

SOURCE : SINGH , 1985

FIG.39

**Table 3.2. Major rivers and their tributaries in Sikkim**

Sl. No.	Rivers	Tributaries
1.	Teesta	Dickhu, Rongyong, Bakchachu, Rongpochu, Zemu Chu, Lachung Chu, Lenak Chu, Lachen Chu, Talung Chu.
2.	Rangit	Rangbhang, Relli, Rathong, Kalej.

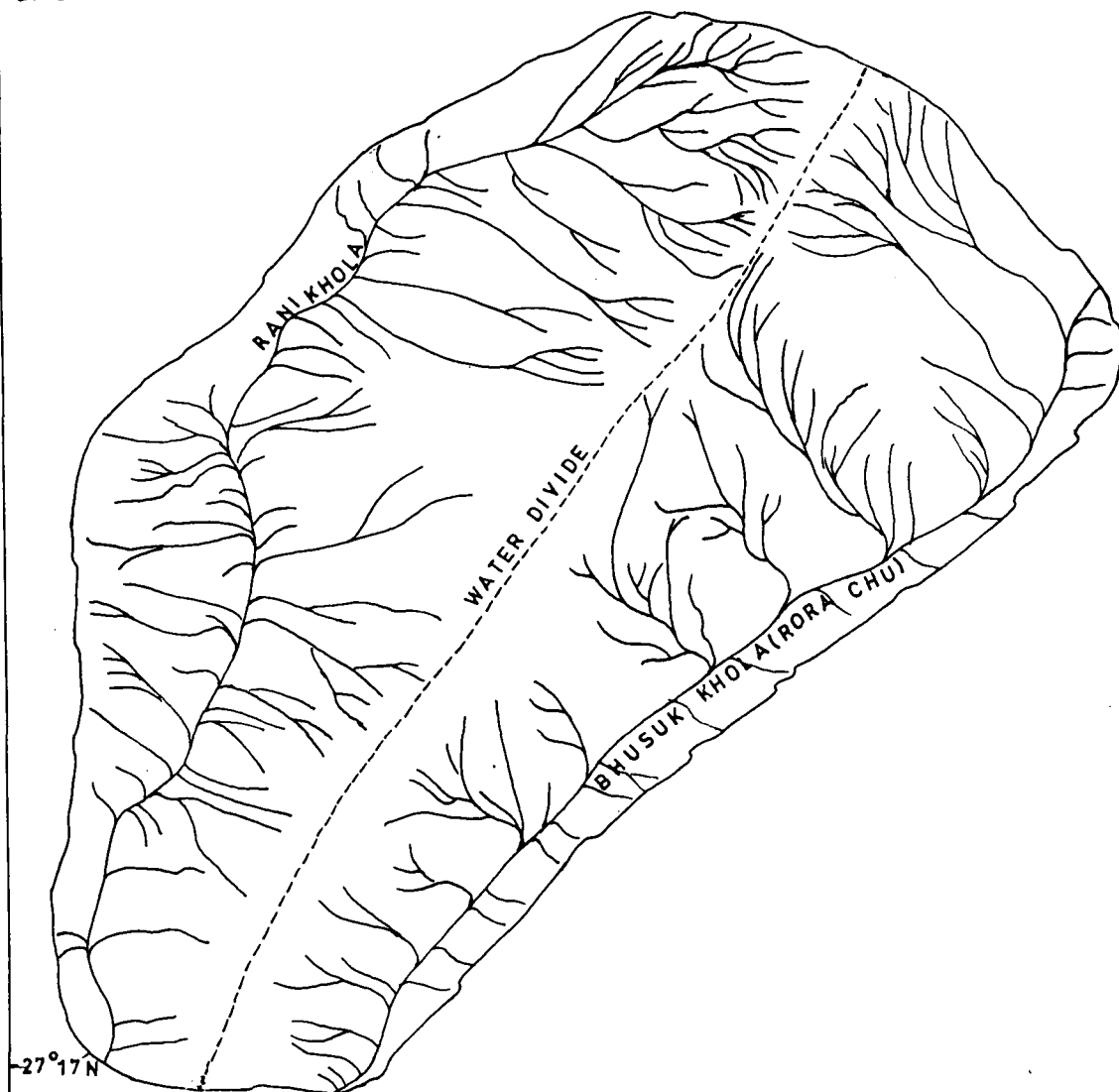
Source: Sikkim: A Statistical Profile, 2002, GOS.

The Gangtok ridge on which the study area spread is a water divide between two small rivers i.e., the Rani Khola and Bhusuk Khola (Fig. 3.10). The Rani Khola is flowing in the western side of the Gangtok, whereas Bhusuk Khola flows in eastern side from north to south direction. The Rani Khola and Bhusuk Khola meet each other at Setipool (near Ranipool), i.e., about 12 km from Gangtok, and one km from Ranipool. The Rani Khola originates from the Gangtok Reserve Forest at an elevation of about 2400 m. While the Bhusuk Khola rises from the Shotak Reserve Forest at an elevation of 2800 m. Indeed, Gangtok ridge acts as water divide between these two rivers. That is why the western and eastern slopes of the Gangtok ridge contribute rainwater to the Rani Khola and Bhusuk Khola, respectively.

Analysis of hydrological parameters over space and time in a drainage system (small or big) reveals the nature of geoenvironment and their impact on fluvial geomorphology. Such an analysis helps immensely in evaluating number of landform characteristics and making decision on the future pattern of natural and economic development of a region concerned (Gogoi, 2002). For the proper understanding of

GANGTOK  
DRAINAGE

27°22'



27°17'N



88°35'E

SOURCE : 78<sup>A</sup>/11

FIG. 310

geoenvironment of Gangtok it is very important to understand the different aspects of morphometry and discharge of rivers of the study area. Therefore, drainage density, drainage frequency and discharge have been discussed here.

**3.1.4.1. Drainage Density:** Indeed, Drainage Density (Dd) of a stream network has long been recognized as topographic characteristics of fundamental significance. This could be the fact that drainage density is a sensitive parameter which in many ways shows relationship between the form of basin and the processes operating along the stream courses. The density of stream network reflects topographic, lithological, soil and the vegetation control. The measurement of river density depends on the total length of the rivers per unit area. Horton (1932) first defined density of drainage network in 1932. According to Horton (1945) drainage density is length of streams per unit area of the catchment and is expressed as:

$$Dd = dL/A$$

Where,

Dd= drainage density

dL= the total length of streams and

A= the Area

The drainage density is determined by rainfall, topography, infiltration capacity of terrain, and initial resistivity of the terrain to erosion (Horton, 1945). Drainage density is also rarely correlated with average slope of the basin. The rock characteristics and the

influence of vegetation cover may also influence the drainage density. Coarse grained hard rock may give a drainage density of <5 whereas shale forming badlands may give values ranging from 50-1300. Maximum drainage density more than 6 km/sq km in the Rani Khola found in the northeastern corner, while in the Bhusuk Khola it is found in two small pockets (Fig. 3.11 and 3.12). Rani Khola basin covers an area of 22.61 sq km and the Bhusuk Khola has 18.2 sq km.

#### **3.1.4.2. Drainage frequency: According to Horton (1945) Drainage Frequency**

(Df) is the total number of streams per unit area and is mainly dependent on stream order.

Drainage frequency can be expressed as:

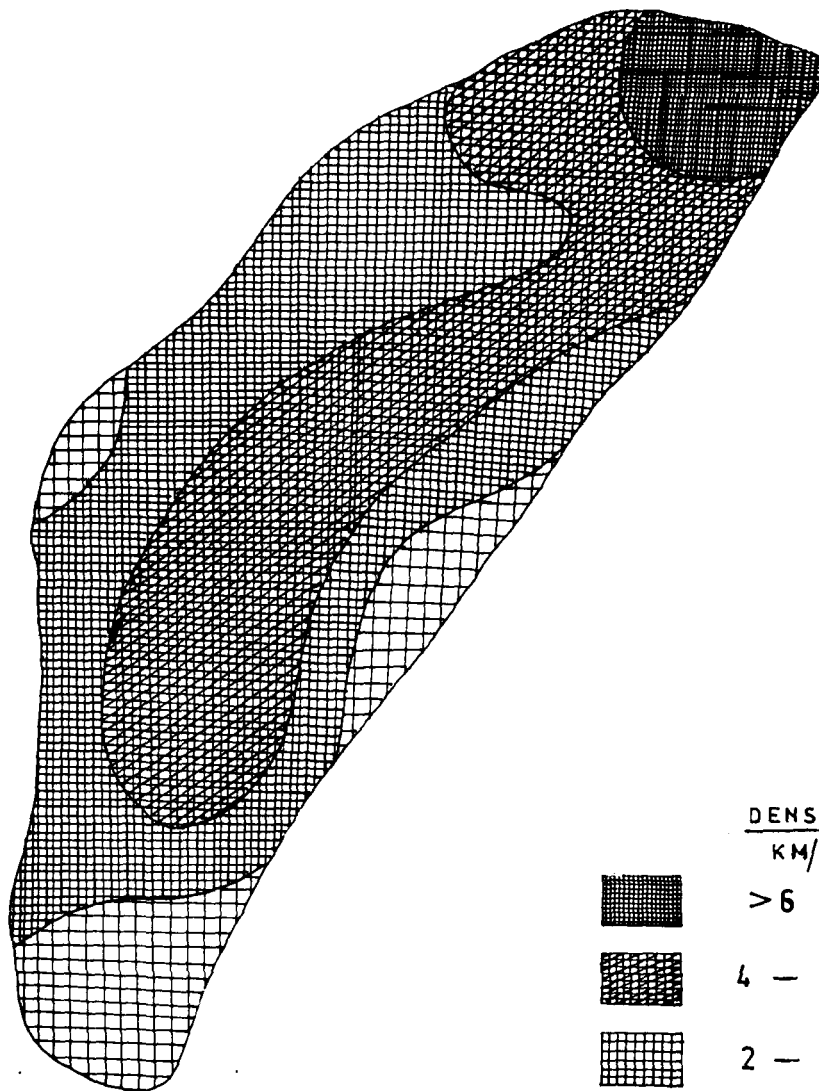
$$DF = \Sigma N/A$$

Where, DF = Drainage or Stream Frequency

N = Number of Stream , A = Area

Maximum drainage frequency of more than 15 numbers of streams per sq km in the Rani Khola basin is again in the northeast corner and also in the central western part, while in the Bhusuk Khola it is found only in the northwestern corner (Fig. 3.13 and 3.14). Both the corners belong to the higher steep slopes of the Ganeshtok area. In both cases i.e., Drainage Density and Drainage Frequency, the Rani Khola reveals slightly higher value as compared to the Bhusuk Khola. Generally speaking, the greater the drainage density and stream frequency the faster is the runoff. Therefore, flooding is more likely in basins with a high drainage density and stream frequency (Kale and Gupta, 2001). It has been observed that rock types, permeability of rocks, soils and vegetation are the most important controlling factors on the drainage density and frequency.

RANI KHOLA  
DRAINAGE DENSITY



DENSITY  
KM/KM<sup>2</sup>



> 6



4 - 6



2 - 4



< 2

0 1  
KM

FIG. 3.11

BHUSUK KHOLA  
DRAINAGE DENSITY

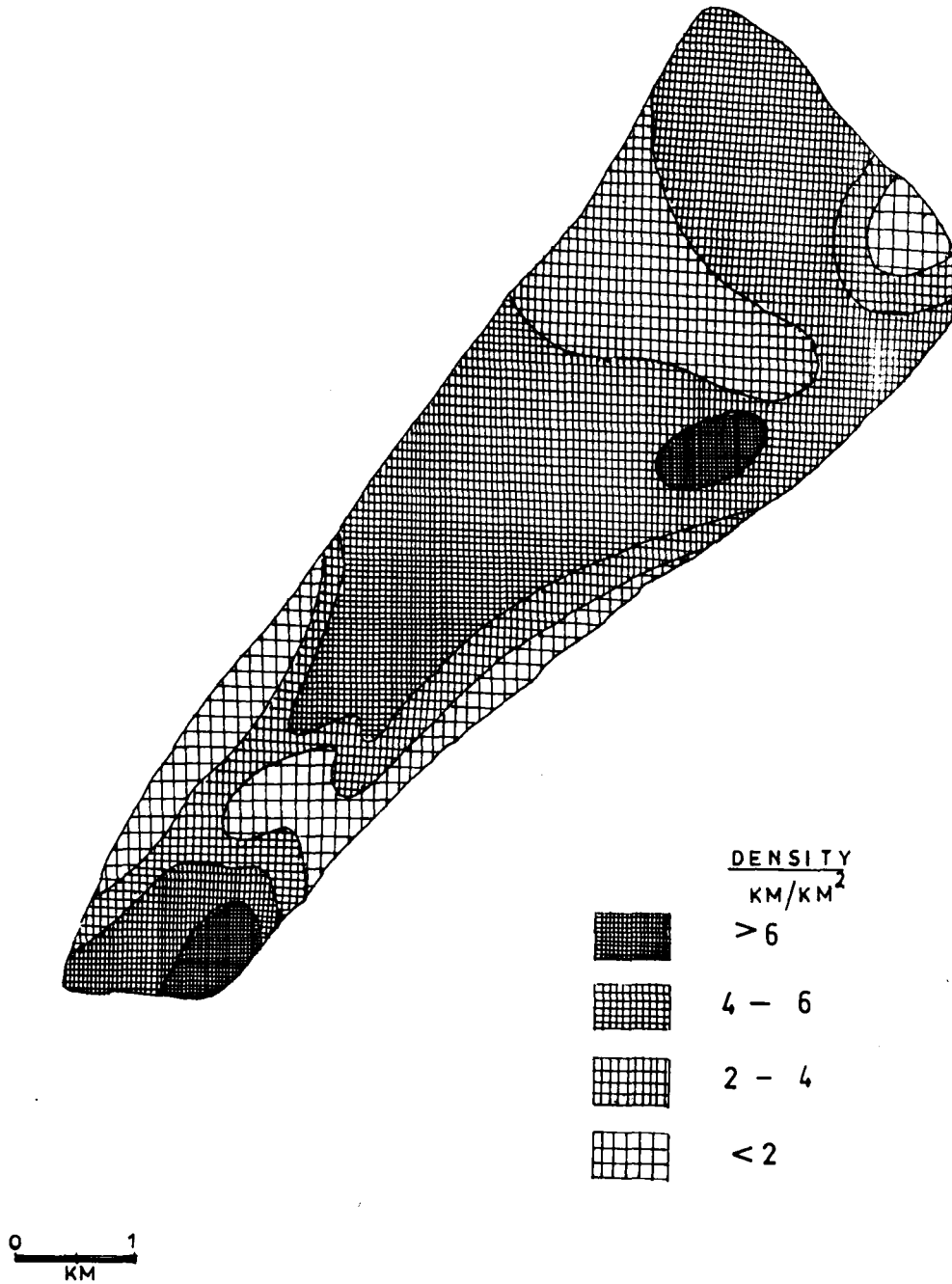


FIG. 3.12

RANI KHOLA  
DRAINAGE FREQUENCY

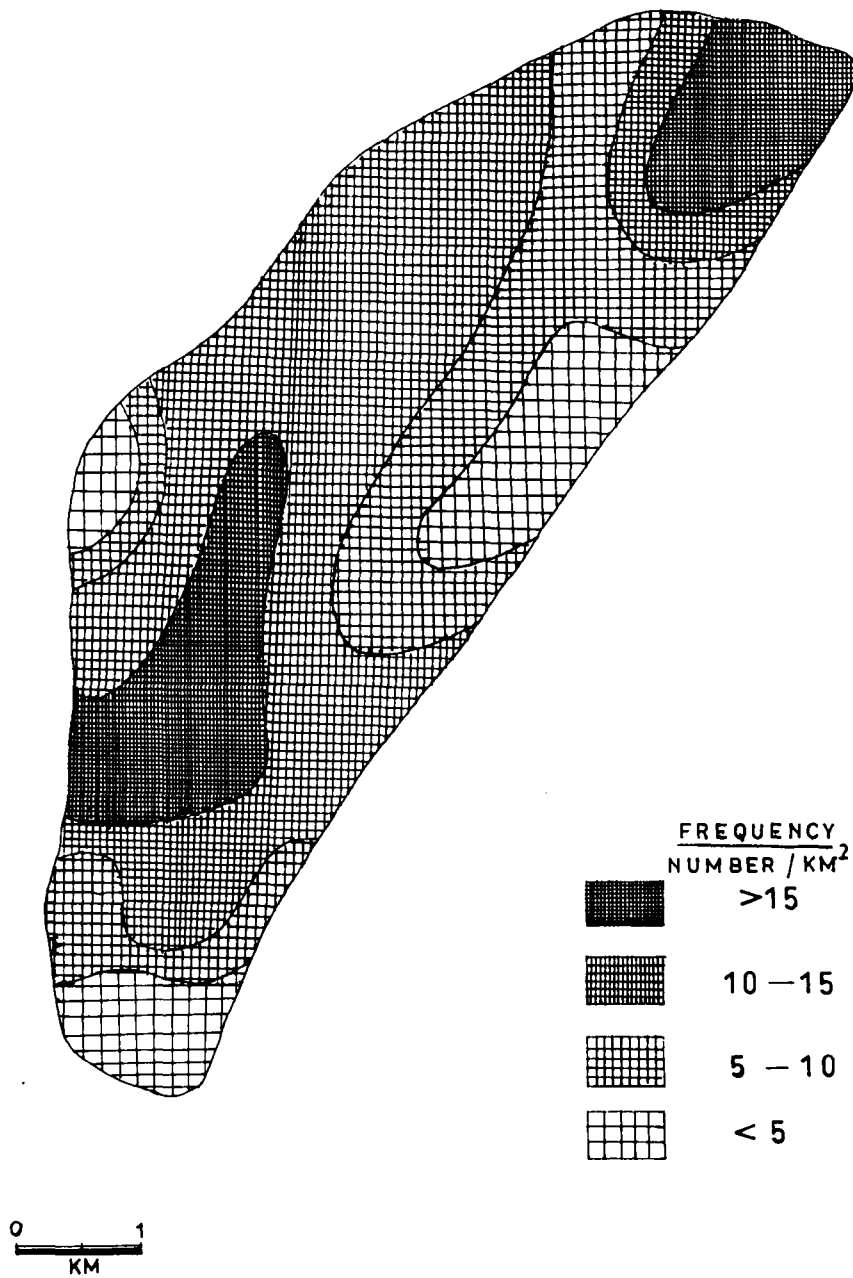
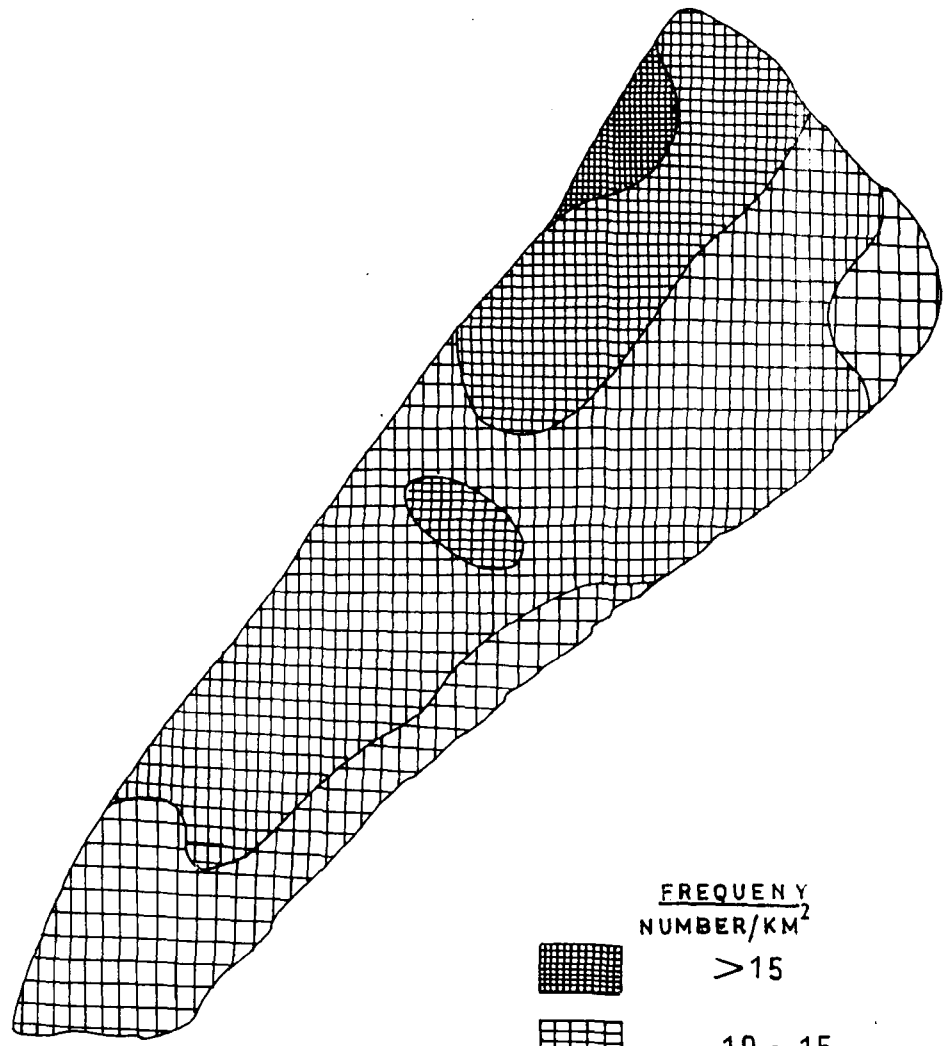






FIG. 3.13

BHUSUK KHOLA  
DRAINAGE FREQUENCY



FREQUENCY NUMBER/KM <sup>2</sup>	
	> 15
	10 - 15
	5 - 10
	< 5

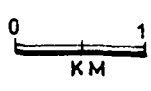


FIG.3.14

Some more aspects of morphometry of the Rani Khola and Bhusuk Khola are given in Table 3.3. It is clear from the table that both the rivers have almost similar basin shape, i.e., elongated (1.43 to 1.47). Hydraulic sinuosity is more in the Bhusuk Khola than Rani Khola, but the topographic and standard sinuosities are more in the latter. Comparatively straight course the former is quite evident from 0.88 standard sinuosity index.

**Table 3.3. Some morphometric aspects of the Rani and Bhusuk Khola**

River	Air length in Km. (AL)	Channel length in Km (CL)	Valley length in km (VL)	Channel index (CL/AL) (CI)	Valley index (VL/AL) (CI)	Hydraulic sinuosity index $\frac{CI-VI}{CI-I} \times 100$	Topographic sinuosity index $\frac{VI-I}{CI-I} \times 100$	Standard Sinuosity index CL/VL
Rani Khola	7.0	11.50	10.05	1.60	1.43	28%	72%	1.44
Bhusuk Khola	7.5	11.00	12.50	1.67	1.47	30%	70%	0.88

Source: Based on the Topographical data.

**3.1.4.3. Discharge:** The discharge in the river is the volume of water that flows through it in a given time. It is defined as the outflow of a canal or stream, where the river enters another stream or body of water. The volume of the discharge is generally determined by factors such as climate, vegetation, soil and slope. Discharge is usually measured in cubic meters per second, expressed as cumec, and is calculated in the cross-sectional area of the channel multiplied by the velocity of the flow of water. However, abiotic environmental factors such as depth and width of channel, velocity, duration, and oscillation of flux and characteristics influence the discharges which subsequently affect the physical environment (Pirazizy, 1992). The measurement of discharge is important for making accurate assessment of the available water resources for planning and

development. Further, discharge measurement gives accurate assessment of the available and the dependable natural water resources of the river basin. There are various methods of discharge measurement viz., area-velocity method, area-slope method, colour velocity method, salt velocity method, radiotracer method, hydraulic model etc. However, for the present work following area-velocity method has been adopted:

$$Q = AV$$

Where, A = Area (width x depth)

V = Velocity

**Table 3.4. Discharge in the Rani and Bhusuk Khola**

River	Catchment Area (Km <sup>2</sup> )	Average daily discharge (m <sup>3</sup> /s)	Daily maximum discharge (m <sup>3</sup> /s)	Daily minimum discharge (m <sup>3</sup> /s)
Rani Khola	22.61	57	83	31
Bhusuk Khola	18.2	36	49	23

Source: Field Work, 2004-05.

The mean daily discharge of Rani Khola is 57 cumec and of the Bhusuk Khola is 36 cumec (Table 3.4). Compared to it the Teesta has the average daily discharge of 850 cumec. All three forms of discharge are more in the Rani Khola basin compared to the Bhusuk Khola basin. This is because of large basin area and number of streams in the Rani Khola basin.

## **3.2 GEOLOGY**

Geologic characteristics of an area include discussion and analysis of lithology (rock types) and structure, including the seismic activity, and all have been discussed here. This is because types of rocks and structure of the rocks (joints, cracks, bedding planes, faults, thrusts, seismic activity etc.) create their own environment on one hand, while on the other they influence other components of geoenvironment and geohazards as well.

### **3.2.1. Lithology**

The Himalaya is one of the youngest mountain systems in the world. It is one of the most fascinating and unique landforms of the earth. Geologically it is a very complex mountain, and its origin is not yet clearly understood. The major geological formations belong to Pre-Cambrian to Tertiary age. Based on geological characteristics, the Himalaya may be broadly divided from south to north into: the Siwaliks, Lesser Himalaya, Central Crystalline, and Tethyan Himalaya (Krishnan, 1960). Whereas Wadia (1960) has divided the Himalaya into three broad physiographic zones: i) Higher Himalayan Zone, ii) Lower Himalayan Zone, and iii) Outer or Sub-Himalayan Zone. These zones are separated by major faults or thrusts making each different morpho-tectonic unit. Recent years have witnessed numbers of voluminous publications on different aspects of Himalaya by Valdiya (1973), Pande (1975), and many others, who attempted to describe each structural zone individually. From west to east the Himalaya Mountain is divided into three main zones, viz., the Western Himalaya, (including the Kashmir Himalaya, Himachal Himalaya, and Garhwal Himalaya), the Central Himalaya (comprising of the Nepal Himalaya), and the Eastern Himalaya (including the Sikkim-

Darjeeling Himalaya, Bhutan Himalaya and Arunachal Himalaya). Sikkim lies in the western most part of the Eastern Himalaya.

As Sikkim form part of the Eastern Himalaya it possesses almost all geological and geomorphologic characteristics of the Himalaya Mountain. Stratigraphically it extends over the Lesser Himalaya and the Greater Himalaya Ranges. Geological studies of this part of the Himalaya started with the publication of the first account on *Geological and Mineral Resources of Darjeeling District* by Bose (1979) and others. In the following years, important contributions were made by Auden (1925), Heim and Gansser (1939), Ray (1947), Ghosh (1952), Raina and Bhattacharya (1975), Roy (1976), Acharya and Roy (1977), Acharya (1978), Das *et al.*, (1993), Bhargava, (1995), Thakur (1986), Neogi *et al.*, (1989), Singanenjan (1999), Ravikant (1993), Tashi (1993), Singh *et al.*, (2000), and many others.

For the appraisal of geoenvironment of an area, it is important to understand first the geology of the region, which directly helps to assess and manage the geohazards of the particular area. In the northern part of the state, the rocks have been tectono-stratigraphically differentiated in three belts viz. Inner Belt, Axial belt, and Trans-Axial belt (GSI, 2001). The higher region to the north and beyond forms the trans-axial belt. Sikkim is mostly covered by Proterozoic- Precambrian metamorphites of low to medium grade (Daling group), high-grade gneiss (Darjeeling gneiss and Kanchendzonga gneiss), Chungthang Formation (quartzite, calc-silicate rocks, graphite schist, marbles and amphibolites) intrusive granites (Lingtse, granite gneiss) and phanerozoic rocks including Gondwana and Tethyan rocks. The Daling-Darjeeling-Buxa nomenclature was originally

described in 1875 from the areas in Darjeeling foothills. The regional geological setup of the Sikkim Himalaya is best displayed in the Teesta Gorge. The axial zone of North Sikkim Himalaya exposes the central crystalline represented by a high meta-sediments. This high grade crystalline rocks are separated from the Daling and Darjeeling group by a prominent dislocation zone i.e., The Main Central Thrust (MCT), which is a very important tectonic feature occurring all along the Himalaya Mountain. The Main Central Thrust (MCT) passes about 5 km northeast of Gangtok and crosses the Teesta River near Manul. On the other hand, the Main Boundary Fault (MBF), another dislocation zone, is found in the south, which crosses the Teesta near Kalijhora. The fossiliferous Palaeozoic and Mesozoic sequence occupy the northern part of the area. The Tethyan sedimentary rocks (Mesozoic) are also exposed in the northern part, and are represented by Everest phyllite series. Further, Daling series is found in the central part which can be classified into three formations: i) Gorubathan Formation ii) Reyan Formation, and iii) Buxa Formation. Again, an important feature of the Sikkim Himalaya is the lateral arc of thrust surface, known as Teesta culmination across the Teesta River (GSI, 2001). In brief, Sikkim Himalaya is characterized by the harder rocks of granite, gneiss, dolomite, sandstone, quartzite etc. occupying the hill tops and high slope ranges, while the softer slate, phyllites, schists etc. occur in the valley and lower slopes of hills. Since, pure quartzite is rare in the state; it really means phyllitic quartzite here. Besides, a number of economic minerals like copper, iron, pyrites, granites, limestone, coal, graphite, talc etc. are found here.

Geologically, the East District of Sikkim falls in the southern part of the Lesser Himalaya. The geological setup and stratigraphic units of the district are very complex owing to tectonic attributes, polycyclic deformation, and events of multiphase

metamorphism. 'Deposition of geological formation in the reverse tectonic order from south to north, that is the rocks of higher grade occupying higher structural levels and lower grade rocks at the bottom, commonly referred to as inverted metamorphic sequence, forms a remarkable feature of the area' (GSI, 2001). The repetition of stratigraphic units due to thrusting is the special features of the East District. Table 3.5 and Figure 3.15 show the Tectono-stratigraphic succession of the rock types of the area.

The study area- Gangtok is situated in the crucial geological domain. This is because the Main Central Thrust (MCT) passes through the northeastern part of Gangtok, separating Darjeeling gneiss from mica schist where palace is located. The rocks of Darjeeling Gneiss Group are also exposed at the higher levels around Ranipool, Rongli, Gangtok and further eastwards. The lithology of the study area comprises of three main types of rocks: i) Schist, phyllite and banded gneiss, ii) Quartzites, and iii) granite-gneiss (Fig. 3.16). It has been observed that the Lower Schists are again exposed on the Institute of Tibetology ridge and in the Syari valley. The variants of schist like- garnetiferous muscovite schist, staurolite bearing garnetiferous muscovite schist and quartz biotite schists are found in upper Syari valley (Singanensjam, 1999). A thin band of grey quartzite is also seen in the Tibetology ridge. On the other hand, Lingtse gneiss i.e., Phyllonites are exposed along the Indira By-Pass. Generally, the phyllites are uniformly fine-grained, grey to slightly greenish with quartzite bands. Besides, along the Gangtok ridge axis (which runs NNE-SSW direction) the Lingtse gneiss is exposed in Amdo Golai to the Secretariat Building (Tashilling) and also towards the south east of it.

**Table 3.5. Tectono- stratigraphic succession of rocks of East District, Sikkim**

<b>NORTH</b>			
<b>GROUP</b>	<b>FORMATION/SUBGROUP</b>	<b>LITHOLOGY</b>	<b>AGE</b>
Darjeeling-Sikkim	High grade gneiss of central crystalline	High grade gneiss and Augen gneiss	Achaean to Proterozoic
	Chungthang Sub group	Cal-silicate, marble and quartzite with amphibolites, high grade schist and inter-banded gneiss.	
<b>THRUST</b>			
Daling	Lingtse Gneiss	Granite gneiss with biotite rich layers and basic intrusive	Precambrian to middle Palaeozoic
	Main Central Thrust (MCT) OR Central Crystalline Thrust (CCT)		
	Reyang	Variegated phyllite with thin band of carbonated and calcareous quartzite	
	Gorubathan	Metawacke, Sericite-chlorite phyllite/ Schist inter-banded with quartzite	
<b>THRUST</b>			
Gondwana Group	Dumka (Damuda)	Sandstone and shale with carbonaceous matter	Permian
	Rangit Pebble State	Pebble/Phyllite	Upper carboniferous to Permian
<b>SOUTH</b>			

Source: Anonymous, 2001.

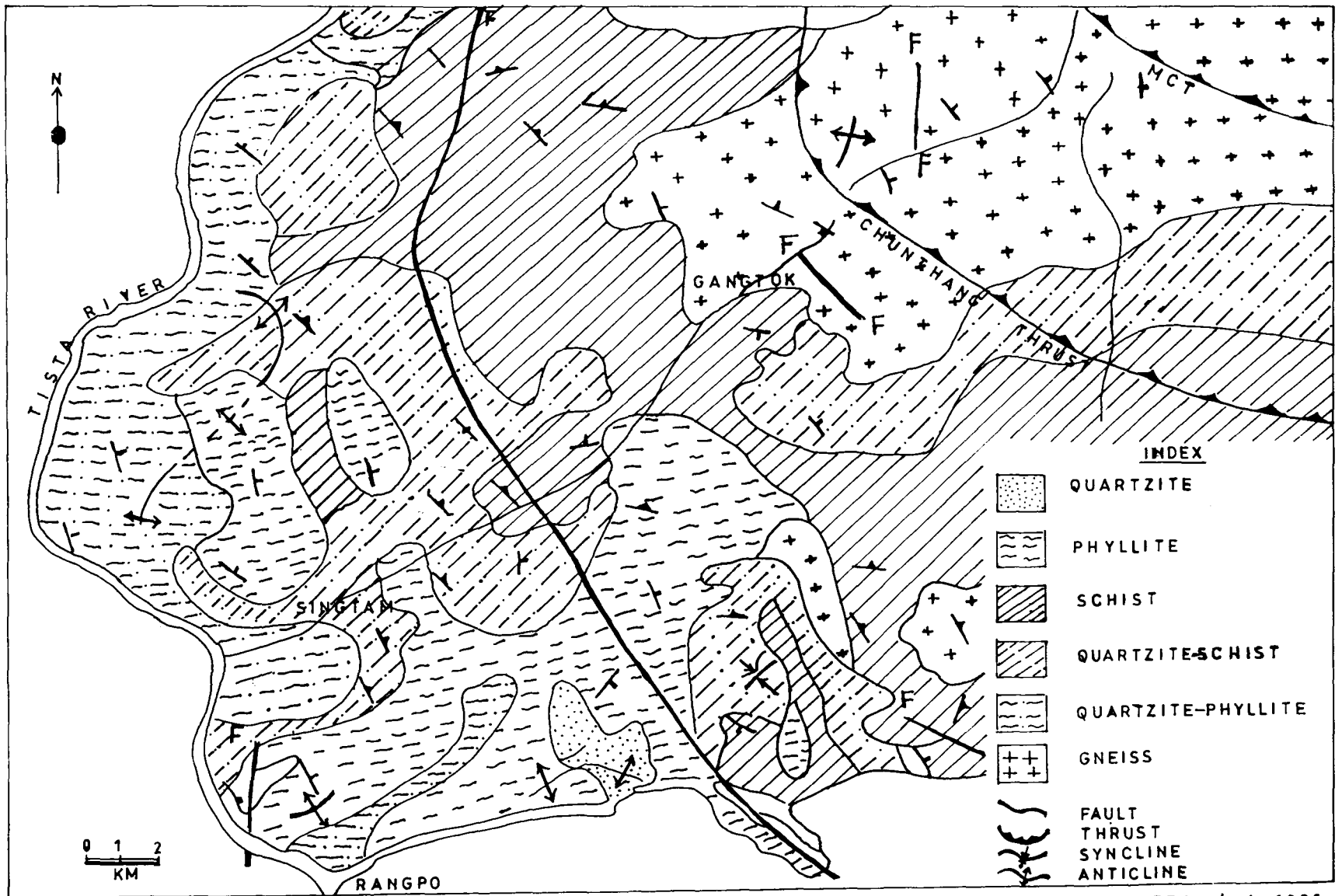


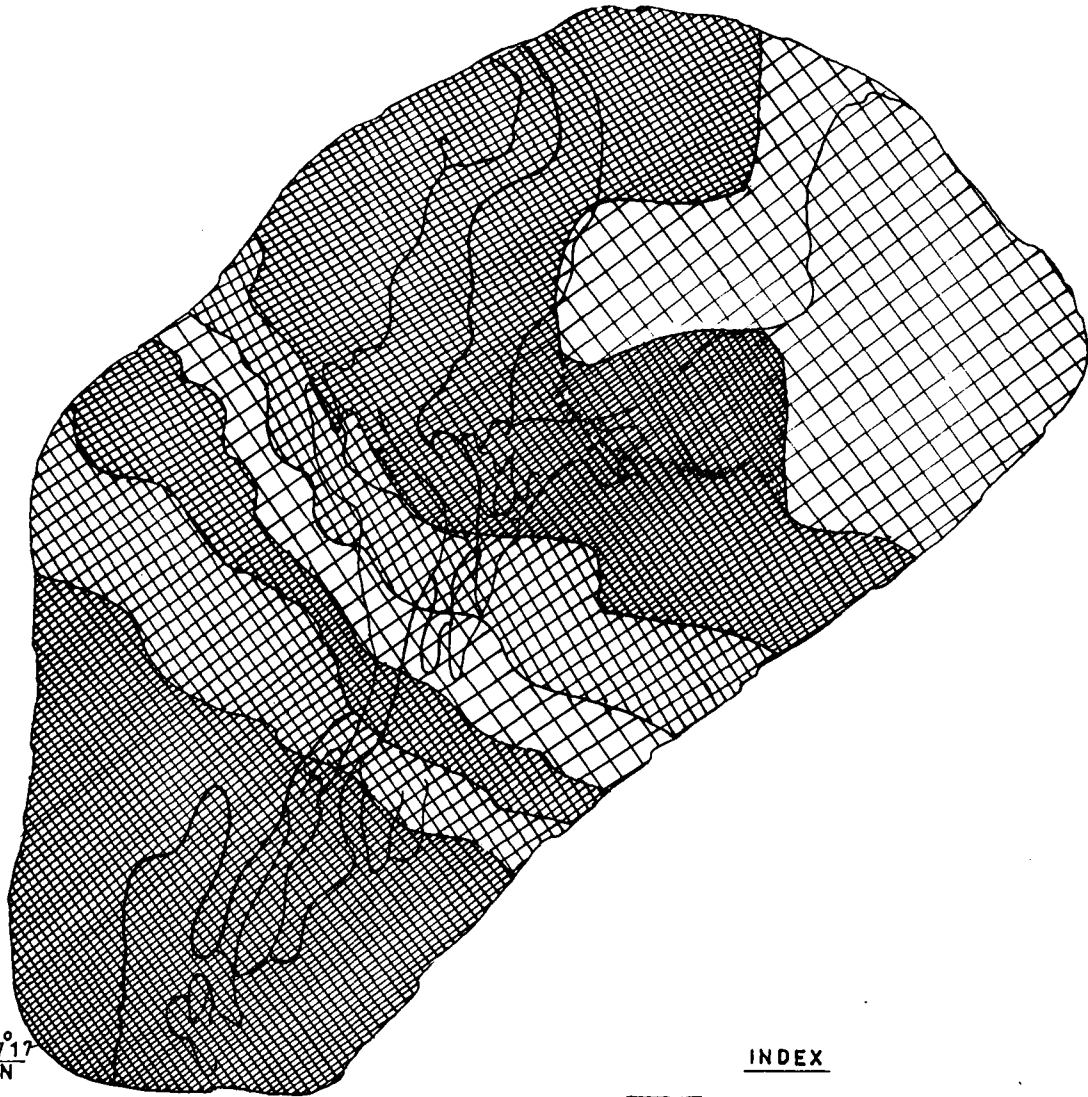
FIG.3.15 GEOLOGICAL MAP OF EAST DISTRICT, SIKKIM

SOURCE : MEHROTRA et al.,1996




GANGTOK  
LITHOLOGY

27°22'

27°17'  
N



INDEX

-  SCHIST, PHYLLITES  
BENDED GNEISS
-  QUARTZITES
-  GRANITE GNEISS



88°35'E

88°39'55"

FIG.3.16 SOURCE : FIELDWORK , 2004-05 AND  
DIFFERENT LITERATURE

The upper schist zone of the study area overlies the Lingtse gneiss and underlies the Darjeeling gneiss that defines the Main Central Thrust (MCT), separating the Central Gneissic Complex (CGC) and Daling Schists. The upper schists is exposed all along the Tathenchon area and also between the Secretariat building and Zero Point. The high grade, quartz-felspar-sillimanite and Kyanite, i.e., garnetiferous muscovite schists, quartz biotite schists etc. are exposed towards the Secretariat building. Near the Chandmari area typical development of phyllonite has been seen. In fact, lower and upper schist zone of Gangtok is a part of Gurubathan Formation of Daling Group of rocks. Darjeeling Gneiss, the fourth litho unit of the study area, overlies the Daling group of rocks, which is exposed near the Ganeshtok, Raj Bhawan, the T.V Tower, VIP Colony and the Chandmari.

The phyllites are found near 6<sup>th</sup> Mile, Sumdur and Lower Tadong area, but major portion of the study area is occupied by high grade polytic rocks i.e. mica schists with or without garnet, staurolite, sillimanite, kyanite etc. Tashi (1993) reported that there are some minor occurrences of other lithounits besides the above mentioned. To him, quartz veins and lenses are ubiquitous in phyllite, mica schists and gneiss, and within the gneissic terrain there are occasional bands less than one metre in width and extending for 10-15 metres in length of amphibolite (very rich in hornblende), almost monomineralic biotite, thick bands of calc-silicate quartzite and pegmatities.

### **3.2.2. Structure, Seismicity, and Tectonics**

Different views have been expressed about geological structure of Sikkim. It has been considered as a 'domal cross feature' by Gansser (1964), or a 'wedge' by Windley

(1983) . Generally, the tectonic trend and strike of the major thrust planes is nearly east west trending in the Eastern Himalaya. Whereas, the dip is towards north. “Near Gangtok, there is a sudden swing of the strike, which has been demarcated by structural analysis and the NNW trending belt constitutes a dextral shear zone. This zone apparently extends northward beyond Dikchu and southward beyond Rangpo. The NNW-SSE dextral shear is synchronous and genetically related to E-W thrust planes of the Himalayan orogeny. The general tectonic picture reveals the complexity of the regional geological setup” (Rawat, 2005: 310).

In the Sikkim Himalaya, the MCT separates the Darjeeling group of rocks in the south from Chungthang formation and Kanchendzonga gneisses in the north. The MCT and MBF are the two major structural discontinuities that could be considered as the potential source of earthquake activity in the study area. Interesting to note that a SSE-NNW trending lineament passes across Gangtok, increasing chance of tectonic activity in the area. In fact, the areas where the transverse or oblique faults intersect the MBF of MCT are in general, the areas of high seismicity. Some earthquakes located close to the MCT in the Northern Sikkim have shown left-lateral shear solutions on the NE-SW oriented faults that lie in the line of the Yadong-Gulu graben characterized by many N-S and NE-SW striking fault-scarps of Quaternary age. Earthquake activity during the period 1964-1992 suggests that the regional seismicity of Sikkim Himalaya is relatively high to the North of The Main Boundary Thrust (MBT). Activity decreases progressively southward from the Lesser Himalaya to the fore deep region (Nath, *et al.*, 2000).

Sikkim lies in the mobile belt of India which is seismically very active. As it is part of the Himalaya Mountain and lying in close proximity to the Northeast India, it has experienced a number of earthquakes. The earthquake is one the most devastating geohazards and it is discussed here as a part of geoenvironment that happens to trigger huge landslides common in the study area.

It is worth mentioning that medium to big range earthquakes have killed and damaged hundreds and thousands of lives and property over the last 25 years. About one billion people were added to cities of developing countries, a disproportionate number of which are earthquake-prone. Over the next 25 years, 2 billion people will be added to those cities. At the same time, the earthquake-resistance of these cities has been decreasing (Tucker, 2004). Earthquakes are one of the worst among the natural disasters. About one lakh earthquakes of magnitude more than three hit the earth every year. Although, many parts of the Indian subcontinent are susceptible to different types of hazards, nearly 54 per cent of its landmass is vulnerable to earthquakes following. Table 3.6 and Figure 3.17 reveal the major earthquakes in different parts of Indian since 1800.

A close examination of the Table 3.6 and Figure 3.17 clearly show that in the past two hundred years, earthquake activity has been more severe in the Hindu Kush-Himalaya region and its vicinity, affecting Kashmir, the area around the Kangra Valley, and the tri-junction of India, Nepal and Tibet, the east Nepal-Bihar border and the whole of northeast India. Although faults exist all along the Himalaya, they are not equally active (Lall *et al.*, 1981).

Table 3.6 Major earthquakes in India since 1800

Date	Place/Area	Magnitude on Richter Scale	Effect
01-09-1803	Mathura	6.5	Shock was felt upto Kolkata.
16-06-1819	Kuchchh	8.0	Chief towns of Tera, Kathara and Mothala razed to the ground over 2,000 people died in Bhuj alone
16-06-1828	Near Srinagar	6.0	Kashmir valley affected and more than 1000 persons were killed.
1848	Mount Abu	6.0	Few People Killed
10-01-1869	Cachar, Assam	7.5	Felt over an area of 6,40,000 sq km. Heavy damage to Silchar, Sylhet, Cherrapunji, Shillong, Manipur and some other towns.
30-05-1885	Srinagar	7.0	Quake felt upto Shimla, Lahore and Peshawar, nearly 3,500 persons lost their lives large features opened upto the ground
12-06-1885	Shillong	8.7	Widespread destruction in Shillong and Parts of Assam and Sylhet of Bangladesh.
14-07-1885	Bengal	8.5	The epicentre of the quake was 40 km North of Dhaka. Felt over an area of 6 lakh sq km over Bangladesh, Bihar, Bhutan, Sikkim, Bengal, Manipur and parts of Myanmar.
12-06-1897	Assam	8.7	Lost of large number of lives and property™, especially Guwahati and Shillong death toll upto 1500 in this quake. Tremors were felt over an area of 4.5 million sq. km in India and neighbouring countries. It was one of the biggest earthquakes ever hit the earth.
04-04-1905	Kangra Himachal Pradesh		About 20,000 people died. Serious damages were seen in Dehradun, Mussoorie, Chamba and other neighbouring areas cause severe distributaries to streams and springs
08-07-1918	Srimangal, Eastern Border of Bangladesh	7.6	Heavy damage to large areas of Bangladesh, Assam and Myanmar.
02-07-1930	Dhuburi (Assam)	7.1	Affected areas were Dhuburi, Cooch Bihar, Lakhimpur and Rangpar, Railways culvert and bridges were damaged.
15-01-1934	Bihar-Nepal Border	8.4	Affected large parts of Motihari, Darbanga, Patna and Kathmandu. About 10,000 people died. Shocks were felt over an area of 5 million sq km.
1941	Andaman	8.1	Heavy Damages
26-01-1950	Near Andaman	8.1	Large area rocked. High waves in the sea.
15-08-1950	Assam	8.7	More than 1500 people died. Landslide blocked Subansiri river for a number of days. Shocks were felt over an area of 4.5 million sq km mostly Assam and Arunachal Pradesh were affected
21-07-1956	Anjar, (Kuchchh Peninsular)	7.0	About 100 people died. Heavy damage to buildings was caused.

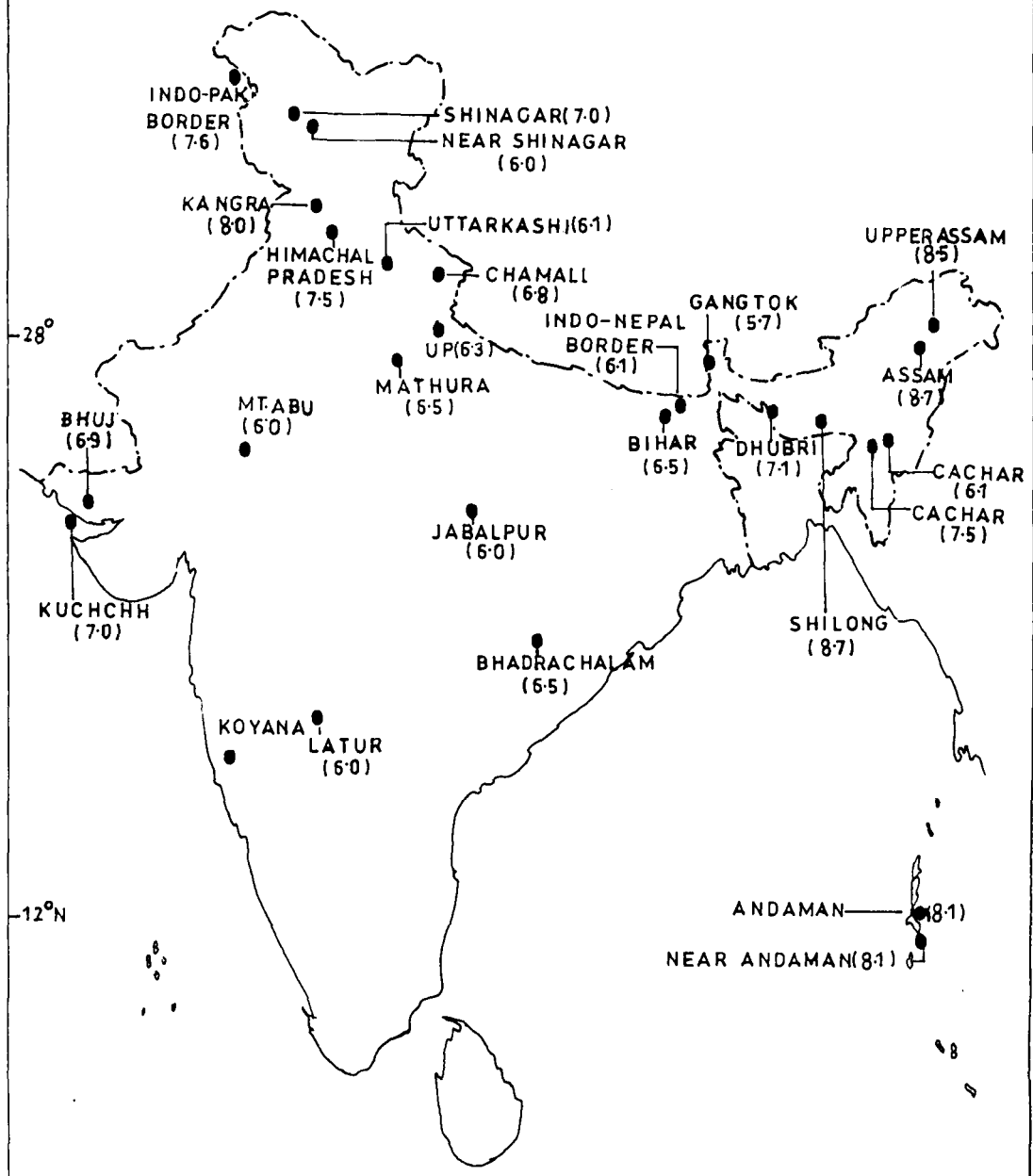
1958	U.P	6.3	Lost of life and property.
27-06-1966	India-Nepal Border	6.1	Indo-Nepal Border were rocked
11-12-1967	Koyna, Maharashtra	6.3	About 200 persons lost their lives. Shock felt over a distance of 700 km.
13-04-1962	Bhadrachalam, (Andhra Pradesh)	6.5	Shock felt part of Andhra Pradesh and Tamil Nadu.
19-01.1975	Himachal Pradesh	7.5	Rocked parts of Kinnaur and Lahul-spiti
31-12-1984	Cachar	6.1	3000 dwellings destroyed in an area of 200 sq km around Sonai
1986	Dharmasala	5.7	Lost of life and property
21-08-1988	Bihar	6.5	900 people killed in Bihar and Nepal.
20-10-1991	Uttarakashi	6.1	Affected large parts of Almora, Chamoli, Uttarakashi, Nainital, Dehradun, and Uttar Pradesh.
30-09-1993	Latur, (Maharashtra)	6.0	Large area of Maharashtra rocked more than 10,000 people lost their lives. Severe damaged to property, lakhs rendered homeless.
29-03-1999	Nandprayag (U.P)	6.8	Affected large parts of Uttar Pradesh, Himachal Pradesh, Punjab, Haryana and Delhi, parts of China and Nepal were also affected.
11-11-1999	Hindukush	6.2	No death reported
26-01-2001	Bhuj (Gujarat)	6.9	More than More than 19,000 people were lost their lives. Severe damaged to property Lakhs rendered homeless.
2005	India Pakistan Border	7.6	More than 10,000 people lost their lives, heavy damage of property.
24-02-2006	Gangtok	5.7	Two people killed and damage of property.

Source: Based on Different Literature.

In fact, this region has been experiencing many earthquakes since time immemorial. Some important earthquakes had hit the northeastern region in the medieval period (Bhuyan, 1962). It is found that India's northeast region had suffered from earthquakes of different magnitudes during 1536, 1548, 1596, 1607, 1642, 1663, 1715, 1735, 1776, 1869, 1875, 1897, 1918, 1930 and 1950 (Gogoi and Barman, 1991).

Due to plate tectonic movements, the Himalaya Mountain have undergone complicated Earth-movements, imparting complicated structure to the mountain range of which, besides normal faults, four interrelated geological features are most spectacular. They are recumbent folds, thrust fault, nappe and window. It is estimated that Indian

### SOME MAJOR EARTHQUAKES IN INDIA SINCE 1800



0 250 500  
KM

76°E SOURCE : BASED ON DIFFERENT LITERATURE

FIG. 3.17

plate is pushing in the north and northeast direction at an annual rate of 5 cm (Hemmady, 1996).

Further, the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT) are the two major discontinues in 2400 km long east-west stretch of the Himalaya. The major tectonic features of this region include, from south to north, the Himalayan Frontal Fault (HFF), the Main Boundary Thrust (MBT), the Main Central Thrust (MCT) and the Indus Tsangpo Suture Zone (ITSZ). In addition to the four great earthquakes of magnitudes exceeding eight in 1897, 1905, 1934 and 1950, another ten earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during past 100 years (Bhatia, Kumar and Gupta, n.d.). Moreover, the entire North East India lies in the high earthquake prone zone number IV. The theory of plate tectonics relates it to the convergence of the major Indian plate with the major Eurasian plate and also to minor Burmese plate. The hilly terrain and the complex geological structures of the NE Region are due to the constant movement of the Indian plate along with various geomorphic processes for the past few million years. Earthquakes of feeble, moderate to high intensity are a regular phenomenon (Roy, 1999). Sharma (1999) has reported that 15 major earthquakes have hit the Himalaya segment (from Nepal to Assam) since 1255, out of which two earthquakes (1887 and 1950) hit Assam. In the past 50 years collapse of man-made structures, landslides and avalanches caused by the Himalayan earthquakes have killed more than 20,000 people. Due to increase of population, denaturalization of landscapes, rapid urbanization and construction of unsafe dwelling houses have added to future disastrous possibilities in which even a medium intensity tremor can cause

catastrophic causality. However, several lines of evidence show that one or more great earthquakes may be overdue in large part of the Himalaya (Bilham, 2001).

However, the Indian Standards Institution (now renamed as Bureau of Indian Standards) prepared the first seismic zones of India in 1962. This map accompanies the standard ISI: 1893-1962: 'Recommendations for Earthquake Resistant Design of Structures'. It has undergone revisions in 1966, 1970, 1975 and 1984. It is reported that another revision has become due after the Bhuj quake (Hemmady, 1996). Table 3.7 and Figure 3.18 reveal some of the major earthquakes of North Eastern Region.

The Himalayan fore deep is an east west tectonic basin located along the southern margin of the Himalayan fold belt. The basin formed during the late Paleocene-Neogene times and is related to the upheaval of the Himalayas. Darjeeling-Sikkim Himalayan block is situated to the north of the Himalayan fore deep. Based on geology and seismicity, the Himalayan region can be divided into different seismo-tectonic blocks. The Darjeeling-Sikkim area constitutes one of them, where a good number of earthquakes ( $M > 4.0$ ) have occurred in the past (Nath, 2000). In fact, all the major tectonic features in the study area are active, as evidenced by the association of epicentres of several earthquakes with them. Studies of the great earthquakes ( $\geq 7.75$ ) have shown that they occur at plate boundaries which have not ruptured during the past several decades or more (Naithani, 2000).

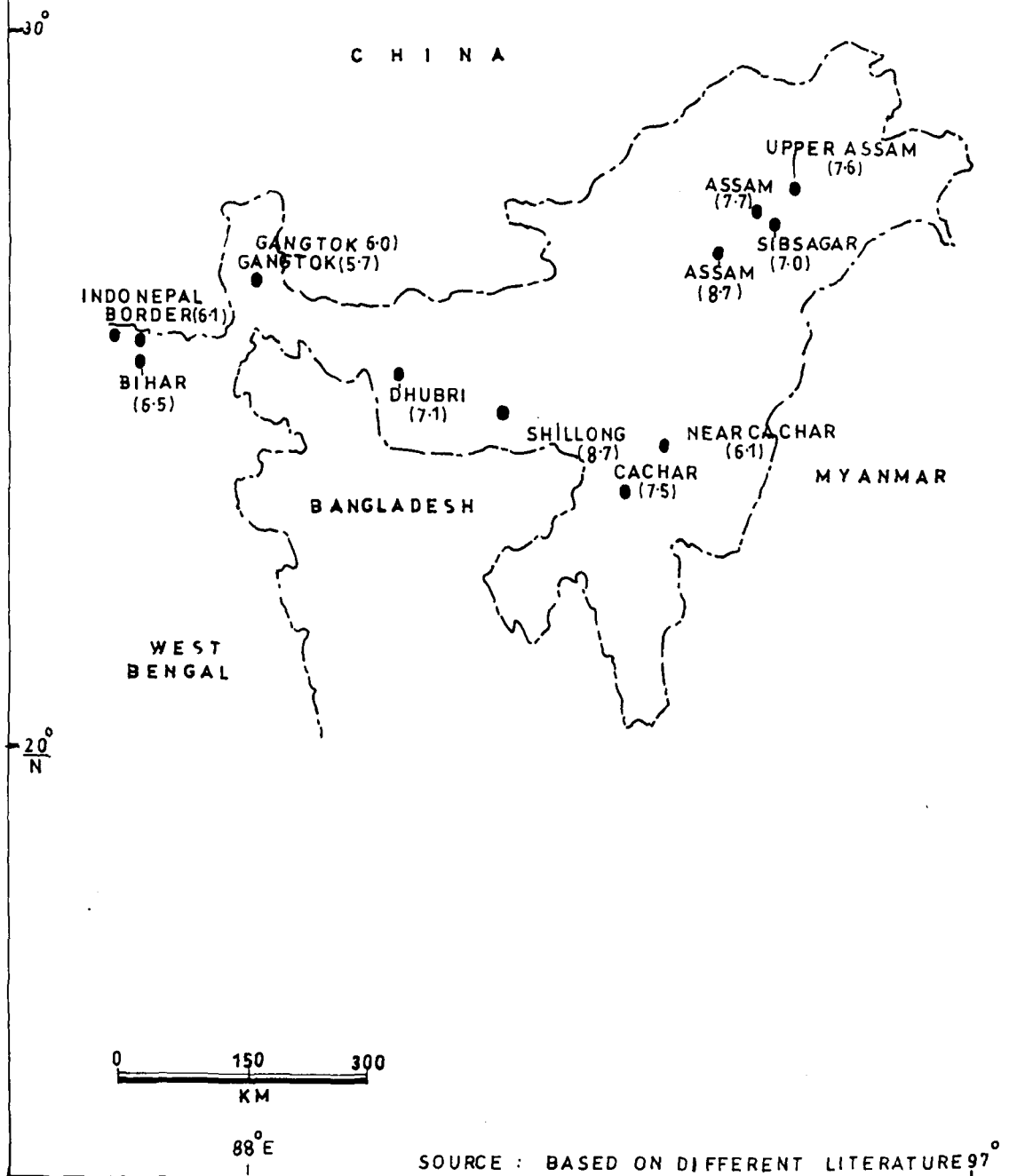
**Table 3.7 Some major earthquakes of North Eastern Region**

Place	Date/Year	Magnitude on the Richter Scale	Remarks
Cachar	21-03-1869	7.05	Numerous earth fissures and sand craters
Shillong Plateau	12-06-1897	8.7	About 1542 people died
Sibsagar	31-08-1906	7.0	Property damage.
Myanmar	12-12-1908	7.5	Property Damage
Srimangal	08-07-1918	7.6	Area of 4,500 sq. suffered heavy damage
SW Assam	09-09-1923	7.1	Property damage
Dhuburi	02-07-1930	7.1	Railway culverts and bridges damaged.
Assam	27-01-1931	7.6	Destruction of Property
Bihar Nepal Border	1934	8.3	About 10,000 lives lost
N-E-Assam	23-10-1943	7.2	Destruction of Property
Assam	1947	7.75	Damage caused at Dibrugarh, Jorhat and Tezpur
Upper Assam	29-07-1949	7.6	Severe damage
Assam	15-08-1950	8.7	About 1520 people were died. Severe damage of property
Nepal-India-Border	1966	6.1	80 people lost their lives.
India-Nepal Border	1980	6.1	Collapse of buildings, about 200 people died.
Sikkim	20-11-1980	6.0	Cracks seen in many buildings.
Indo-Myanmar Border	6-08-1988	7.5	No causality reported
Gangtok, Skink	14.02.2006	5.7	Few people killed and heavy lost of property

Source: Based on different literature.

As mentioned earlier that Gangtok is located on the steep ridge, its stability not complemented in the least by the fact that it lies in an earthquake prone region. Most of the tremors of the region do not even get noticed, but anything above three on the Richter scale gets felt on the surface. For Example, a big earthquake was recorded at the noon on 20<sup>th</sup> November 1980. This one measured six on the Richter scale and had its epicentre near Gangtok. Although, nothing collapsed at the time, the High Court and the Secretariat Buildings developed noticeable cracks. An unpublished report on History of Sikkim mentions about the great earthquake of 1897 as 'a great earthquake occurred, the shocks of which were so fierce and continued for long in which the Palace walls, the Tashilling Monastery, several Chortens and Mandangs, the Yangang and Rumtek monasteries and

# SOME MAJOR EARTHQUAKES OF NORTH EAST INDIA SINCE 1800



SOURCE : BASED ON DIFFERENT LITERATURE 97°

FIG.318

the Tumlong Palaces were destroyed. The Palace being quite unsafe and uninhabitable, the Highness had again a temporary bamboo dwelling made and to live there till the new Palace would be built. White (1887-1908) noted an incident as “while the house was building, the Maharani came several times to see how it was getting on and told me I had built the walls much too thin and it would never stand. In their own houses and monasteries the walls are very thick, from 3 feet to 4 feet 6 inches, and have always a small chamber. However, later on I had the best of the argument when in the earthquake of 1897, the Palace, notwithstanding its thick walls, collapsed entirely and had to be rebuilt, while the Residency, through badly cracked, remained standing”. From the above discussion, it is clear that since time immemorial several big to medium range earthquakes have hit Gangtok. Table 3.8 reveals the different earthquakes in and around Gangtok since 1840.

The Table 3.8 indicates that almost all the earthquakes were of the maximum magnitude ranging from 5.0 to 6.5 on Richter Scale. Records further confirm that about 30 earthquakes have occurred in Gangtok and its surrounding area in the recent past. Data available also reveals that the recurrence of a big earthquake is at interval of 15 to 20 years. Moreover, forecast on the basis of available literature is that an earthquake of

**Table 3.8 List of earthquakes in and around Gangtok since 1840**

Sl. No.	Date	Latitude	Longitude	Magnitude
1	10-8-1843	27.0	88.3	5.5
2	27-2-1849	27.0	88.3	6.0
3	13-5-1852	27.0	88.3	6.5
4	25-9-1899	27.0	88.3	6.0
5	17-2-1909	27.0	87.0	5.0
6	15-1-1934	26.6	86.8	8.3
7	9-6-1936	27.5	87.0	5.5

8	7-9-1936	27.5	87.0	5.7
9	29-1-1938	27.5	87.0	5.8
10	21-8-1960	27.0	88.5	5.5
11	22-2-1963	27.2	87.1	5.2
12	27-3-1964	27.1	89.4	5.0
13	30-8-1964	27.4	88.2	5.1
14	12-1-1965	27.4	87.8	5.8
15	12-1-1965	27.3	87.7	5.2
16	4-12-1971	27.9	88.0	5.2
17	22-3-1973	28.1	87.2	5.0
18	26-11-1975	28.2	87.8	5.0
19	19-06-1979	26.7	87.5	5.2
20	19-11-1980	27.4	88.8	6.0
21	5-4-1982	27.4	88.8	5.0
22	27-9-1988	27.2	88.4	5.0
23	22-5-1989	27.4	87.9	5.0
24	9-1-1990	28.2	88.1	5.7
25	25-1-1996	28.0	87.0	5.2
26	26-4-1996	27.8	87.6	5.2
27	25-9-1996	27.4	88.5	5.0
28	14.02.2006	27.7	88.8	5.7

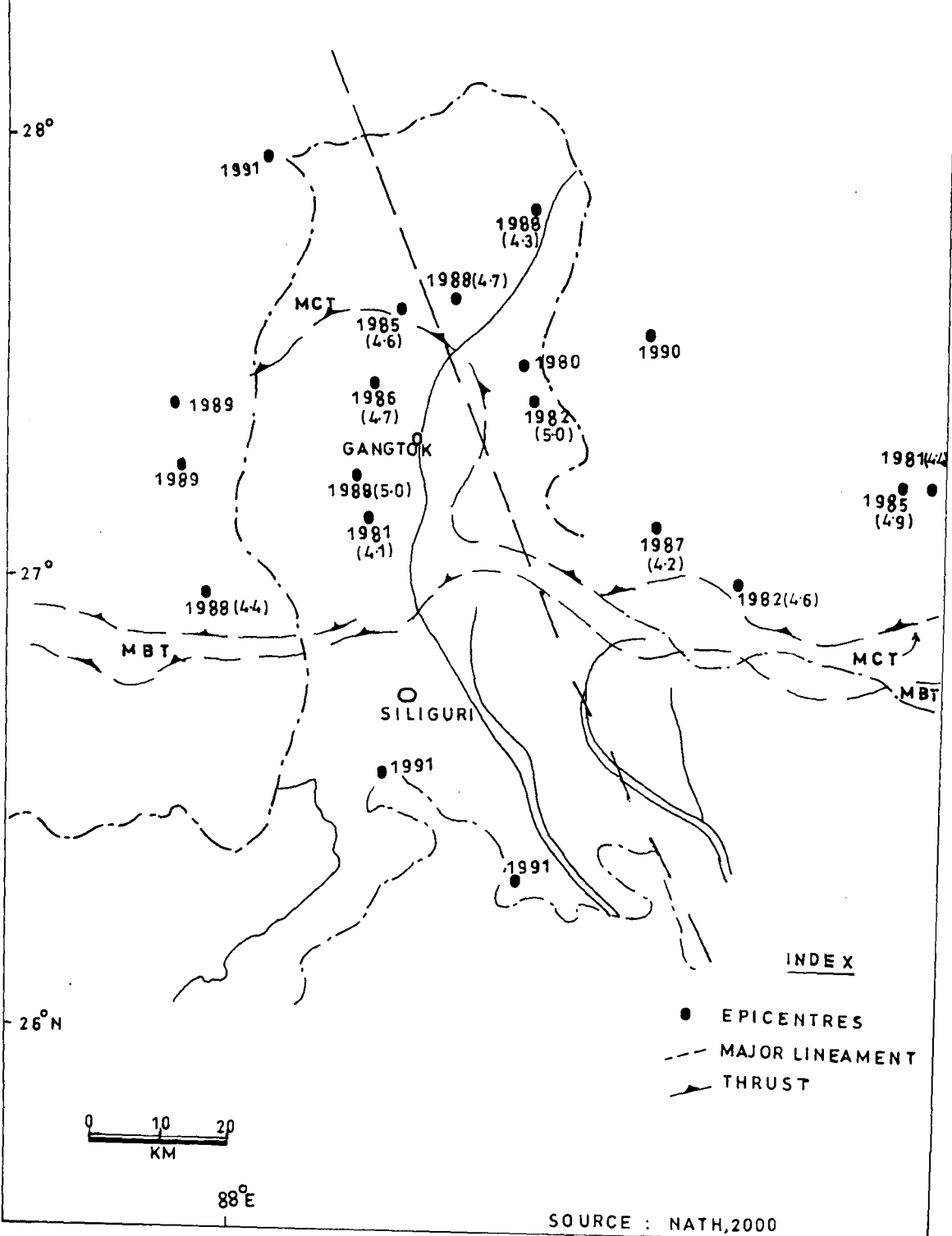
Source: Vulnerable Atlas of India, 1997, and Different Literature.

greater than 8.0 magnitude on the Richter scale is due at any time in the North-East India, particularly in the Sikkim Himalaya. As per diatancy model, delay in the occurrence of the earthquake will only increase magnitude of the future earthquake. Further, the recent teleseismic data reveals that the Himalaya is one of the young regions of deformation, where tectonic motions and earthquakes are very pronounced. Indeed, the shallow-depth earthquakes in the region are widespread and scattered. But sometime deeper earthquake events are reported from the Hindu Kush-Himalaya Region. It is important to note here that big earthquakes are always related with the large scale landslides. In a great majority of cases, landslides take place with the earthquake shock, and a few of them may also occur hours or and days after the shock (Naithani, 2000).

Sikkim Himalaya falls in active seismic belt (Figure 3.19 and 3.20). Data available also reveals the recurrence of big earthquakes in intervals of 10 to 15 years in the region in November 1980, Gangtok was shaken by a big earthquake that damaged many concrete structure here. On the other hand, landslides of all descriptions occur in almost all types of rock formation in Sikkim. Inherent geologic settings, crucial geomorphic features, geotechnical instability, seismic activity, excessive rainfall, deforesting and unplanned construction etc. are the main causes of landslides of the region. Further, high-rise RCC buildings in different parts of the region are at great risk because geological setting can trigger greater losses during the earthquake and landslide geohazards. In fact, earthquakes affect man and environment in a number of ways. Figure 3.21 clearly shows direct and chain effects of earthquakes. It appears from that almost entire natural and human systems come under the affect of earthquakes, and that reminds that how powerful is one stroke of nature in the form of shaking of the surface of the earth. That is why earthquake geohazard is an integral part of geoenvironment of an area.

Actually, different hill towns in India, including Gangtok, are prone to different kinds of geohazards as landslides, earthquakes, avalanches, soil erosion, deforestations etc. Since, Gangtok is located on a steep ridge, its stability is not complemented in the least by the fact that it lies in the earthquake prone region at an elevation of 1800 m from the mean sea level. Risk from disasters like landslides, slope failure and earthquakes remain ever present (Now, 2005). It is important to mention here that, through Gangtok has varied geoenvironment, yet human interference has destroyed its landscape, robbed valuable green cover and created Geohazards. It has been already facing a number of problems due to rapid rise of population and it has little scope for infrastructural

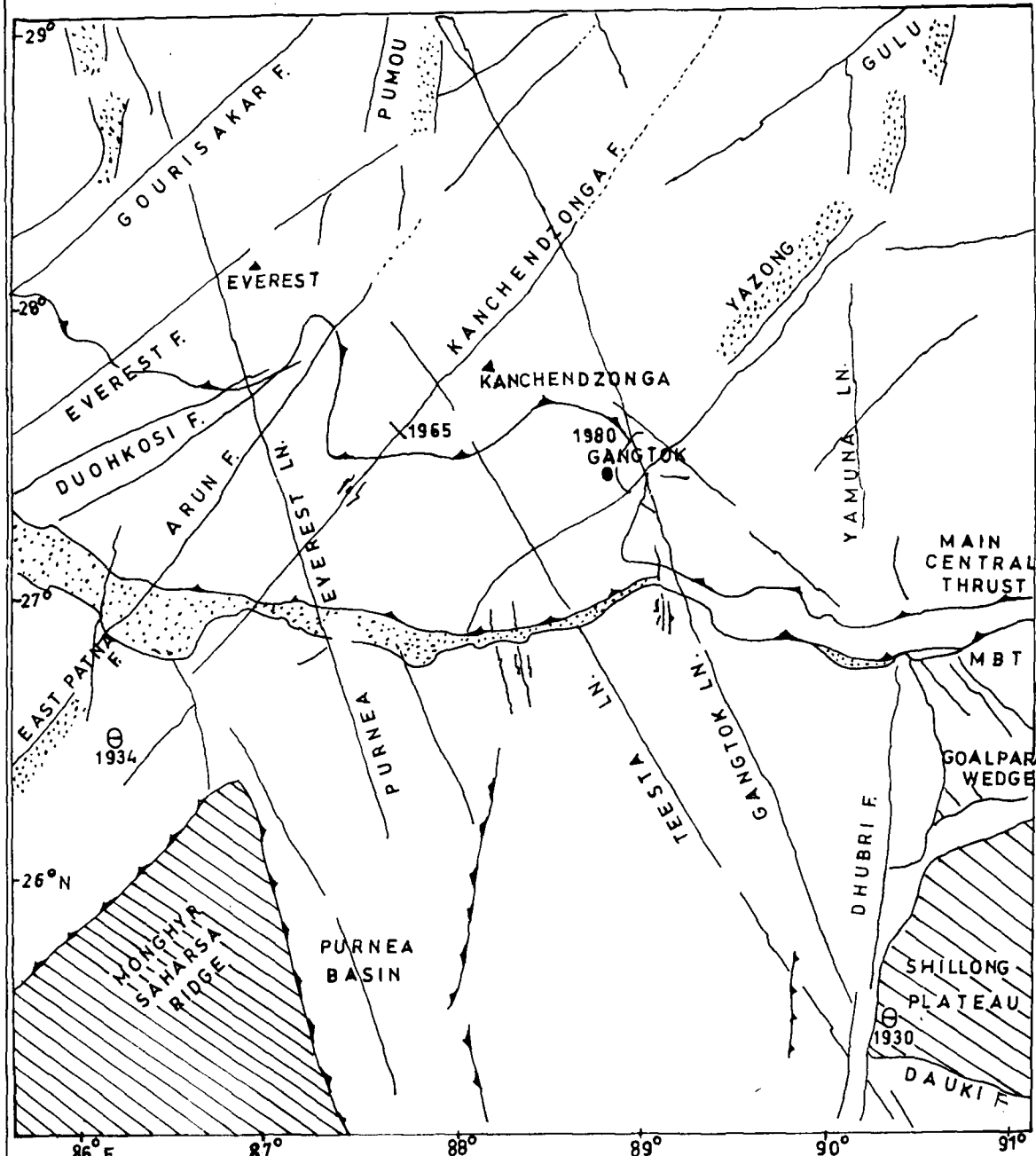
# SEISMICITY MAP OF SIKKIM HIMALAYA



SOURCE : NATH, 2000

FIG. 3.19

# SEISMOTECTONIC MAP OF SIKKIM HIMALAYA AND SURROUNDING AREAS

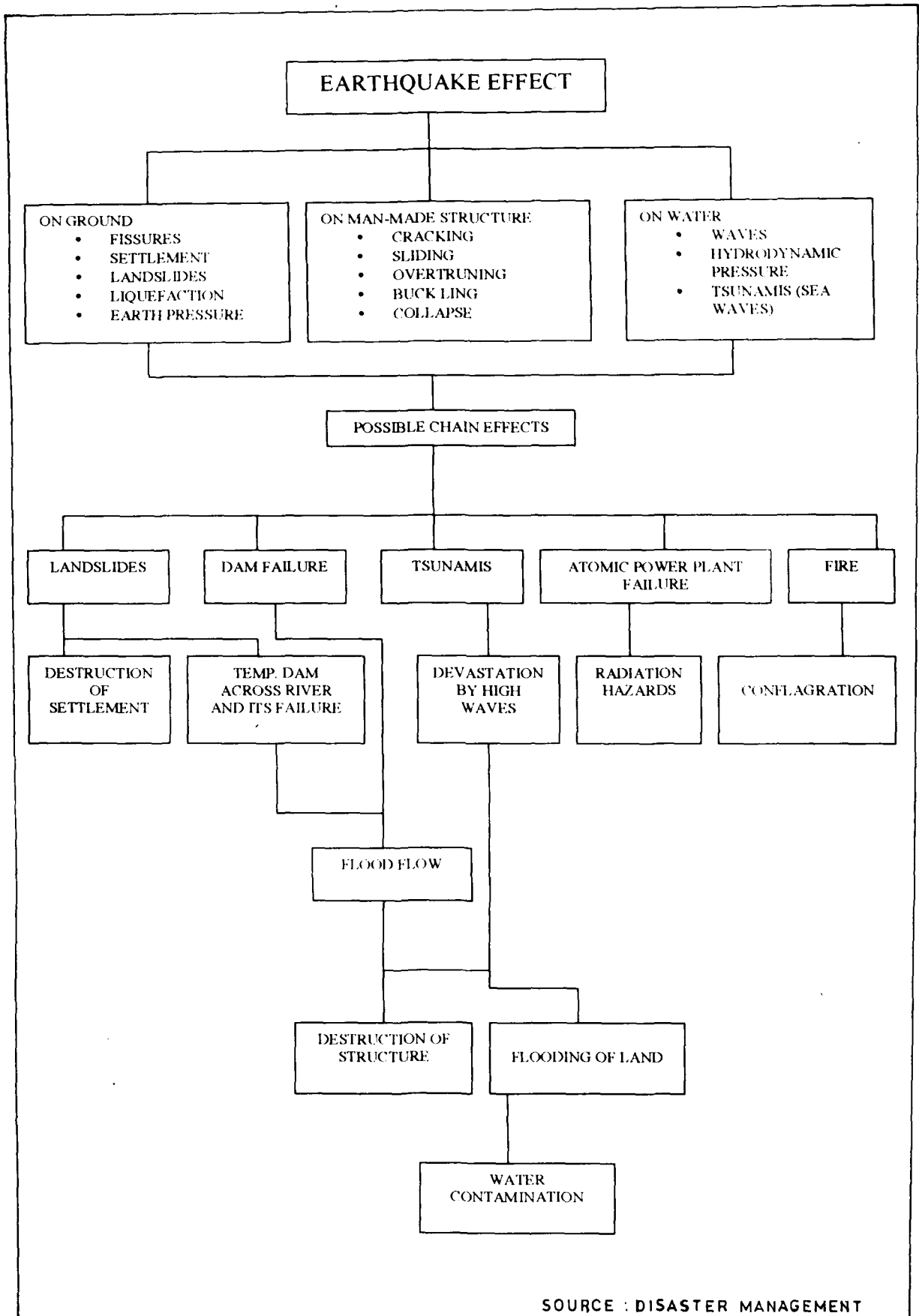


INDEX

THRUST  
 LN LINEAMENT  
 F FAULT

SOURCE : AFTER DASGUPTA et al.,1987

FIG.3.20



SOURCE : DISASTER MANAGEMENT

FIG.3.21 DIRECT AND CHAIN EFFECTS OF EARTHQUAKES

development for availability of space. Gangtok and the suburbs are experiencing unprecedented runaway developmental activities. Systematic degradation of the land can be seen everywhere even by untrained eyes (Tashi , 1993). It is understood from the study that the factors like situation, location, slope relief, soil, underlying geologic structure, hydrology and human activities etc. are the main cause and agents of the occurrence of different hazards of the study area. A mild earthquake of 5.6 intensity struck Gangtok on 14<sup>th</sup> February 2006, due to which cracks were developed in number of RCC buildings, indicating the vulnerability of such structures to earthquakes and as a consequence heavy loss of life and property (Plate 5 to 8).

### **3. 3 SOILS**

Soil is a natural body of minerals and organic matter in which plants can grow. Soils form the upper most layer of the land surface that plants use and depend on it for nutrients, water and physical support (Strahler and Strahler, 1996). Soil is not only a basic component of biotic environment but also one of the pivotal factors of landform development and modification, which always reflects the topographic, geomorphic, hydrologic and environmental dynamics. Although, a soil scientists restrict the term 'soil' the horizons of weathered, unconsolidated material that contains organic matter and is capable of supporting plant growth, but most geographers and geologists commonly use the term soil for the layer of weathered, unconsolidated materials on top of bedrock. In geomorphology the term 'soil' implies a three-dimensional body at the earth's surface which supports plants and generally produced out of alteration of weathered material so that a distinct layering of its minerals and organic components appears. The origins of the soil, its description as well as classification are examined in pedology, i.e., the study of

soil as a natural body. Further more, the whole processes of soil formation is governed by different factors like parent materials, climate, topography, biosphere and time. The parent material, topography and time are the main passive soil formers, while climate and biosphere are the active soil formers.

In fact, soils are one of the important parameters of studying geoenvironment of a particular area. Soil studies have also been used in applied geology and for determination of the land and so on (Tashi, 1993). However, pedological studies of India have been done by a number of scholars and researchers on the Eastern Himalaya in general and Sikkim in particular. Pradhan (1972), Dutta (1980), Chakraborty and Chakraborty (1980), Khera and Pradhan (1980), Dutta (1981), Singh and Raman (1982), Biswas *et al.*, (1985), Gangopadhyaya *et al.* (1986), Lahiri and Chakravarti (1989), Pradhan (1990), Tashi (1993) etc. have contributed a lot in this field. Due to the variations of climate, physiography, geology and forest different soil types are seen in Sikkim. Soils of Sikkim are very young and not well developed due to the high slope, high rainfall and extensive erosion etc. Granite, gneiss, shale and mica schists with intermittent pockets of sandstones are the main parent material. Daling group of rocks is found in the central part of Sikkim, which consists predominantly of slates of phyllosilicates. As far as the genesis of soil of the state is concerned, rocks of the Dalling group contribute the most. The colour of the soil is varying from yellow brown to dark red brown. Generally, red and yellow subsoils are very common. At the lower altitudinal areas of the state, grey, mixed red and black soils are seen, while brown forest soils are common in the higher altitudinal areas. By and large, the soils of the state are loamy in texture with varying amounts of coarse fractions. A stiff reddish loam has developed on the most common rock type- the Darjeeling gneiss

(Chopra, 1979). Sikkim soils are found to be acidic in reaction, having pH value between 4.5 to 6.8 or even more, and having high organic matter content (Gupta *et al.*, 1985). According to Gangopadhyaya *et al.*, (1996) some high altitude forest soils of Sikkim are also acidic with high organic matter content at the surface, which decreases down the profile and it ranges from 1.77 to 7.63 per cent. Most of the soils of Sikkim are classified as Entisols, Mollisols and Inceptisols. The occurrence of Alfisols has also been observed in different parts of the state. This group of soil has shown comparatively better development in soil formation. It is observed that Entisols are dominant (43%) followed by Inceptisols and Mollisols occupying 33.4% and 23.61%, respectively. A brief description of different characteristics of soil of Sikkim is given below (Table 3.9).

**Table 3.9 Characteristics of the soils of Sikkim**

Texture	Loamy sand to silty clay loam
Depth	From four inches and in some places practically nil several feet deep depending upon the weathering processes in underwent.
Soil Reaction	All acidic, having pH ranging from 4.3 to 6.4 with mean value 5.37
Organic matter content	High between 0.36% to 5.61% with mean value 2.74%
Available Nitrogen	10-280 ppm with mean value 99.21 ppm
Available Phosphorous	4.0-175 ppm with mean value 46.87 ppm
Available Potash	45 to 490 ppm with mean value 184.71 ppm
Lime Requirement	Most between 2.0 tonnes per acre but varies from 0 to 16 tonnes per acre.

Source: Sikkim: A Statistical Profile, 2002.

Majority of the soils of this region has medium status of Nitrogen, Phosphorus and Potassium. On an average the availability of N, P and K in soils of Sikkim is medium. The content of N, P and K in these soils ranges from 5 to 336, 0.065 to 68.76 and 0.66 to 622 kg/ha, respectively.

The soils of Gangtok are not highly developed and thick, except clay soil, being located on the steep slopes mainly in the western side of the Gangtok ridge. The soils of

the study area have been put in four categories, viz., Fine Loamy, Fine Loamy Fragmented, Sandy Loamy Skeletal and Coarse Sandy Loam (Fig. 3.22). The central part of the study area is a built up area, hence put as unclassified zone. The soils in Gangtok are moderately deep somewhat excessively drained, coarse loamy soil and well-drained loamy fine silty soil. The summit region of the Gangtok ridge is covered by the thin and sandy soil, while at the shoulder, it is very thin and highly disturbed soil, for example in the Balwakhani to TNSSS area. Furthermore, the eastern slopes of the ridge also highly disturbed zone hence have very thin soil. Table 3.10 shows characteristics of a soil profile of the study area. Soil texture changes from sandy loam to loamy sand, means it becomes coarser, hence porous enough to allow faster passage of infiltrating rainwater.

**Table 3.10 Soil profile description of one pit of the study area**

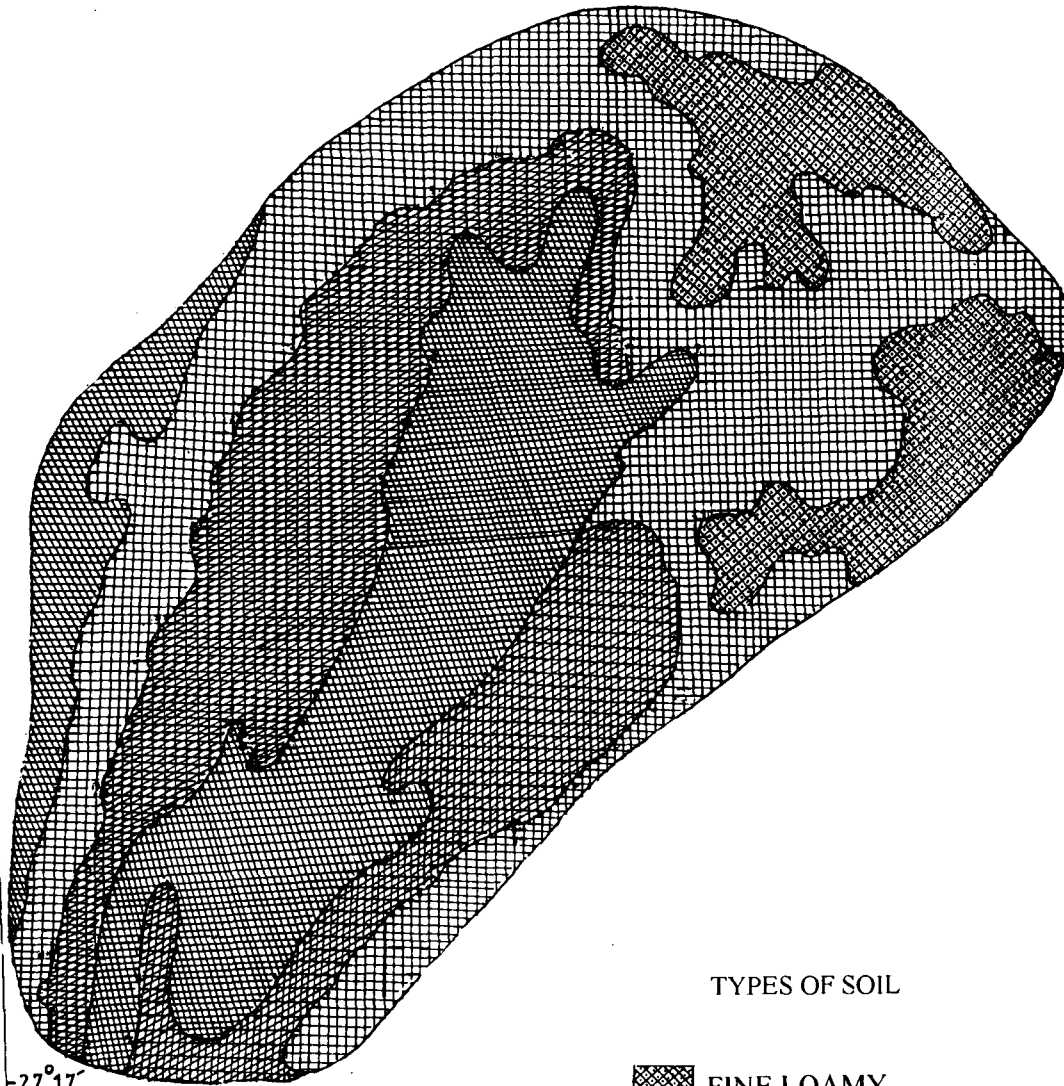
Horizon	Depth in (cm)	Colour (Dry)	>2 mm Fraction %	Soil Texture
A	0-15	10 YR 4/1	25	SL
AB	15-25	10 YR 3/2	15	SL
BW	25-60	10 YR 6/4	55	LS
CR	60	10 YR 6/2	-	-

Source: Tashi, 1993

Towards the foot slope and toe slope the soil is well developed as seen near ICAR Complex, Tadong area, Namnang, part of Lower Sumdur area, Sichey School, Lingding-Phewa Busty, near Dear Park and Libing. Table 3.11 reveals the same clearly, particularly presence of clay particles around 83 cm below the surface, and this manner soil of this pit differs from the above mentioned pit.






GANGTOK  
SOILS

27°22'



27°17'  
N

TYPES OF SOIL

-  FINE LOAMY
-  FINE LOAMY FRAGMENTED
-  SANDY LOAMY SKELETAL
-  COARSE SANDY LOAM
-  BUILT UP AREA



SOURCE: MODIFIED AFTER NATIONAL SOIL SURVEY  
AND LANDUSE PLANNING, NAGPUR

88°35'E

FIG. 3.22

**Table 3.11 Soil profile description of one pit of the study area**

Horizon	Depth in (cm)	Colour (Dry)	>2 mm Fraction %	Soil Texture
A	0.40	10 YR 2/1	20	SL
AB	40.83	10 YR 3/4	10	SL
BW	83.283	10 YR 6/8	25	SC
CR	283.335	10 YR 6/4	35	SC

Source: Tashi, 1993

To determine texture of soils of the study area 15 soil samples were collected from different localities of Gangtok. Test results of the physical analysis (based on USDA texture triangular diagram) of the soils are given in Table 3.12.

**Table 3.12 Texture of soils of different localities of Gangtok**

	Sand %	Silt %	Clay %	Texture (USDA)
Sumdur (6 <sup>th</sup> mile)	66.02	11.50	22.48	SCL
5 <sup>th</sup> Mile	51.00	17.39	31.61	SCL
Tadong	52.11	19.01	28.88	SCL
AmdoGolai	48.32	22.23	29.45	SCL
Deorali/Syari	53.41	19.33	27.26	SCL
Gangtok	44.23	30.01	25.76	L
Zero point	54.21	21.23	24.52	SCL
Development Area	59.01	23.00	17.99	SL
Burtuk	47.01	21.52	31.47	SCL
Chandmari	56.01	18.22	25.77	SCL
Tathenchen Area	54.22	24.31	21.47	SCL
Secretariat	42.03	24.23	33.74	CL
Cantt. Area	40.11	26.23	33.74	CL
Sichey Area	44.22	26.11	29.67	CL
Sialgaon	50.11	24.00	25.89	SCL

Source: Based on fieldwork and laboratory tests, 2005.

Table 3.12 clearly shows that the most common soils are sandy clay loam, because out of 15 soil samples sandy clay loam characteristics are found in 10 samples. Presence of clay loam soil is next to the sandy clay loam. One case each of clay loam and

loam is also found in the study area. It is evident that clay contents are found in almost all soil samples, and presence of clay in the soil is considered favourable to occurrence of landslides. This is because when clayey soils become wet after infiltration rainwater in to the ground they act as lubricant and provide the plane on which land slides down the slope. Due to higher percentage of clay the water holding capacity is also high in the soils, which varies from 37 to 55 (Table 3.13). This Table also reveals physical and chemical properties of soil of the different parts of the Gangtok.

**Table 3.13 Physical and Chemical Soil Properties of Gangtok**

Ranipool	63.00	14.00	22.50	SL	37.00	5.8	236	14.00	92.00
Tadong	53.40	18.00	28.00	SCL	45.00	5.7	222	22.00	168.00
Gangtok	40.00	32.00	28.00	Cl	55.00	6.2	225	53.00	137.00

Source: Environmental Assessment of Urban Settlement Gangtok.

From the Table 3.13 it is clear that the percentage of sand particles is highest (63.00) in Ranipool area, while it is lowest (40.00) in Gangtok. Contrary to it, percentage of clay is the highest (28.00) in Gangtok and lowest (22.50) in Ranipool. Similar is the case of silt particles, i.e., highest (32.00) in Gangtok and lowest (14.00) in Ranipool. All this is because Ranipool is along the river, and Gangtok is on the higher slopes of the ridge, where transported and in situ soils are found, respectively. Further, the value of pH has seen highest (6.2) in Gangtok and lowest (5.7) in Tadong. Besides, water holding capacity also seen highest in Gangtok area due to higher percentage of clay particles in the soil.

### **3.4 HYDROLOGY**

Water is the basis for all life forms. It is one of the most complex natural resources because of its nature and characteristics. A comprehensive understanding of its inherent features and its occurrence and distribution is necessary for an integrated planning aimed at an optimum development of water supply, irrigation, health, industry and power and transport sectors of a country. Water forms an important component of geoenvironment of an area because its abundance or scarcity influence functions and processes of the other components of the geoenvironment. It plays crucial role in geomorphology, soil formation, growth of plants etc. More importantly, in the present context water is related directly or indirectly with the processes triggering occurrence of landslides.

A large number of perennial rivers that are fed by snow melting and rainwater drain the state Sikkim (Fig.3.9). The total number of rivers in Sikkim is estimated to be 64 with their total length nearly 3,022 kilometres. These 64 main streams have their 475 other tributaries (Appendix I). The two main river systems of the state are the Teesta and Rangit. The Teesta river rises from the Lange Glacier (Lake Cholamu- 8550 m) which is the part of the Zemu glacier on the southeastern slopes of the Kanchendzonga massif. The total catchment area of the Teesta river is about 10,100 sq km. Within a few kilometres of its origin, the Teesta falls very sharply at the tongue of the Zemu Glacier, which is about 4000 m from the mean sea level. After flowing in deep gorges and valleys its gradient drops to 1000 m near Mangan. It is joined by many tributaries viz., Lhonak, Lachung and the Rangit at different places. Here, it is mentionable that the peak flood

velocity of the river reaches 10m/sec carrying an estimated discharge of 24,000 cumec. The discharge figures for the Rani and Bhusuk Khola basins of Gangtok have been mentioned in drainage section above. The study area has numerous streams and *jhoras* as source of water for the people of Gangtok.

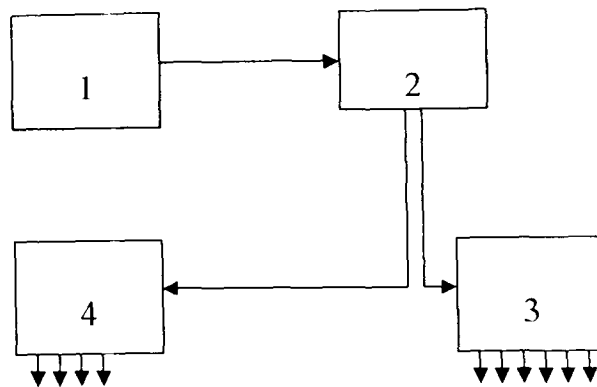
#### **3. 4. 1 Gangtok Water Supply System:**

It is worth mentioning here that water supply is one of the statutory functions of municipal authorities and bodies in India. Safeguarding public health is obligatory for them and protected water supply is one of the imperatives for this (Krishna, 2000). According to the report of National Institute of Urban Affairs (1989), Municipal bodies in Indian cities devote 12.8 per cent of their revenue expenditure to water supply.

As far the water quality is concerned the quest for pure water dates back to antiquity. In modern times, it has led to the formulation of specific standards to provide a basis for judging the quality of water. These standards are exposure limits for bacteriological, viral, chemical and physical agents that have been adopted by government on appropriate authorities and therefore have legal force. The purpose of standards is to minimize all the known health hazards, since it is obviously impossible to prevent all pollution (Park, 2002). In the year 1993, the World Health Organization has published the *Guidelines for Drinking Water Quality Vol. 1*, to ensure the safe and standard drinking water supply.

In fact, Water Security and Public Health Engineering Department (WC&PHE) not only manage safe and sufficient water supply system (Fig. 3.23) for Gangtok but also to a number of other urban centres of the state. Although the leakage of water from the

## GREATER GANGTOK WATER SUPPLY SYSTEM



To 2 -zonal Reservoir +  
2 - Sub-zonal Reservoirs

To 8- Zonal Reservoir +5  
Sub-zonal Reservoirs.

- 1= Head works (RL=2600m)
- 1-2= Raw water tank mains (capacity=40.50 MLD)
- 2= Water Treatment Plant (RL=1890m. capacity=36.32 MLD)
- 2-3 = Clear Water Mains (capacity = 28.97 MLD)
- 2-4=Clear Water Mains (capacity = 9.00 MLD)
- 3 = Main Distribution Reservoir Enchey (RL = 1818m)
- 4 = Main Distribution Reservoir old Selep (RL = 1780m)

SOURCE : PHE, GOS, GANGTOK

FIG. 3.23

water pipes is a common phenomenon in almost all the water supply systems of urban India, but the leakage from the water supply system of Gangtok appears to be maximum.

Surface water is the main source of water supply in Gangtok. The source of Gangtok water supply system is at Tamzey (23 km towards north) at an altitude of 4,240m above mean sea level. Before, distributing the water through pipeline network to different areas of the Gangtok, it is stored for chlorination at Selep Tank (1818 m). A total of 7.50 MGD raw water treatment is carried out in this plant. The Selep water treatment plant presently has treatment capacity of 13.36 millions litres daily. Treated water is stored in the reservoir of 45.45 million litres capacity at Selep. This plant was set up during 1970's with a capacity of 1 MGD.

**Table 3.14 Population and Demand of Water of Gangtok**

Area Gangtok	Population (P)	Water Demand in MLD
Year 2002-2003	115,000	26.71
Year 2005-2006	125,000	29.18
Year 2030-2031 Projected	260,000	61.11

Source: Annual Report, WS&PHE, GOS

It is a fact that with passes of time the population of Gangtok also been increasing day by day and consequently demand of water is also increasing. Table 3.14 and Figure 3.24 show the demand of water in Gangtok with rise of population. It has been estimated that around 80 per cent of the population are presently using water from the Gangtok Water Supply System, i.e., Under WC and PHE. Remaining 20 per cent population still not covered by the existing water supply schemes hence, they are using the potable water from different 'Jhoras' (small streams and springs). Besides, Gangtok being a tourist spot

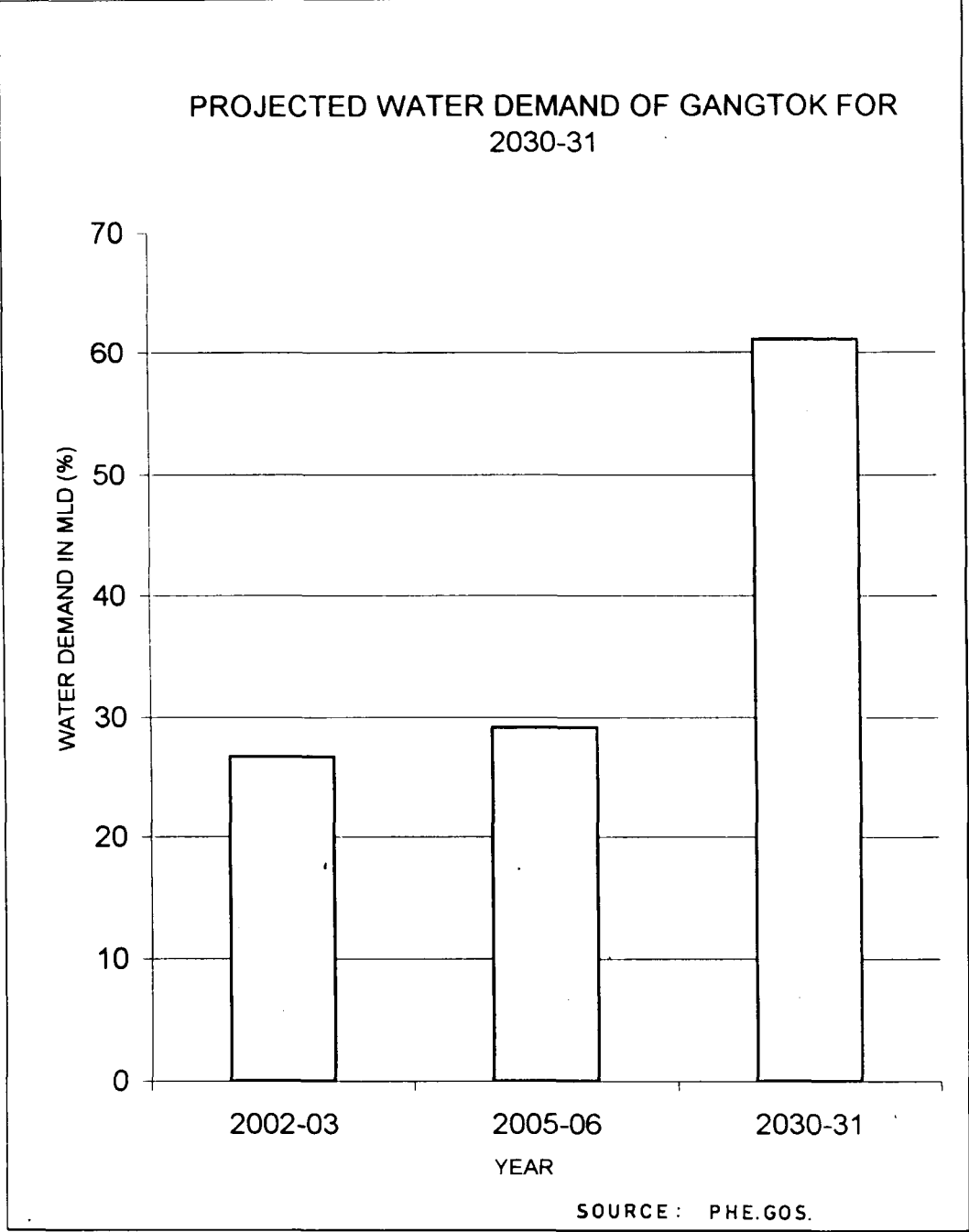


FIG. 3.24

and state capital, a mark number of floating population is daily coming to Gangtok. Therefore, Gangtok water supply system has to cater the needs of these floating populations. It has been observed that the demand of the water in Gangtok has been increasing very steeply during past few years. Existing demand of water is estimated at 27.00 millions litres per day.

It is important to note here that the State Pollution Control Board of (SPCB) Sikkim has already done an in-depth study of quality of drinking water of Gangtok (SPCB, 2004). Therefore, most of the information has been gathered from it. However, raw samples were personally collected, tested, and verified at Sikkim Govt. College Laboratory, Tadong. Water quality may be described in a variety of ways. A common approach is to express the amount of a dissolved chemical substances present as a concentration in parts per million (ppm) or for very dilute substances, parts per billion (ppb). Another way to express overall water quality is in terms of total dissolved solids (TDS), the sum of the concentrations of all dissolved solids chemicals in the water; other parameters may also be relevant in describing water quality (Montgomery, 2003). The study undertaken by SPCB is based on the "Standard Methods for Examination of Water and Waste Water" 18<sup>th</sup> Edition 1992, prepared and published by American Water Works Association, American Public Health Association and Water Pollution Control Federation. The study has revealed that the pH value is seen highest in the old market area (8.2) and the lowest in the Hospital Point. The high conductivity of the water is observed as 540  $\mu\text{mhos/cm}^2$  at the Syari, Panihouse, Deorali Bazaar, Forest Colony, P&T Colony, and Zero Point area. Whereas the lowest conductivity of water is seen at Palzor Stadium Complex, Diesel Power House area and Hospital complex.

The Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) values have also been recorded from the different parts of Gangtok. Dissolved oxygen value was recorded as 11.2 mg/L at Development Area and 13.4 mg/L at Kazi Road, Namnang and New Market area. On the other hand, the highest BOD value was found to be 2.2 mg/L at Deorali area and lowest 1.8 mg/L at Hospital Point and Development area. The analysis of Nitrate ( $\text{NO}_3$ ) and Sulphate ( $\text{SO}_4$ ) indicates that the highest value of Nitrate is observed at Hospital Point (41 mg/L) and lowest at New Market Area (26 mg/L). Sulphate was recorded as highest 24 mg/L at Hospital point and lowest (16 mg/L) at Deorali area.

Further, the total hardness ( $\text{CaCO}_3$ ) of water shows highest (105 mg/L) at Hospital Point and lowest 77 mg/L at New Market Area. Calcium ( $\text{CaCO}_3$ ) study indicates that the concentration of  $\text{CaCO}_3$  was found to be within the national standard (75 mg/L). The highest (68 mg/L) concentration of calcium was recorded at Development area and lowest (54 mg/L) at New Market Area. The Magnesium concentration was observed as highest (35 mg/L) at Kazi Road, Arithang and Old Market area whereas it was observed lowest (23 mg/L) at New Market area, against the national standard of Magnesium concentration as 30 mg/L.

The highest (127 mg/L) Chlorides (Chlorine) concentration was observed at Development Area and the lowest (105 mg/L) at Deorali Area. The concentration of Chlorides in all parts of Gangtok shows below the national standard (250 mg/L). The lowest (0.7 mg/L) of free  $\text{CO}_2$  was recorded at New Market Area and highest (1.2 mg/L) at Old Market Area. Similarly Total Dissolved Solids (TDS) was observed highest (43 mg/L) at Balwakhani Area and lowest (26 mg/L) at New Market Area. The Total

Suspended Solid (TSS) was also recorded highest (104mg/L) at Lall Market Area, Old Market Area and the Balwakhani Area, while the lowest (1.1mg/L) was recorded at Deorali Area.

The study of microbial contamination of drinking water of Gangtok shows that it is the highest during the monsoon period and lowest in winter period. The findings further revealed that the water is contaminated when the runoff rainwater is mixed with the source of drinking water and along the open canal through which water passes before reaching the point of chlorination and distribution (Lama, *et al.*, 2004). The study also reveals concentration of fluoride and arsenic in the water of Gangtok. The water quality of streams and *jhoras* can be seen from the Table 3.15. From the above discourse, it is clear that the water of Gangtok, except that of the *jhoras*, is free from marked pollution, hence, suitable for drinking and other purposes.

**Table 3.15 Water Quality of Streams and *Jhoras* of Gangtok**

Source Name	Source	Sct.	Temp (A)	Temp. (W)	pH	Cond.	Sal.	Ord.	Cor.
Goshkhan Jhora	Spring	12.10 (PM)	13.5 <sup>0</sup> C	12 <sup>0</sup> C	5.3	650	0.25 %	Toxic	Blackish
Hospital Jhora	Spring	12.20 (PM)	10.5 <sup>0</sup> C	10 <sup>0</sup> C	5.8	300	-	Toxic	Muddy
Paljor Stadium Jhora	Spring	12.10 (PM)	17 <sup>0</sup> C	14 <sup>0</sup> C	5.5	200	-	Toxic	Yellowish
Fisheries Jhora	Spring	1.00 (PM)	18 <sup>0</sup> C	15 <sup>0</sup> C	5.4	200	-	Toxic	Darkish
Rani Khola	Spring	1.35 (PM)	19 <sup>0</sup> C	12.5 <sup>0</sup> C	6.1	60	5.3	-	Clear
Adampool Khola	spring	3.10 (PM)	19 <sup>0</sup> C	17 <sup>0</sup> C	6.3	100	5.3	Toxic	Muddy

Source: State of Environmental Pollution Report Sikkim 2004.

The type and amount of generation of waste and methods of disposal of waste (both solid and liquid) are directly or indirectly related with degradation of the geoenvironment of a place, particularly urban and industrial centres. Since in most of the places water supply and sanitation go together under the umbrella of one department it is relevant to include information on the type and amount of waste generated and how it is disposed off in the study area. In Gangtok, it is the Department of Water Security and Public Health Engineering which is entrusted with the task of water supply, and collection and disposal of waste. A sewerage scheme is working for the benefit of the residents of Gangtok. Treatment of the solid waste is done at the treatment plant located at Adampool, below Gangtok. The Department also possesses technicians and machineries to test the quality of sewage before the same is disposed to the nearest river. This is being done to protect the river water and aquatic life present there, and safeguard the environment (Now, 2004). Initially over 11000 m of pipelines have been led to cater to the areas of New Market, Old Market, Kazi Road and Tibet Road. Since then many other areas have been included in the sanitary system. Today, the Gangtok sewerage system covers the areas such as Namnang, Deorali, Development Area, GICI Area, Diesel Power House Area, Arithang Area, Church Road Area, Part of Sichey Area, SNT Colony, Upper Sichey, Bhanugram and DPH Area, PNG Road, Tadong Area, Upper Deorali, Kanchan View Point Area, Dara Gaon, Krishi Bhawan, Saraswati Mandir Area etc. During the last four years, many areas of Gangtok were covered with the sewerage Sub-mains to collect the domestic waste for treatment in the Treatment Plant. However, after 1994, the WC&PHE Department have spent Rs. 1086.55 Lakh on Gangtok sewerage and drainage works (Now, 2004). The main line is 30 inch in diameter which has been laid along NH-31A from the main hubs of the Gangtok to treatment plant.

It is important to mention here that the Department of Urban Development and Housing Development is engaged in the management of garbage and solid waste of different parts of Gangtok. According to a report, Gangtok generates approximately around 42 tonnes municipal waste per day (Table 3.16).

**Table 3.16 Main sources of solid waste of Gangtok**

Sources	Percent
Domestic	34.19
Commercial	28.10
Institutional	19.20
Agriculture	3.17
Industrial	0.12
Others	15.22

Sources: State Pollution Control Board, Sikkim

This garbage and solid waste of Gangtok is collected and transported through motor vehicles (Trucks & Utility Services) and ultimately dumped at Marchak, along the National Highway 31-A, which is located at a distance of 15 km away from Gangtok. Artificial drainage networks cover Gangtok. The department of Urban Development & Housing Development and Irrigation Department has been dealing with it. The hub of Gangtok is especially well connected with artificial drainage networks. Being located on the hill slopes Gangtok does not experience water logging, but in many areas problem of seepage water has been seen. It is due to the seepage from the water tanks. In fact, due to the steep gradient most of the precipitation of Gangtok flows down the slope as surface runoff through streams. The infiltrated rainwater generally comes out as seepage and springs.

### 3.5 CLIMATE

If strict meaning of geoenvironment is considered then climate should not form part of it. But as the present study is focussed on landslide hazards, the rainfall plays a crucial role in it. However, there are some geoscientists who include climate as a component of geoenvironment. In the mountainous areas like the Himalaya inclusion of climate in geoenvironment is relevant from the point of view great variations in climate with the increase in altitude, and presence of different microclimates in the valleys and crests of the hills. The altitudinally governed variations in different elements of climate also give rise to different geoenvironment belts in the mountains like the Himalaya. It is a well-established fact that climate and weather play an overriding role in planning and management of geohazards of a particular area. It is, therefore, essential to make full use of all available climatological information in the appraisal of geoenvironment and management of geohazards.

**Table 3.17 Climatic divisions of Sikkim Himalaya**

Sl. No	Type of climate	Altitude range
1	Tropical	Below 610 m
2	Sub-Tropical	610 to 1524 m
3	Temperate	1524 to 2743 m
4	Sub-Alpine	2743 to 3962 m
5	Alpine	3962 to 5182 m

Source: Sikkim: A Statistical Profile, 2005.

Sikkim being in the Himalaya Mountain, its climate varies from warm and humid tropical in the lower altitude to chilly cold of alpine type in the higher altitudes. This variation is caused by its geographical location, relief and change in altitude. On the basis of altitude Sikkim is basically divided into five climatic zones (Table 3.17). Tropical climate prevails up to elevation of 610 m, and Sub-tropical between 610 m to 1524 m.

Temperature climate is found between 1524 m to 2743 m. Sub-Alpine climatic zone is found between 2743 m to 3962 m. Finally, above 3962 m Alpine climate with perpetual snow prevails.

Though Sikkim is small in area (7096 sq km), it shows maximum climatic diversity. In fact, abrupt variation in altitude of about 8000 m in less than 100 km results in abrupt change in climatic conditions. In Sikkim two main climatic elements- the temperature and precipitation- are very much related to altitude and as a result great variations are found in them (Pradhan, 1990).

### **3.5.1 Precipitation**

Two types of precipitation occur in Sikkim. Higher altitude areas receive precipitation in the form of snowfall. Most of the snowfall is brought by the western disturbances. While heavy rainfall is caused by the Bay of Bengal branch of southwest monsoon, in which proximity of Sikkim Himalaya to the Bay of Bengal plays a favourable role. About 70 per cent of the total annual rainfall is received from the southwest monsoon that strikes the Sikkim Himalaya through the opening of the Malda gap. Rainfall is the most important climatic parameter influencing other components of physical environment and man also. The Sikkim Himalaya experiences an average annual rainfall of 1200 mm to 2600 mm, and in certain pockets, it goes as high as 5000 mm (Krishna, 1997). Figure 3.25 clearly depicts two points- i) the spatial distribution of rainfall in Sikkim Himalaya, and ii) influence of altitude on amount and spatial distribution of precipitation. The later point is also clear from Figure 3.26. The isohyet map clearly shows that the southern part receives higher rainfall and it decreases towards

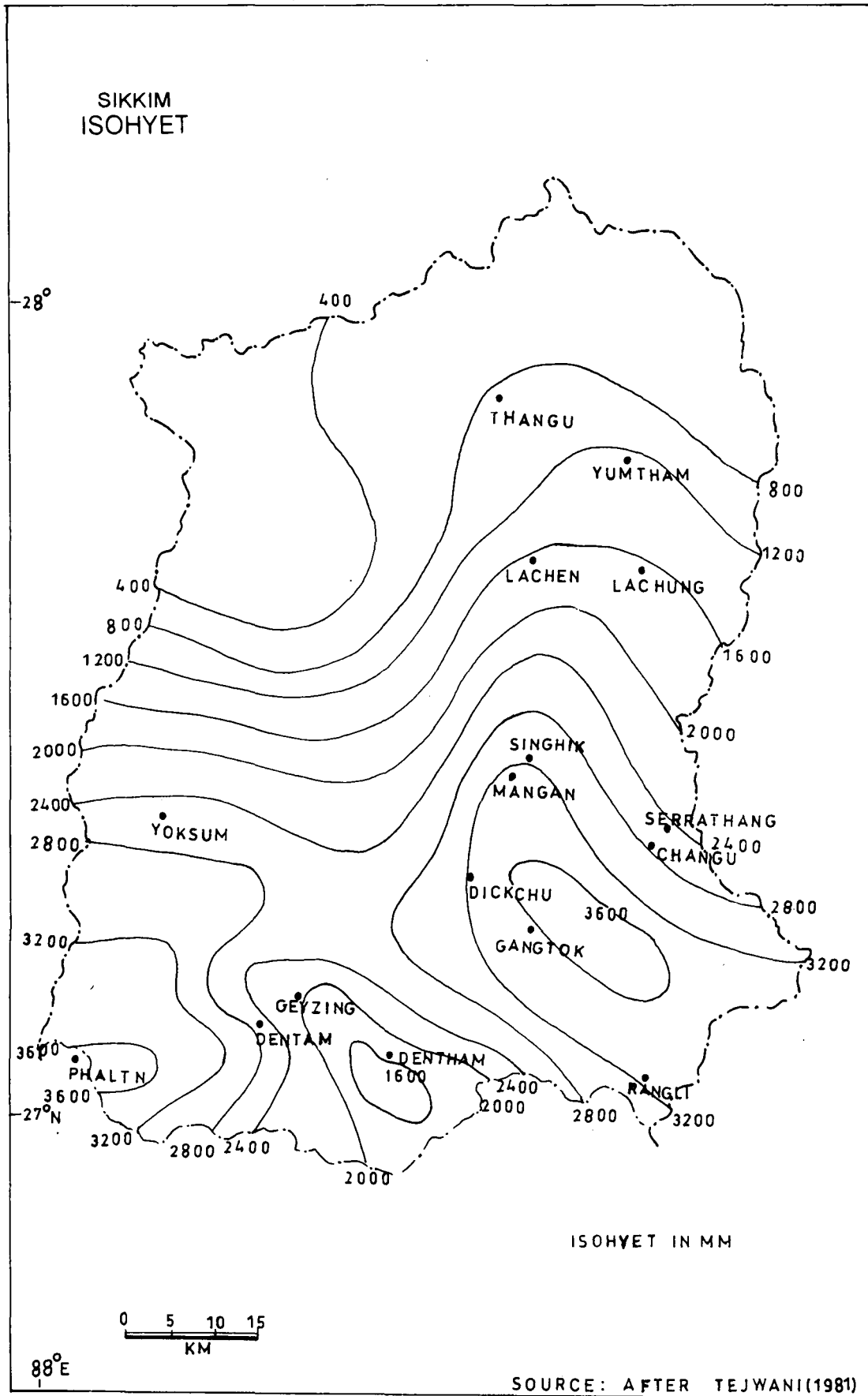
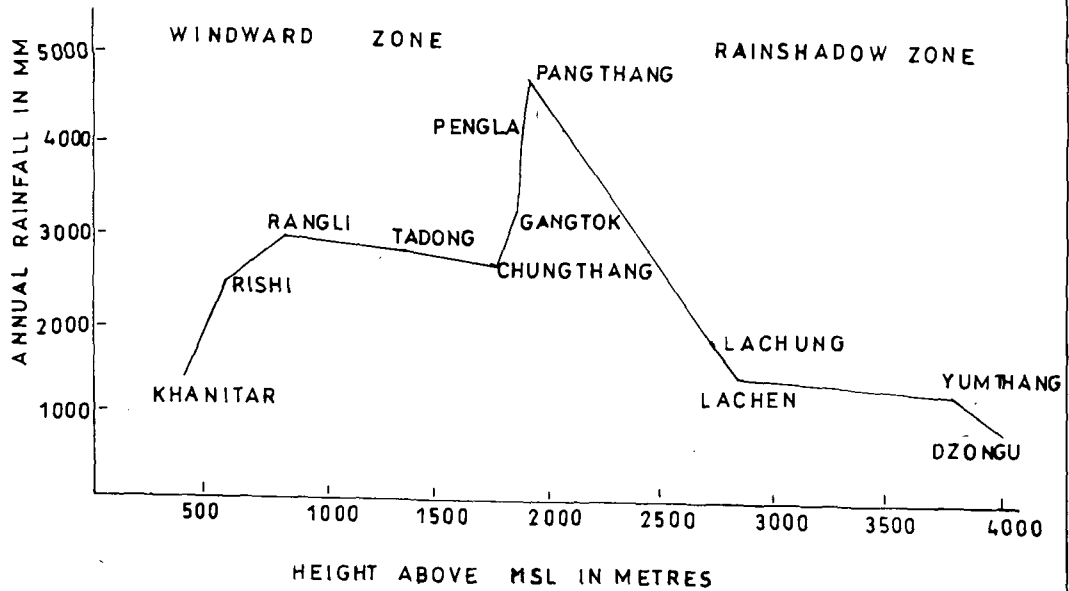


FIG.3.25

## RAINFALL IN RELATION TO ELEVATION IN SIKKIM



SOURCE : AFTER BANDYOPADHYA AND SINGH, 1998

FIG.3.26

the north and northwest. In fact, in the mountains first rainfall increases up to certain height then it declines. Most important point to note is that the isohyet of maximum precipitation of above 3600 mm is located around Gangtok, and that is relevant from the point of view of occurrence of landslides in the study area. Another, important point in the spatial distribution of rainfall is that the Teesta and Rangit valleys are oriented almost north-south and open towards south, thus allow penetration of the southwest monsoon

**Table 3.18 Rainfall characteristics of Sikkim**

Station/Height in metre above mean sea level	No of years of data	Annual	Highest Annual Rainfall as % of Normal & Years	Lowest Annual Rainfall as % of Normal & Years	Heaviest Rainfall in 24 hours	
					Amount (mm)	Date
Yumthang (3673)	22	a. 417.4 b. 160.2	108 (1960)	91 (1964)	84.1	28.9.60
Thangu (3812)	16	a. 821.1 b. 100.0	182 (1961)	57 (1959)	101.6	18.5.54
Lachen (2697)	17	a. 1652.4 b. 161.3	115 (1963)	78 (1962)	116.0	26.5.66
Lachung (2633)	13	a. 1703.5 b. 154.8	130 (1974)	79 (1962)	216.0	13.10.73
Chungthang (1631)	20	a. 2647.3 b. 153.6	115 (1955)	88 (1964)	261.6	22.7.54
Singhik (1402)	13	a. 2989.4 b. 169.5	136 (1958)	69 (1960)	162.3	22.6.57
Mangan (1310)	16	a. 3238.9 b. 160.5	111 (1961)	84 (1964)	233.0	4.6.67
Gnathang (3752)	9	a. 3289.6 b. 183.7	117 (1962)	108 (1963)	114.3	13.7.61
Chhangu (3840)	9	a. 2900.7 b. 173.3	121 (1958)	85 (1960)	143.5	26.5.58
Serrathang (4114)	7	a. 2209.2 b. 152.8	123 (1958)	35 (1963)	114.3	26.5.58
Rangli (832)	13	a. 3220.6 b. 147.8	142 (1971)	82 (1958)	216.0	13.10.73
Gangtok (1818)	14	a. 3494.5 b. 163.7	111 (1963)	83 (1966)	192.5	3.10.73
Dikchu (869)	13	a. 3235.2 b. 152.0	123 (1971)	84 (1972)	232.2	13.10.73
Geyzing (1520)	16	a. 2392.2 b. 163.7	111 (1961)	86 (1966)	186.7	5.10.68
Yoksum (1780)	12	a. 2619.6 b. 146.4	131 (1959)	57 (1974)	151.8	30.7.81
Dentam (1372)	12	a. 2338.5 b. 134.7	146 (1964)	82 (1958)	152.1	9.7.59
Damthang (1981)	13	a. 2197.0 b. 134.8	187 (1959)	35 (1962)	341.4	4.8.64

Source: Tejwani *et al.*, 1981

winds deep inside, as a result the isohyet lines are curved towards north along these two major valleys. These points are also evident from the Figure 3.25 and Table 3.18. Maximum rainfall occurs around 2000 m altitude, then it declines with the increase of altitude and around 4000 m it is merely below 1000 mm. Figure 3.27 compares the difference in temperature, rainfall and relative humidity between the sub-tropical and temperate zones of Sikkim Himalaya. Both relative humidity and rainfall are relatively higher in the temperate zone, while temperature is low here in comparison to sub-tropical zone.

The relative humidity remains in the range of 70 to 95 per cent through out the year and that shows a high humidity in the area. Particularly in the temperate and sub-tropical zones, the relative humidity is recorded more than 70 per cent throughout the year. Humidity is quite high during the mornings and afternoons. Clouds and fog are common during summer and winter seasons, respectively.

The study area Gangtok has sub-tropical and semi-temperate continental type of climate. Main Gangtok is lying at an elevation of 1800 m above the mean sea level, so rainfall is quite high. Gangtok get an average annual rainfall of 300 cm. Sometimes the average annual rainfall varies from 300-400 cm. Within Gangtok, though it is a small area, the rainfall varies even within the study area due to hilly terrain. The rainfall starts at Gangtok towards mid- March and it lasts till September-October. Whereas June, July and August are the wettest months. Winter is generally dry in Gangtok, except some occasional drizzle and rare snow fall. Table 3.19 reveals the rainfall characteristic of Gangtok. A high of about 25 to 28 rainy days characterise the peak monsoon months of June, July and August, shortly followed by September and May, while October suddenly have very less of 9 rainy days due to retreat of the monsoon. Almost similar picture is

seen in case of average monthly rainfall, which is about 760 mm in June and July, very high indeed.

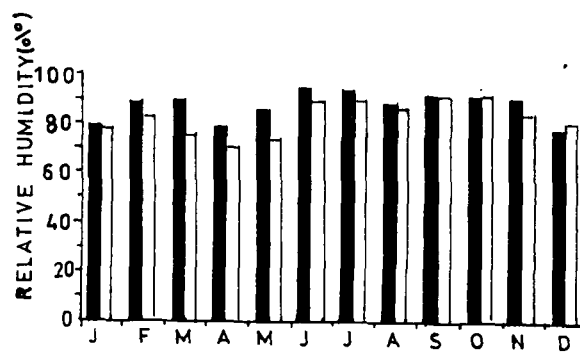
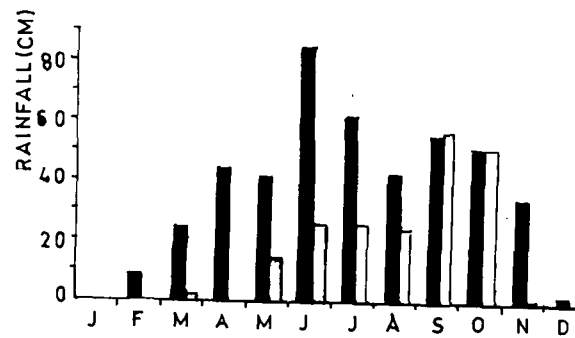
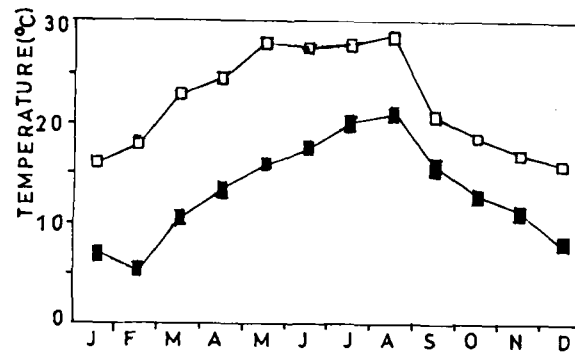
**Table 3.19 Rainfall characteristics of Gangtok**

Characteristics	May	June	July	August	September	October
Number of rainy days (>2mm daily)	22	25	28	27	23	9
Average mean rainfall (in mm)	620	760	765	569	491	169

Source: *Status Report for Initiating Landslide Studies in Sikkim, Dehradun.*

Monthly variability of rainfall for years 1990 to 2001 in Gangtok has been depicted in Figure 3.28. It is seen that during the twelve years a maximum of more than 1200 mm monthly rainfall was recorded in June 1997 which happens to cause two major landslides in Gangtok. The highest pre-monsoon monthly rainfall of about 950 mm occurred in the month of May 1996. Maximum monthly rainfall in the later period of monsoon has been seen in month of September 1991. It is also observed that up to the month of March for the twelve years rainfall is recorded less than 200 mm, and same is the case of November and December. Total annual rainfall for the years 1973-2002 shows two trends. One is yearly fluctuation and second is decline in the total annual rainfall in Gangtok (Fig. 3.27). The maximum annual rainfall of about 4400 mm was recorded in 1978, while the lowest of 2400 mm was seen in the year 1982.

### DIFFERENCE IN CLIMATIC ELEMENTS IN TEMPERATE AND SUB-TROPICAL ZONES IN SIKKIM



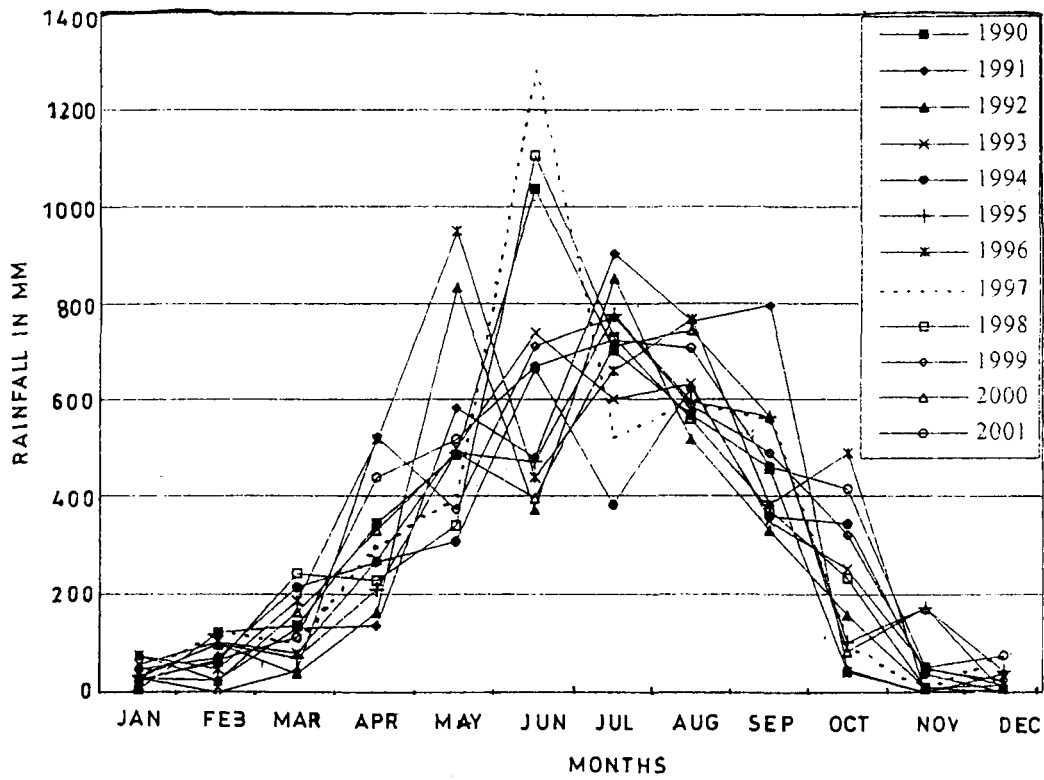
MONTHS

TEMPERATE  
 SUBTROPICAL

SOURCE : SIKKIM STUDY SERIES

FIG. 327

RAINFALL IN GANGTOK  
(1990-2001)



SOURCE : KRISHNA AND KUNDU, 2002

FIG. 3.28

### 3. 5. 2 Temperature

Temperature plays an important role in determining the weather and climate of a place. The temperature varies according to attitude, rainfall and nearness to the snow line in Sikkim. At places like Ranipool, Rangpo, Singtam, Jorethang and Namchi, which are situated at the low altitudes temperature varies from 6 to 36 degree C. For Example, at Namchi, which is the headquarters of South District, has recorded maximum of 35 degree Celsius and minimum of 6 degree Celsius. The maximum temperature is recorded usually during the months of July and August, and minimum during December and January. The mean temperature of the lower altitudinal zones varies from 4.5 degree Celsius to 18.5 degree Celsius, whereas at the higher altitudinal zones it varies from 1.5 degree Celsius to 9.5 degree Celsius (Anonymous, 2003). Sometimes, at night temperature falls suddenly and air becomes moist and misty. Further, foggy weather is a common feature in the entire state from May to September.

Table 3.20 shows the monthly maximum, minimum and average temperature of Gangtok (1986 to 1990). Gangtok gets maximum temperature of 23 degree Celsius and the minimum temperature of 18 to 26 degree Celsius in summer; it decreases to 12 to 2 degree Celsius in winter months.

**Table 3.20 Maximum, minimum and average temperature at Gangtok  
(1986-1990)**

Month	Temperature in °C		
	Maximum	Minimum	Average
January	12.1	3.4	7.8
February	13.8	4.7	9.3
March	17.0	7.8	12.4
April	20.1	12.1	16.1
May	21.5	13.7	17.6
June	22.1	16.0	19.1
July	21.4	16.4	18.9
August	21.9	15.9	18.9
September	21.2	15.3	18.3
October	21.0	15.4	18.2
November	17.0	8.3	12.7
December	14.4	6.2	10.3

Source: Agricultural Finance Cooperation Ltd., 1998.

**Table 3.21 Special weather phenomena of Gangtok**

Mean No of days	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Thunder	0.2	0.2	7.2	12.9	12.1	3.4	2.9	1.9	5.3	1.7	0.6	0.1	48.5
Hail	0.2	1.1	2.0	2.0	1.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	7.5
Dust storm	0.0	0.0	0.4	0.2	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.0
Fog (Thick)	3.1	3.7	1.3	2.9	5.9	13.4	17.8	17.8	11.9	7.1	2.6	3.3	90.8

Source: Sikkim: A Statistical Profile, (1979-1980 & 1991-1992)

From March to September thundering is common phenomenon associated with pre, during and post monsoon period. Hail storms occur in the pre-monsoon period. While fog is almost common through out the year, especially during the monsoon (Table 3.21)

**Table 3.22 Mean cloud cover and average wind speed at Gangtok  
(clouds in Octas)**

Month	0830 hrs	1730 hrs	Wind speed (km/h)
January	3.7	5.6	2.8
February	4.1	6.6	3.0
March	3.1	6.4	5.0
April	3.6	6.4	5.4
May	5.1	6.8	4.5
June	7.0	7.2	3.2
July	7.4	7.6	2.5
August	7.2	7.6	2.3
September	6.5	7.0	2.7
October	4.0	5.5	3.6
November	3.3	5.2	3.4
December	3.2	5.1	2.9
Annual	4.9	6.4	3.4

Source: Sikkim: A Statistical Profile (1979-1980 & 1991-1992).

Cloudy weather conditions and Gangtok are inseparable. Afternoon is cloudy almost daily, particularly in pre, during and post monsoon period (Table 3.22). Due to the severe cold waves during winters discomfort is felt in different parts of Gangtok, particularly in the higher elevations. Generally severe cold waves of highest intensity are experienced in the months of December to February. Table 3.23 reveals the frequency of cold waves at Gangtok. It shows that there is rise in the minimum temperature of Gangtok. The annual spells of cold waves and severe cold waves decreased gradually from 1990 onwards. One point is very clear that frequency of cold waves has over the years from 1981 to 2002, but one point is not sure- is it regional evidence of global warming phenomenon.

**Table 3. 23 Frequency of cold waves over Gangtok (1981-2002)**

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Frequency	7+1*	4+3*	8+6*	13+4*	21+6*	24+11*	6+3*	Nil	2+1*	3+1*	2+1*
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Frequency	1+2*	2	Nil	1	Nil	1	1+1*	Nil	3	Nil	Nil

\*Frequency of cold waves

Source: Meteorology Department Gangtok.

As far as the evaporation is concern Gangtok has experience less amount evaporation because Gangtok is located at an elevation of 1800 m from the mean sea level, hence temperature is not high to cause higher loss of water to atmosphere (Table 3.24).

**Table 3.24 Mean daily evaporation (mm) at Gangtok**

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1975	-	-	-	-	-	1.4	0.8	1.1	0.8	0.8	0.8	0.8
1976	0.7	0.9	2.2	1.9	1.5	0.9	0.7	0.8	1.1	0.9	0.6	0.7
1977	0.7	1.1	1.6	0.8	1.6	0.8	0.9	0.9	0.9	1.3	0.8	0.7
1978	-	0.9	1.6	1.8	1.2	1.3	1.1	1.1	0.8	1.1	0.6	0.9
1979	0.8	1.0	1.8	1.6	1.5	1.4	1.7	0.8	1.0	1.0	1.0	1.3
1980	0.7	0.5	1	0.4	1.1	1.1	1.3	0.9	0.8	1.4	0.9	0.9
Mean	0.7	0.9	1.6	1.5	1.4	1.1	1.1	0.9	0.9	1.1	0.8	0.9

Source: Sikkim A Statistical Profile 1979-1980

### 3.6 FORESTS

Forest is defined as a large tract of land covered with the different types of plant forms like shrubs, herbs and trees. It is a very striking feature of land surface. Ecologically, a forest is a plant community predominantly of trees and other woody vegetation, usually with a closed canopy. It is important to mention here that the forests

of the Eastern Himalaya are different from those of the Western and Central Himalaya. This differentiation is due to the high annual precipitation which is fairly well distributed almost throughout the year. Further, altitude and latitude also contribute to this variation of the forests of the Eastern Himalaya. Figure 3.29 shows different types of forest of the Eastern Himalaya according to the different altitudinal and physiographic zones. From tropical wet evergreen forests in the foothills (below 1000 m) to alpine stony desert, meadow and bush type vegetation in higher (above 4000 m) alpine zone are found in the Eastern Himalaya, including Sikkim. In between there exist sub-tropical and temperate forests.

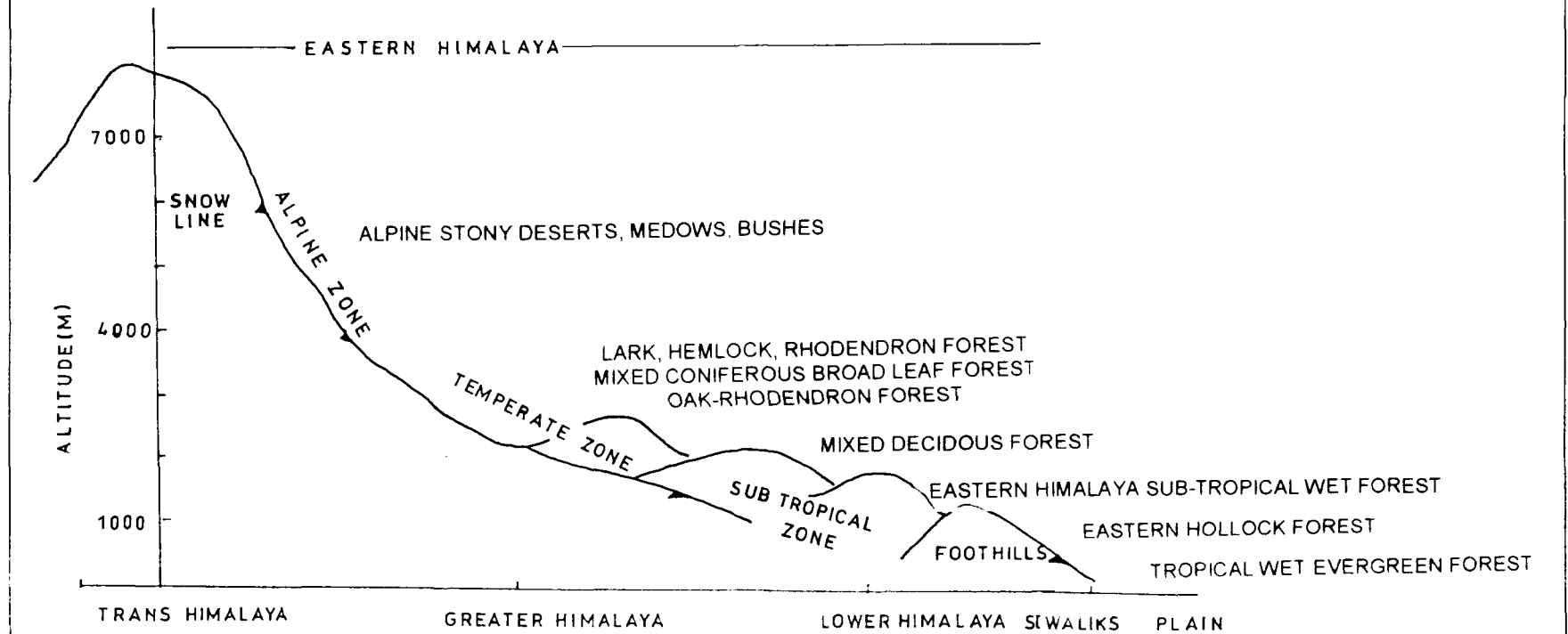
**Table 3.25 Classification of forest cover in Northeast India**  
(Figures in percentage)

State	Total	Reserved	Protected	Unclassified	Total	Shifting Cultivation (1987-97)
Tripura	0.63	0.36	0.05	0.22	0.63	0.06
Sikkim	0.26	0.22	0.03	0.01	0.26	*
Nagaland	0.86	0.01	0.05	0.80	0.86	0.39
Mizoram	1.59	0.71	0.36	0.52	1.59	0.38
Meghalaya	0.95	0.10	0.01	0.85	0.96	0.18
Manipur	1.50	0.14	0.40	0.96	1.50	0.36
Assam	3.07	1.81	0.40	0.89	3.07	0.13
Arunachal Pradesh	5.15	1.53	3.61	0.01	5.15	0.23
Total	14.01	4.88	4.91	4.23	14.02	1.73

Source: National Remote Sensing Agency (NRSA), Hyderabad.

Sikkim is endowed with very rich forests and still a large area is under forest cover (Fig. 3.30). Most of the deforestation is evident in the southern parts, however the blank areas of the north and northwest are mostly either snow covered or stony cold

# VERTICAL BELTS OF EASTERN HIMALAYA



SOURCE : KUMER, 1999

FIG. 3.29

SIKKIM  
FOREST COVER

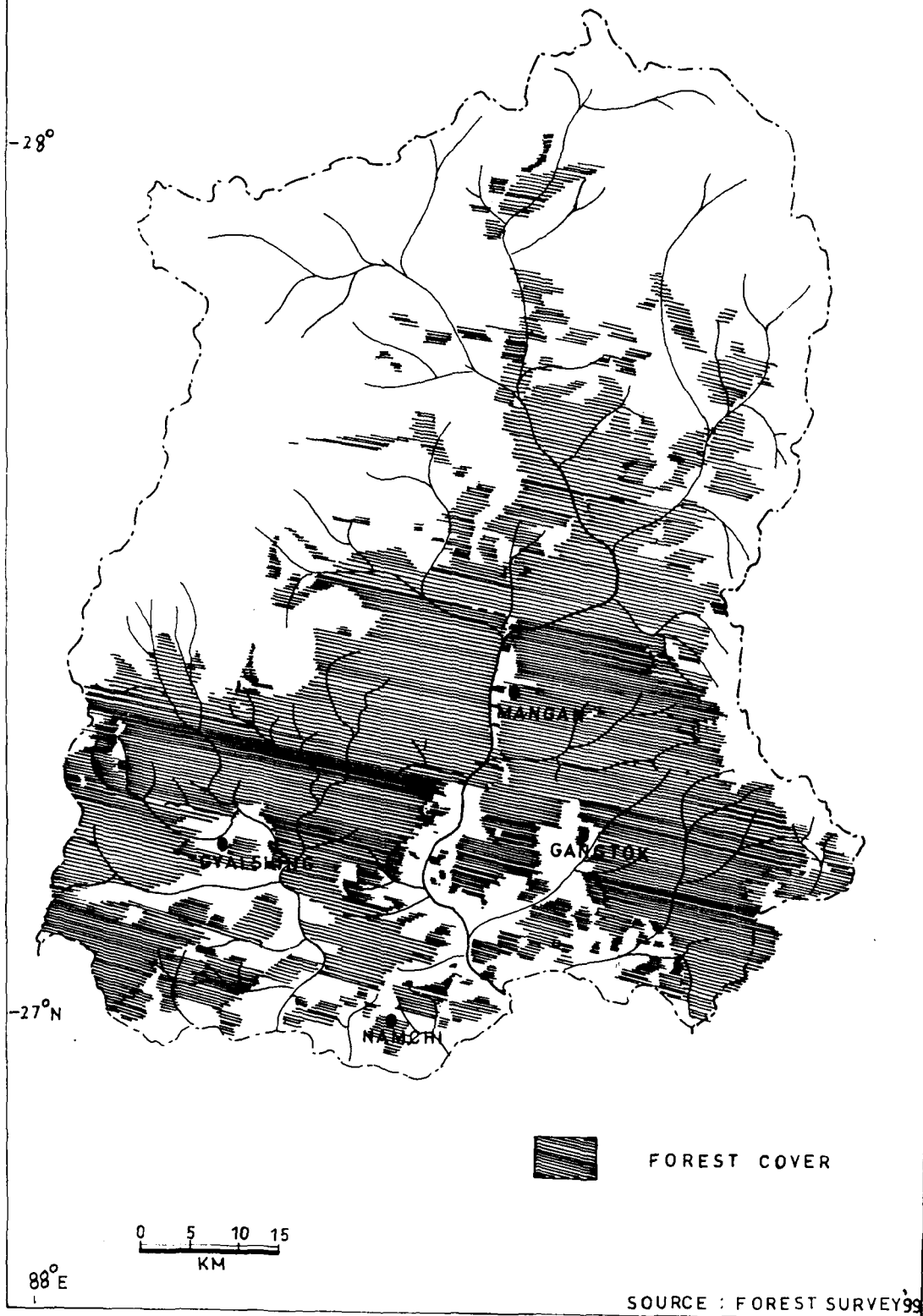


FIG. 3.30

desert areas. According to satellite data of November 1998, the total forest cover in Sikkim is 3,118 sq km, i.e. 43.94 per cent of the total geographical area of the state. Of this, dense forest accounts for 2,363 sq km and open forest 755 sq km (Table 3.25)

**Table 3.26 District wise forest cover in Sikkim (in sq km)**

District	Geographic area	1999 assessment		Total
		Dense forest	Open Forest	
North District	4226	847	223	1179
South District	750	421	129	550
East District	954	501	115	616
West District	1166	594	179	773
Total	7096	2363	755	3118

Source: Anonymous (2003-2004).

Sikkim has six distinct forest zones (Lama *et al.*, 2004) as under:

**Lower hill forest (200-900 m):** It consists of three main types viz., Sal forest, dry mixed forest and wet forest. Sal forests are generally confined in the Teesta and Rangit Valleys.

**Middle hill forest (900-1800 m):** The predominant of trees in this zone are *Musre Katus* and *Dalne Katus*. Besides, rhododendron, walnut and other trees are also noticed.

**Upper hill forest (1800-2450 m):** In this forest range species like Mawa (*Engelthardtica spp.*), Rani Champ (*Michelia excelsa*) etc. are common.

**Rhododendron and oak forest (2450-3555 m):** In this range the main trees are *Quereus Lamellosa*, *Quereus pacheyphylla* (mostly mixed with *Aar Camphilla*), Rhododendron etc. Rhododendron occupies the middle storey in the entire conifer forests of Sikkim.

**Conifer forest (2700-3500 m):** The distribution of conifer forest is dependent on the amount of precipitation. In the low rainfall zone of North District, most of the conifers are found.

**Alpine pasture (Above 3700 m):** It comprises of dwarf junipers and Rhododendron, extensive grassy meadows with *Dischampsia*, *Carstitosa*, *Salix Sikkimenses*, *Rosallal spp.* etc.

Being a high rainfall zone, the region is endowed with luxuriant vegetation, which is comprises with rich species diversity. Due to its humid climate and variation in altitudes at different places, there is an abundance of vegetation of all sorts (Chopra, 1979). Sikkim is believed to house more than 5955 species of Trees, Shrub, Orchids, Bamboo, Rhododendrons, and Medicinal plants. Important species include- Sal, Lali, Siris, Tarsing, Panisaj, Pipli, Arupati, Walnut, Bhujpata, and different varieties of junipers (Table 3).

**Table 3.27 Various floral species of Sikkim**

Diversity	Numbers
Flowering Plants	4500
Orchids	515
Rhododendron	36
Conifers	16
Bamboos	23
Ferns and Ferns Allies	362
Tree Ferns	8
Primulas	60
Oaks	11
Medicinal Plants	424

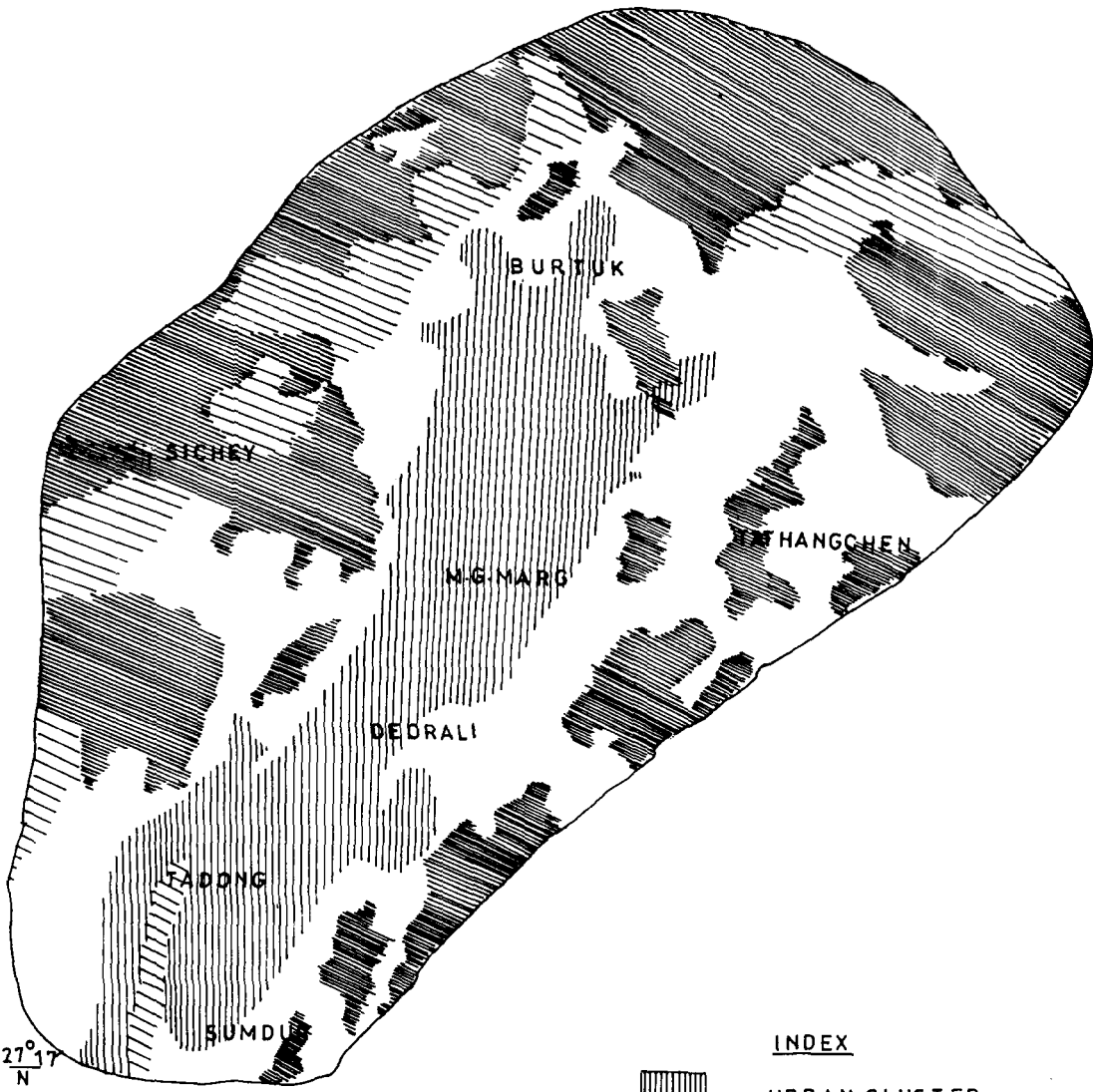
These species underline the socioeconomic importance of the forests. Dr. J. Hooker and Sir King have also written about the rich plant diversity of the region. Different medicinal plants and orchid species are also found all over the region. According to a report, more than 500 medicinal plants are found in different parts of the state, among which the famous species includes *Aconitum luridum*, *Acorus calamus*, *Oxoxylum indicum*, *Evodia fraxinifolia*, *A. foros* etc. Chopra (1979) has mentioned that a shrub 'Assam-lata' which has been found to be very useful for the cure of 'Kalaazar' grows wild in the Singtam and Rangpo area.

On the other hand, Sikkim is known worldwide for her orchids. More than 515 species of orchids of different genera are seen in Sikkim. Some famous variety as Vandas, Dendrobium, Cattleyas, Cyambidium, Uricefera Lancifolia, Cymbidium whiteal Goodyera dongcheni etc. are found in the different altitudinal zones. These orchids have great medicinal value also. For example, Gastrodia spp and Orchids habenarius. Various protected areas like Reserve Forest, Sanctuaries and Biosphere Reserves are the major habitat of this various forest diversities of the state.

It is mentioned earlier in Chapter-II that when Gangtok became the fourth capital of Sikkim during the regime of Chogyal Thudon Namgyal, it was a small village in the midst of the thick jungle surrounded by a few hamlets. During that period about 90 per cent area of Gangtok was covered by forests, because the population of Gangtok during the time was also very small. Now with the increase of population situation has changed. Figure 3.31 depicts forest cover of Gangtok as found in 2005.




# GANGTOK FORESTS COVER

27° 22'



27° 17' N

## INDEX

-  URBAN CLUSTER
-  DENSE FOREST
-  OPEN FOREST



88° 35' E

SOURCE : FIELD SURVEY 2004-05 AND IRS LISS III , 09-11-2002

FIG. 3.31

In fact, Gangtok has been already facing a number of problems due to rapid rise in population and it has a little scope for infrastructure development for availability of space. The degradation of forest diversity of Gangtok results from the hands of local people, who are primarily engaged in different constructional activities in and around of Gangtok. For example, constructions of roads, buildings, expansion of existing urban area etc. are the main causes of forest degradation in Gangtok. The ruthless deforestation of Sikkim over the years by the Army and Private contractors has led to gross ecological imbalance in Sikkim (*Telegraph* 20/06/1990).

Forest cover data for the year 1994 to 1998 reveals that 11 sq km forested land was lost in these years for various reasons in the state. The causes of depletion and degradation of forest are also related with phenomena like landslides, soil erosion, loss of soil fertility and loss of biodiversity of the state and Gangtok in particular. The different varieties of trees, herbs, and grasses are seen in the study area such as *Schima wallichii*, *C.tribuloides*, *M.villosa*, *Castanopsis tridica*, *M.villosa*, *Cinnamomum tamda*, *Ailanthus*, *Ardisia*, *Lobelia*, *Polygonum*, *Corlogyre*, *Vanda Cristata*, *Dendrobuim* etc. Beyond the suburban areas, there some cultivated fields of paddy. Large cardamoms are also seen in different parts of Gangtok, especially in sloppy areas. Bamboos clusters also exist.

Figure 3.31 depicts forest cover in Gangtok. It is shown as dense forest, open forest and urban cluster. The later simply means the built up area of Gangtok settlement. The dense forests cover 16.80 sq km area (i.e., 41.17 per cent). While 4.90 sq km area (i.e., 12.00 per cent) is under the open forests. It means 53.17 per cent area of Gangtok is forests, which is a good sign. But it is to be noted that most of the built up area is at the cost of forests

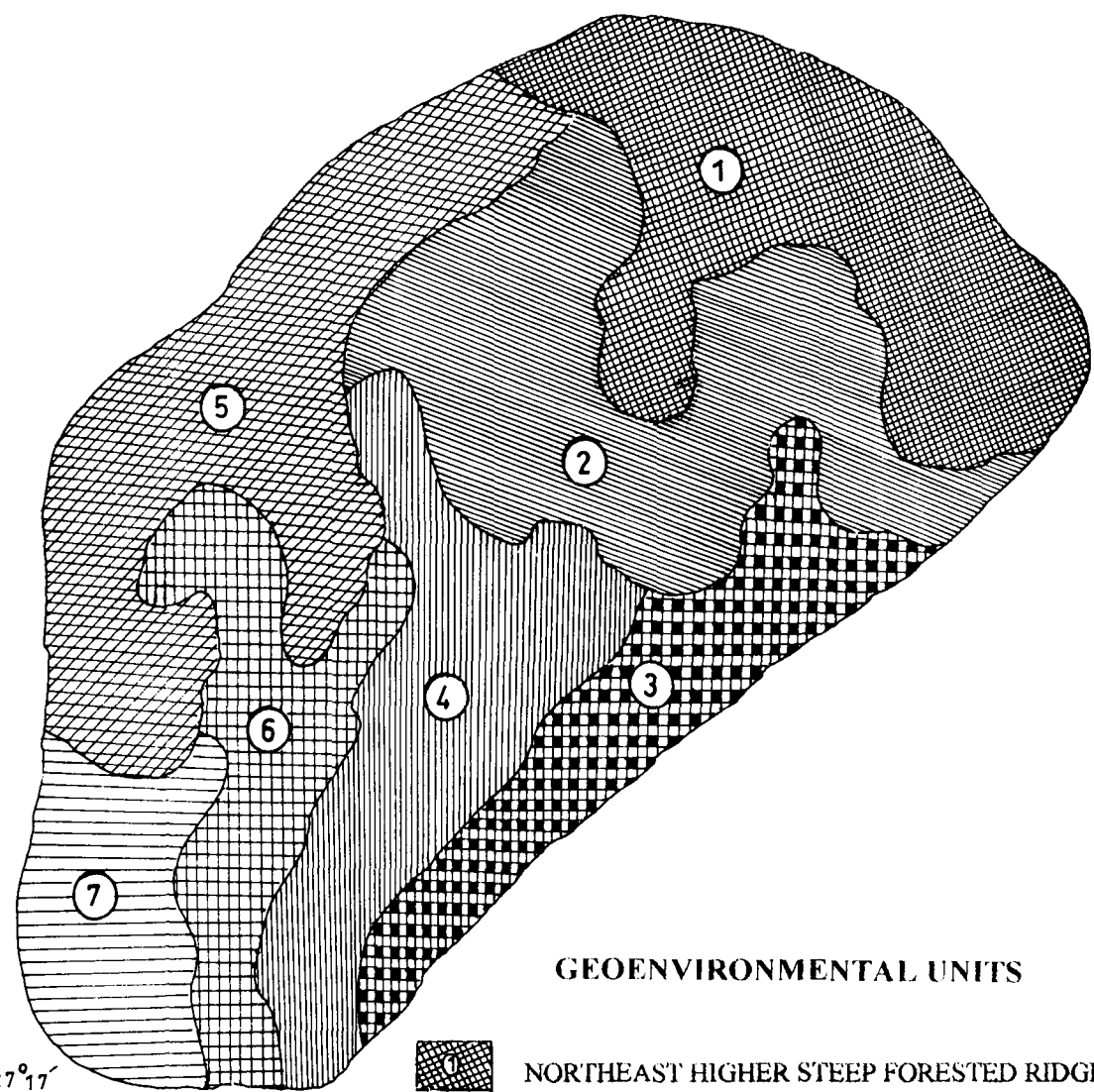
### 3. 7 GEOENVIRONMENTAL UNITS

As mentioned earlier delineation of geoenvironmental units is essential to comprehend totality of geoenvironmental appraisal of an area. After mentioning nature and characteristics of different components of geoenvironment of Gangtok, it worthwhile to understand the geoenvironment from holistic point of view, and also the variation within it. This is an attempt to demarcate areas having some sort of homogeneity in different elements of geoenvironment of Gangtok. It is like finding unity in diversity. Delineation of geoenvironmental units has been done by overlapping maps of landforms, slope, relief, geology, hydrology, soil and forest. Of course, in the hilly terrain, like that of the Himalaya Mountain, especially the ridge on which Gangtok is situated, slope and altitude are main variable/basis on which micro-level geoenvironmental units can be demarcated. The main purpose of this exercise is to see potential and constraint of geoenvironment in term of development of Gangtok. No doubt, the study area as whole is a microscopic unit in itself, but keeping in mind the ridge on which Gangtok is located, and growth and development of Gangtok, it necessary to understand further micro level variations in geoenvironment. It should also be made clear here that the landslide geohazard, which is an extreme phenomenon of geoenvironment has been discussed in details in Chapter IV. Altogether seven geoenvironmental units have been identified in the study area, details of which have been given in Table 3.28 and figure 3.32.








**GANGTOK  
GEOENVIRONMENTAL UNITS**

27°22'

27°17'  
N



**GEOENVIRONMENTAL UNITS**

-  1 NORTHEAST HIGHER STEEP FORESTED RIDGE
-  2 MIDDLE STEEP DEFORESTED RIDGE
-  3 EASTERN DEFORESTED STEEP RIDGE
-  4 LOWER CENTRAL DEFORESTED RIDGE
-  5 WESTERN FORESTED MODERATE SLOPE
-  6 DEFORESTED RANI VALLEY
-  7 SOUTHWEST DEFORESTED MODERATE SLOPE



88°35'E

FIG. 3.32

Table 3. 28 Geoenvironmental Units of Gangtok

Geoenvironmental Units	Area/km <sup>2</sup>	Localities	Characteristics
1. Northeast Higher Steep Forested Ridge	7. 21	Ganeshtok area, Rongek area, northeast Burtuk, VIP Colony, and Parts of Chandmari and Phatek area	Steep slope ranging from 50 <sup>0</sup> -70 <sup>0</sup> . Altitude between 1600m to 2400m. More than 80 per cent granite rocks, 20 per cent schist, phyllite and bended gneiss. Fine loamy and sandy loamy skeletal soils. Forest cover 70 per cent. Medium to high drainage density and drainage frequency.
2. Middle Steep Deforested Ridge	8. 32	Upper and Lower Burtuk Baluakhani, Zero Point, Development Area, Rajbhavan, Chandmari and Tathenchen area	Steep slope- 50 <sup>0</sup> -60 <sup>0</sup> , altitude 1200m to 1800 m. On about 70 per cent area schist, phyllite and bended gneiss, and on 20 per cent granite. Mostly sandy loamy skeletal and coarse sandy loam soils. Forest on only 10 per cent area. Moderate to high drainage density and drainage frequency.
3. Eastern Deforested Steep Ridge	5. 11	Western parts of Bhusuk Khola valley, Namnang area, and Cantonment area	Moderate slope- 30 <sup>0</sup> -50 <sup>0</sup> . Situated between 1000 m to 2000 m. Schist, phyllite and bended gneiss on 60 per cent area, by quartzite on 30 per cent and on 10 per cent granite gneiss. Sandy loamy skeletal, coarse sandy loam and partly fine loamy soils. Forests on 30 per cent area. Moderate drainage density and drainage frequency.

4. Lower Central Deforested Ridge	5. 10	Palzor stadium, Diesel Power House, Hospital area, Palace, Secretariat, Deer park, Govt. Press, Pani House, Deorali, Syari, and part of Lower Tadong	Moderate slope- 30 <sup>0</sup> -50 <sup>0</sup> . Altitude between 1000 m to 1600 m. On 65 per cent area schist, phyllite and bended gneiss, on 25 per cent quartzite and on 10 per cent by granite. Mostly coarse sandy loamy soil. Merely 10 per cent under forest. Low to high drainage density and drainage frequency.
5. Western Forested Moderate Slope	7.75	Upper and Lower Sichey, Govt. India Press area, and northern part of Arithang	Moderate slope, ranging from 30 <sup>0</sup> -45 <sup>0</sup> . Situated between 1000 m to 1800 m. Schist, phyllite and bended gneiss (>70%), quartzite (25 %), and rest is granite. Sandy loamy skeletal, coarse sandy loam and partly fine loamy fragmented soils. Forests on 85 per cent area. Moderate to high drainage density and drainage frequency.
6. Deforested Rani Valley	4. 50	Sialgaon, Phewabasty, Upper and Lower Tadong, 5 <sup>th</sup> Mile and Sumdur	Moderate slope (30 <sup>0</sup> -50 <sup>0</sup> ). Situated between 900 m to 1400 m. Schist, phyllite and bended gneiss (> 65%), quartzite 20 per cent and granite 15 per cent. Coarse sandy loamy soil. Forests only on 5 per cent area. Moderate drainage density and frequency.
7. Southwest Deforested Moderate Slope	2. 82	Lumseybasty, 6 <sup>th</sup> Mile and part of 5 <sup>th</sup> Mile area	Low moderate slope ( 30 <sup>0</sup> -40 <sup>0</sup> ). Altitude below 1200 m. Covered with schist, phyllite, and bended gneiss. Coarse sandy loamy to fine loamy fragmented. Open forests on 10 per cent area. Moderate to high drainage density and frequency.

Source: *Field work and different literature*

Layers of different variables have been overlapped to demarcate the seven geoenvironmental units. The main purpose of the geoenvironmental units is to see the totality of the geoenvironment and variations within it within the study area. The unit two, i.e., Middle Steep Deforested Ridge is the largest in area, while unit seven is the smallest. Geoenvironmental unit one- Northeast Higher Steep Forested ridge and the unit three- Eastern Deforested Steep Ridge have constraints for the development in Gangtok. In other words, no further expansion should take place in these units, as first one is the area to be kept free from any disturbance, while the second area is too steep to develop, otherwise it will invite more geoenvironmental problems. On the other hand, location of the main settlement on unit two- Middle Steep Deforested Ridge is a matter of great concern, for it is a steep slope area on which thousands of RCC buildings have come up which are at great risk in the event of an earthquake or a landslide. It appears that entire area may slide down one day either during a cloud burst, which are very common, or may crumble and collapse during an earthquake, as it happened recently on 14<sup>th</sup> February, 2006. Keeping the characteristics of geoenvironmental units in mind it can be suggested that no further expansion should take place on the steep slopes and in forested areas. These two places should be kept free from human interference, otherwise more problems will follow. Moreover, on the steep slopes and sites of landslide, fast growing vegetation should be grown which can hold the slope material. Channels in the upper parts of the landslide area should be diverted to check role of runoff and infiltration of rainwater in triggering landslides.

## **CHAPTER- IV**

# **GEOHAZARDS OF GANGTOK**

After comprehending geoenvironment of Gangtok, it is important to discuss geohazard aspect of it. In fact, natural hazards are an indispensable part of physical environment of an area. Likewise, geohazards are part of geoenvironment, therefore, landslides geohazard of Gangtok has been discussed in the following lines. Nevertheless, before, coming to that, it would not be out of place to mention about 'hazard', its causes and affects in general.

Hazard is defined as a dangerous condition or an event that threatens or has the potential for causing injury to life or damage to property or the environment. WHO (1999) has defined 'hazard' as 'any phenomenon that has potential to cause disruption or damage to people and their environment'. A hazard is any activity, situation or substance that can cause harm. Hazard implies the probability of a destructive phenomenon occurring as a product of nature such as a landslide, a flood or a volcanic eruption; it is a natural hazard (Kale and Gupta, 2001). Hazards can be categorized in various ways on different basis. Worldwide the most common and broad category based on causative factors is- i) Natural, and ii) Anthropogenic or man-made hazards. Natural hazards are always the manifestation of geological, geomorphological, meteorological, and biological processes. Natural hazards include-earthquakes, tsunamis, volcanic eruptions, landslides, avalanches, tropical cyclones and other windstorms, floods, wildfire, drought, locust

infestations etc. Natural hazard is a term indicating action of abrupt modifying natural events, such as floods, droughts, earthquakes landslides and the like ---, (O’Riordan, 1986). According to Burton *et al.*, (1978) natural hazards are those elements of the physical environment, harmful to man and caused by forces extraneous to him. More specifically natural hazards refers to all atmospheric, hydrologic, geologic and wildfire phenomena that because of their location, severity, and frequency, have the potential to affect humans, their structures or their activities adversely. It is important to note here that human intervention can increase the frequency and severity of natural hazards. For instance, when the toe of a hill slope is removed to make room for a settlement or road, the earth can move and bury the settlement or road. Further, it also causes natural hazards where none existed before. In short, the natural hazards are hazardous events that cause unacceptably large numbers of fatalities or overwhelming life and property damage. Hazard is believed to be a natural event expected to occur in a definite spatio-temporal definition (Pirazizy, 1992).

Geohazards, however, are the result of complex interaction between various natural geosystems. According to White (1974) where there is perfectly accurate predictions of what would occur and when it would occur in the intricate web of atmospheric, hydrologic, and biological systems, there would be no hazard. Natural hazards are not a product of development. They have always been a part of life, and people develop coping with the mechanisms of it over time to deal with the threats posed by their environment.

Natural hazards further can be divided as i) Geologic or geomorphic or geohazards, ii) Biotic, and iii) Atmospheric hazards. The main types of geohazards are earthquake, landslide, tsunami, avalanche, volcanic eruption, flash flood, soil erosion, slope failure, sinking, subsidence, etc. Actually, geohazard problems exist over a wide range of space and time and also pose serious threat to life and property in the world.

Besides the natural hazards, there are other types of hazard which also pose serious and dangerous threat to life, property and environment, such hazards are categorised as anthropogenic or man-made hazard, e.g., fires, flash floods due to breach of dams, nuclear radiation, pollution of land, water, air, etc. Indeed, traditionally natural hazards have been viewed in an ecological framework. The concept of hazard is incomplete with out human perspective, meaning when man and his property is affected by a natural process or event then only it is called hazard. Otherwise, occurrence of such phenomena in the wilderness, where no man lives, is not termed as hazard. This distinguishes between natural events and their interpretation as natural hazards (Pandey, 2002).

It is important to note here that geohazards are always linked and associated with natural disaster, vulnerability and risk. Often, the word 'natural disaster' is used to mean the natural hazard. Following discussion gives the clear idea about the vulnerability, risk and natural disaster.

### **A. Natural Disaster and Natural Hazard (H)**

Natural Disaster is defined as a serious disruption of the functioning of a society, causing widespread human, material or environmental loss which exceeds the ability of the affected society to cope using its own resources. A disaster is a product of hazard such as earthquake, flood or windstorm coinciding with a vulnerable situation that might include communities, cities or villages. In fact, without vulnerability or hazard there is no disaster. A disaster occurs when hazards and vulnerability meet. According to World Health Organisation (1995) a disaster can be defined as any occurrence that causes damage, ecological disruption, loss of human life or deterioration of health and health services on a scale sufficient to warrant an extra ordinary response from outside the affected community or area. The various forms of natural disasters are basically natural forces, what are seen afterwards are the results of the impact of these forces on human being. Disasters and catastrophe are almost always used in relation to human life or property loss. Large earthquakes or floods in uninhabited parts of the world are not commonly described as disastrous; it is merely a geomorphological event. Whereas, much less violent earthquake, involving loss of human lives and property in densely populated area, is a major disaster (Mukherjee 2002). According to Varnes (1984) Natural Hazard (H) means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon.

### **B. Vulnerability (V)**

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 particular hazard,

on account of their nature, construction and proximity to hazardous terrain or disaster prone area. Vulnerability means the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude. For example, a badly constructed brick building is more likely to disintegrate with the violent ground shaking of an earthquake than cane or thatch hut. Vulnerabilities can be physical, social, or altitudinal and can be primary or secondary in nature. Social and economic conditions also determine the vulnerability of a society to an extent. In short, vulnerability may be defined as the degree of susceptibility to natural hazards, which is indicated by the product of a set of prevailing conditions within which disasters may occur. These conditions may be different from different sections of the society. Depending upon the vulnerability, hazards affect different sections of the society in different ways, all subject to community specific characteristics that make them vulnerable (Satendra, 2001). It express on a scale from 0 (no damage) to 1 (total loss).

### **C. Risk (R)**

The risk management standard defines 'risk' as the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood. Total Risk means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon and consequently the product of specific risk and elements at risk. On the other hand, 'specific risk' ( $R_s$ ) means the expected degree of loss due to a particular natural phenomenon. It is a function of both natural hazard and vulnerability. It may be expressed by the product of  $H$  times  $V$ . Whereas, Element at Risk ( $E$ ) means the

population, properties economic activities, including public services, etc. at risk in a given area. The extent to which risk is either increased or diminished is the result of the interaction of a multitude of causation chains of events. The concept of risk combines the understanding of the likelihood of a hazardous event occurring with an assessment of its impact. Hazardous events can either be naturally occurring or they can be man made. Moreover, event can be sudden, as in the case of an earthquake; or they can occur over a period of time, as in the case of most geohazards. The impact of a hazardous event depends on the elements at risk, such as population or buildings, and their associated vulnerability to damage or change as a result of the event. Total risk can be expressed simply in the following pseudo-mathematical form:

$$\text{Risk (Total)} = \text{Hazard} \times \text{Elements at Risk} \times \text{Vulnerability}$$

$$(R_t) = (E) (R_s) = (E) (H \times V)$$

Where, Risk = Total Risk

Hazard = Natural , Unnatural and Anthropogenic hazards

Elements at Risk = means the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure etc., at risk in a given area

Vulnerability = the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude.

Varnes (1984) pointed out that the French word '*risque*' should be regarded as equivalent to the English work hazard. Whereas risk can be expressed as:

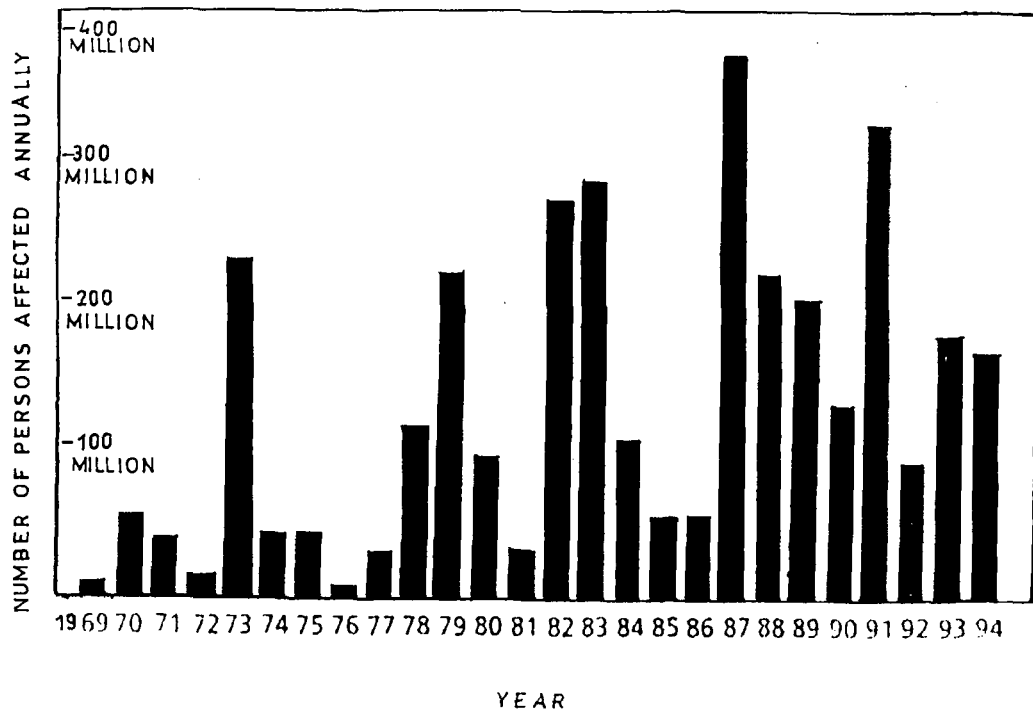
$$\text{Risk} = \text{hazard} \times \text{Potential worth of loss.}$$

Natural processes become natural hazards when they have a negative impact on human activities. The basic premise of natural hazards, therefore, involves the interaction of physical processes and human activity (Pandey, 2002). Geohazards affect health and well being of people, but frequently a large number of people are displaced, killed, injured, or subjected to greater risk of epidemics. It can do great harm to the economy, existing infrastructure and threatens the future of sustainable development. The world is becoming increasingly vulnerable to various types of geohazards and natural disasters.

Nearly three million people worldwide are believed to have been killed in the past 20 years due to the geohazards and natural disaster like- earthquakes, tsunamis, landslides, floods, cyclones, snow avalanches, fires, tornadoes etc. According to United Nations report, in 2001 alone, natural disasters of medium to high range caused at least 25,000 deaths around the world, and economic losses of around US \$ 36 billion. Between the years 1991 to 2000 Asia has accounted for 93 per cent of its population being affected by geohazards and disasters. Figure 4.1 shows the statistics of affected people worldwide between 1969 and 1994. It is clear from it that the number of persons affected by the disasters was very high during 1973, 1979, 1982, 1983, 1987-89, 1991 and 1993-94. Heartening to note that firstly the number of affected persons has been increasing over the years, and secondly the frequency of years with high number of affected persons has also increased lately.

India is struck almost each year by different geohazards. In India 54 per cent of land mass is prone to earthquakes, 70 per cent of the cultivable land is prone to drought, 12 per cent to floods, 8 per cent to cyclones, 85 per cent is vulnerable to a number of

### NUMBER OF PEOPLE ANNUALLY AFFECTED BY DISASTERS IN THE WORLD



SOURCE : WHO,1999

FIG.4.1

natural hazards and 22 states are recognized as multi-hazard states (Anonymous, 2001). Tens of thousands of people are affected by these natural hazards every year. For example, the Orissa cyclone of 1999, The Bhuj Earthquake in 2001, and the Tsunami of 26<sup>th</sup> December, 2004 which badly struck Andaman-Nicobar and part of South India. Geohazards not only damage the lives and property but also lead to enormous economic losses. In the Gujarat earthquakes, more than 19,000 lives were lost, ten lakh houses were damaged and the asset loss has been estimated to be worth Rs. 15,000 crores, while the total expenditure on relief and reconstruction has been to the tune of Rs. 11,500 crores. Here, it is interesting to note that 90 per cent of the natural disasters and 95 per cent of the total disaster related deaths world wide occur in the developing countries in which India has the second largest share (Anonymous, 2001)

However, frequent occurrence of hazards such as landslides, snow avalanche, flood and other types of mass wasting is becoming a common feature in mountainous regions (Gardner *et al.*, 1992). Geohazards are more prominent in the mountainous areas as compared to other parts of the earth. Mountainous areas tend to be prone to a wide range of potentially hazardous geomorphic, geologic, atmospheric and hydrologic processes, such as rock falls and avalanches, landslides, debris flow, soil erosion and snow avalanches in higher ridges. The unique geoclimatic conditions of the Indian subcontinent make the Hindu-Kush Himalaya Region among the most vulnerable to geohazards and natural disasters in the world. Earthquakes, landslides and avalanches occur very frequently and often devastatingly in the Himalaya Mountain (Valdiya, 2000).

In fact, the mountainous regions of Northeast India, including the Sikkim Himalaya, are prone to different types of geohazards viz., earthquakes, landslides and avalanches, soil erosion, etc. The study of mountain environment including its resources, hazards and sustainability are now the common concern of geographers, geomorphologists, geologists, geophysicists and environmentalists of all over the world. Therefore, an intensive and in-depth study of geohazards is very important for planning and development of areas like Gangtok. Sikkim Himalaya as a whole is more prone to avalanches, landslides and earthquake geohazards, however the landslides particularly affect Gangtok. No doubt, earthquakes do affect the study area every now and then, as this geohazard covers a vast area when it occurs, unlike the site specific landslides, discussion on earthquake has already been given in Chapter III under geologic component of geoenvironment. Landslide hazard is regarded as one of the most disastrous geohazards because of its severity, extension, and affects. Therefore, in the following lines, different aspects of landslide geohazard of Gangtok have been discussed.

#### **4.1 LANDSLIDES**

Before discussing landslide geohazards of Gangtok it would be worthwhile to describe about the landslide as a natural phenomenon, factors responsible for it, occurrence of major landslides in the world, India, Himalaya, and damage to lives and property by the landslides etc. Such a background will help to understand the process of occurrence of landslides and the gravity of the problem it causes for man and environment.

A landslide is the rapid sliding of large mass of bedrock (Strahler and Strahler, 1996). It is a movement of mass of rocks, debris or earth down the slope, under the force of gravity, wherever, the mountain slopes are steep, and there is a possibility of large, disastrous landslides. A landslide occurring in a village or town is a hazard, while in a remote unpopulated terrain, it would be like any other geographical event regardless of its intensity and dimension (Shrivastava, 1998). Landslide is the best manifestation of slope instability or slope failure. Under natural conditions material of a hill slope remains at its place, but when some geologic and geomorphic processes operate, the slope stability may be disturbed, leading to sliding of the material under the force of gravity. It comes under the mass wasting process of gradation. The rapid movement of a mass of rock, debris or earth down the slope separated from the stationary part of highlands produces disastrous affects on the natural environment and man made structure, weakens infrastructure facilities, makes people homeless and disrupts the productive base. Landslide is very much a natural process linked to a long chain of mass wasting process which has been operating and will continue to do so on the surface of the earth to maintain equilibrium between areas of high and low relief and can seldom be attributed to a definite cause. Landslides occur almost universally, usually as a function of the slope of the terrain and natural and human actions that reduce the resistance of sliding rocks or soils comprising the slope.

Generally, landslide is considered a type of slope failure in which movement takes place along a single or several sets of discrete shear planes (Shrivastava, 1998). Whilst the causes of movement of slope can be quite complex, all slides have two things

in common- i) they are the result of failure on part of the rock and soil materials that make up a hill slope, and ii) they are driven by gravity. Landslide can vary in size from a single boulder or rock fall or topple to tens of millions of cubic metres of material in a debris avalanche. Landslides can be triggered by earthquakes, volcanic eruptions, soil saturated by heavy rain or a rise in ground water levels and river undercutting. Severe earthquakes in mountainous regions are a major cause of landslides. For example, the Hebgen Lake earthquake of 1959 caused The Madison canyon landslide in Montana. Further, saturated soil shaken by earthquakes creates particularly dangerous conditions. In short, landslides are downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or a combination of all these materials along surface of separation by falling, sliding and flowing at a faster rate but under gravitational force. Rapid movements of sliding rocks, separated from the underlying stationary part of the slope by a definite plane of separation, are termed as landslides (Zaruba and Menel, 1982).

Occurrence of landslide is considered the most complex phenomenon under mass wasting, still many points are not clear, such as what causes a body of slope material to slide down, when the threshold is broken to cause slope failure etc. "In fact, water has a complex effect on the sliding friction between surfaces of rock-forming minerals, increasing the friction for quartz, feldspar, and calcite but decreasing it for the sheet like mica minerals" (Mitchell, 1976: 310-313, *cf.* Bloom, 2003: 169). Laboratory experiments have been conducted to find out the reality behind the sliding of material. Then it is concluded that "the coefficient of sliding friction of a particle is equal to the ratio

between the down slope component of weight and the component of weight acting perpendicular to the slope when the particle is moving” (Bloom, 2003:169).

Landslides do not occur in isolation, but also they are products of their environment and in response influence the environmental conditions (Crozier, 1986). However, environmental stability, especially in case of slope failures, can be defined as the ratio of resilience to stress, that can be indicated as:

$$\text{Stability} = \frac{\text{Resilience}}{\text{Stress}}$$

Petley (1984) also discussed the slopes, defining them as:

$$F_s = \text{Shear strength/shear}$$

If  $F_s > 1.0$  stability is likely, but if  $F_s < 1.0$  instability exists

#### **4.1.1 Classification of Landslides**

Indeed, the material moves down slope under gravity may range in texture from clay to boulders and large chunks of broken bedrock. It can be classified on the basis of the mode and rate of the movement, the shape of the slide surface, the type of material involved and so on. Further, there is broad international agreement that the definitive criteria of mass movement i.e., landslides should include: i) the type of material in motion including its coherence and dimensions, and ii) the type and rate of movement whether falling, toppling, sliding, spreading, or flowing (Cruden and Varnes, 1996). Classification of landslides have been proposed by different scientists in different times viz., Sharpe (1983), Varnes (1958, 1978), Hutchinson (1968), Carson and Kirkby (1972), Dume and Leopold (1978) etc. A general classification of landslides (Table 4.1) in generalize version was given by Dunne and Leopold (1978).

**Table 4.1 Classification of slope movement**

Types	Sub Types
Fall	Rock falls, debris fall, topples.
Slides	Planer slides: Could be in different material and hence further subdivided as rockslides, debris slides, mudslides etc.
Flow	Debris avalanches, debris flow, earth flow, mud flows, Lahars, Solifluction.
Creep	Soil Creep

Source: After Dunne and Leopold (1978).

Cruden and Varnes (1996) have given the latest abbreviated classification of the landslides (Table 4.2). According to them there are five types of landslides- fall, topple, slide, spread and flow.

**Table 4.2 Abbreviated classification of slope movement (landslides)**

Type of movement	Type of Materials		
	Bed Rock	Engineering soils predominantly coarse	Predominantly Fine
Fall	Rock Fall	Debris Fall	Earth Fall
Topple	Rock Topple	Debris Topple	Earth Topple
Slide Rotational (Slump) Translational	Rock Slide	Debris Slide	Earth Slide
Spread	Rock Spread	Debris Spread	Earth Spread
Flow	Rock Flow	Debris Flow	Earth Flow

Source: After Cruden and Varnes (1996).

Based on age landslides can be considered contemporary or ancient. While on the basis of current activity/movement landslides can be active, dormant and relict or stabilized. Active landslides are easy to recognize from their configuration, because their surface forms are fresh, conspicuous, and yet not affected by rain-wash and erosion. Trees are diverted from their original position, roads and tracks traversing the affected area are interrupted, and buildings are often damaged. Dormant slides usually overgrown or obscured by erosion, so that traces of the last movement are difficult to discern. Since

the slide-provoking factors are still operating, the movement may recur. Stabilized landslides, which were initiated under morphological and climatic conditions that cannot occur today, are permanently at rest (Krishna and Kundu, 2002).

#### **4.1.2 Causes of landslides**

Landslide can occur due to a number of factors and causes. These include saturation of slope material from rainfall or seepage; vibration caused by earthquakes; undercutting of cliffs by waves, rivers or by human activity. Besides, landslides can occur due to inherent weakness in geological settings, critical geomorphic features, geotechnical instability, excessive rainfall, deformation and soil erosion, unplanned constructions and excessive ground water seepage. Moreover, the most common cause of landslide is the resisting force, the shearing strength of the material acting along potential slope, may be decreased by excess moisture, and a state of disequilibrium created by the pore pressure. Excess of free water may even convert the material into a suspension, totally or almost deprived of shearing strength.

In fact, landslide is the result of the interaction of geological and geographical environment. Earthquake and rainstorms constitute two of the most important landslide inducing agents (Deoja et al., 1991). Major causative factors of landslide mentioned by them are as follows:

##### **A. Natural Factors**

1. High relief or steep slopes
2. High weathering of the rocks
3. Heavily fractured rocks because of intense folding and faulting

4. Extensive development of weak rocks, e.g., phyllites, slates, schists etc.
5. Seismic activity
6. Concentrated precipitation
7. Undercutting of the banks by deeply incised river and streams

#### **B. Anthropogenic Factors**

1. Intensive deforestation
2. Improper land use
  - i) agricultural practices on steep slopes
  - ii) irrigation on steep vulnerable slope
  - iii) overgrazing
  - iv) quarrying for construction material without considering the condition of the terrain

#### **C. Construction Activities**

- i) improper and haphazard constructional activities in high and steep slopes

Moreover, the types of slope and the angle of slope always have a great influence on landslides events. Straight slopes seldom have landslides and falls, but landslides are common on the convex, concave and the complex slopes. The places where the landslides or falls have occurred are mostly steeper slopes. It is revealed from the earthquakes data of China from 1973 to 1976 that landslide were not found on slope with a slope of less than 25 degree. Ninety per cent of the landslides occurred on slope with a slope angle

ranging from 30 degree to 50 degree. In most cases, falls happens on slopes with a slope angle of 67 degree to 75 degree (Deoja et al., 1991).

Rainfall is another most triggering agent of landslides. Generally, there is a direct correlation between the amount of rainfall and incidence of landslides ((Deoja et al., 1991). The relation between the rainfall and landslide is mentioned below:

i) The cumulative precipitation of an area amounts to about 50 mm to 100 mm in one day, and daily precipitation is more than 50 mm, somewhat small landslide will occur.

ii) When the cumulative precipitation over two days amounts to about 1500 mm, the daily precipitation is about 100 mm; the number of landslides has a tendency to increase with precipitation.

iii) When cumulative precipitation exceeds 250mm over two days and has an average intensity of more than 8 mm per hour in one day, the number of large and vast landslides increases sharply.

Landslides take place due to several reasons, some of which include causative factors whereas there are other either triggering or catalytic in nature facilitating this phenomenon to take place (Krishna and Kundu, 2002). The main factors which influence land sliding are discussed and elaborated by Nilsen and Brabb (1973), Varnes (1981,1984), Hutchinson (1997), Bhandari (1987), Singh (1989), Deoja et al., (1991),

Mehrotra et al., (1993), Singh and Pandey (1996), Anbalagan (1997), Satyanarayana and Cheema (1998), Yudhbir (2000), Shah (2001) and Krishna and Kundu (2002).

#### **4.1. 3 Affects of Landslides**

The unprecedented exploitation of natural resources and development of infrastructural facilities of housing, transportation and power sectors in high risk landslide-prone areas, such as mountains and hill slopes, have increased the incidence of landslides to its own peril. In landslides, the natural slopes that have established a delicate balance with local geology, long-term geomorphology processes, and climate are unable to continue to hold the rock and soil comprising it. Because of disturbance, a large volume of material moves down the slope, known as landslide. Although landslides are a local phenomenon, the total loss of life and property due to landslides is far greater than any other hazards. For example, in Japan alone between 1938 and 1981, nearly 5000 people were killed and 2,90,000 houses were destroyed or badly damaged by debris flows caused by heavy rainfall. In Kobe alone debris flow generated by torrential rainfall in January 1938 caused 450 to 600 deaths and destruction of more than 1,00,000 houses. Earthquake triggered landslides in Kansu province (China) in 1920 destroyed dozens of villages and killed nearly 1,00,000 people. Similarly, massive landslides in 1949 in Tershan Mountains (CIS) triggered by an earthquake buried some 33 settlements killing an estimated 12,000 to 20,000 people. In Peru also three major landslides, during the past 20 years killed more than 20,000 people and destroyed agricultural lands, highways, bridges, culverts etc. (*google.com/ natural disasters*).

**4.1.3.1 Landslide Affected Areas in India:** Vast expanse of areas in India, particularly in the Himalaya Mountain and other hilly terrains, being highly fragile, are perennially under repeated threats of landslides and mass movements. Landslides and other mass movement are serious geoenvironmental hazards in the Himalaya. Massive landslides killing tens of thousands of people with catastrophic damages have occurred in the Eastern Himalayan state of Sikkim (Bhasin et al., 2002). Increase in population and rapid urbanization catapulted frequency of landslides to dramatic proportion in recent decades. It is worth mentioning that the landslides are among the major, hydro-geomorphological hazards that affect large part of our country, especially the Himalaya Mountain, the Northeastern hill ranges, the Western Ghats, the Nilgiris, the Eastern Ghats and the Vindhyan Range.

High rate of mass wasting is found in the young folded Himalaya Mountain, hence the people inhabiting the region face great hardship due to the inherent fragility of the terrain. This is reflected in recurring natural hazards, particularly landslides (Rautela and Lakhera, 2000). Landslide hazards in the Himalaya are due to some complex processes and are most commonly triggered by precipitation. The combination of geological, geomorphic, atmospheric, seismic factors and human activity govern the occurrence of landslides (Joshi and Naithani, 2002). In fact, landslides are considered to be an unfortunate consequence of increased mountain development activity (Eisbacher, 1982). Then, there are landslides in the Western Ghats in the South India, along the steep slopes overlooking the Konkan Coast. Landslides are also very common in the Nilgiris. Some of the worst landslides of India have occurred in Sikkim and Darjeeling Himalaya

in 1968, killing thousands of people. These landslides occurred over a three days period due to heavy precipitation ranging from 500 to 1000 mm in an event of a 100 years return period. The 60 km mountain highway to Darjeeling was cut off at 92 places resulting into total disruption of communication system. Yet another landslide tragedy of unprecedented dimension occurred in the Alakananda valley in July 1970, which was a result of a massive flood in river Alakananda. The great Malpa Rock avalanche of 1998 killed 220 people and wiped out the entire village of Malpa in the Kumaon Himalaya. Another worst hit landslide in South India was Amboori landslide in Kerala in 2001, which killed 23 people. In the worst landslides of the recent times mention may be made of the Runnymede landslide in Nilgiri hills, the Glenmore landslide, the Karadipallam landslide, and the Conoor landslide took more than hundreds lives and heavily damaged the property (*google.com- natural disasters*).

It is clear from the Table 4.3 that landslides in different parts of India take a heavy toll on life and property every year. In fact, they are one of the most significant contributors to aggregate national losses caused by hazards and disasters, both of property and lives. Several major landslides have occurred in the recent past in the geodynamically sensitive entire belt of the Himalaya, resulting in large-scale damages to life and property. Indeed, different types and categories of landslides are take place in the Himalayan region every year. These diverse landslides are the direct and indirect result of the natural and manmade factors. Table 4.4 shows some historical landslide events in the Himalayan Belt, and that indicate susceptibility of the Himalaya to landslides.

**Table 4.3 Some recent disastrous landslides in India**

<b>Location</b>	<b>Month/Year</b>	<b>Damages</b>
Himachal Pradesh	December, 1982	About 1.5 km of NH-22 vanished
Nashri, Jammu & Kashmir	January, 1992	The slide is repeated every year since 1953. Roads, bridges and communication lines disrupted.
Himachal Pradesh	March, 1989	At Nathpa, about 500 m of road was damaged. Roads in frequently blocked due to sliding.
Nilgiris	October, 1990	More than 30 people killed and several injured. Roads, buildings and communication lines disrupted.
Assam	July, 1991	Lost more than 300 people damaged roads, buildings etc. Heavy lost of property.
Uttarakashi, U.P.	1991	More than 2000 lives lost road and other communications completely disrupted in the areas, houses and bridges damaged.
Nilgiris Hills	November, 1992	Roads and communication network damaged and property worth Rs. 5 million was destroyed.
Mizoram	June, 1993	Lost lives and property
Arunachal Pradesh	July, 1993	25 people buried in the debris, road disrupted.
Kalingpong	August, 1993	40 people killed heavy loss of property.
Kohima, Nagaland	August, 1993	Many people injured and over 200 houses destroyed. The NH-39 was cut-off from the rest of the country.
Nilgiri Hills	Nov, 1993	More than 40 people were killed, property worth several lakhs damages.
Kashmir	Jan, 1994	NH-1A severely damaged, closed for several days.
Aizwal, Mizoram	May, 1995	25 people killed, Road severely damaged.
Malori, Jammu	June, 1995	NH-1A severely damaged, six people lost their lives.
Kullu, H.P.	Sept, 1995	More than 20 people killed and lost marked property.
Gangtok, Sikkim	June, 1997	About 50 people lost their lives hundreds houses were devastated heavy damages to property.
Sikkim	Sept, 2005	More than 30 people lost their lives and heavy damage of property, roads communication lines disrupt.
Guwahati Assam	Aug, 2005	10 people lost their lives and damages heavy property.

Source: Generated from various sources.

**Table 4.4 Some historical landslide events in the Himalayan belt**

Location	Month/Year	Damages
Sikkim and North Bengal	Oct, 1968	Widespread mass movement of soil in the form of slides, caused deaths and devastation due to cloud burst, rainfall of the order of 160cm in destruction of large number of bridges including the famous Anderson bridge at Teesta Bazaar.
Darjeeling	1973	Heavy rains resulted in numerous slides and subsidence resulting in disrupting of road and rail communication on Siliguri-Darjeeling Sector for considerable time.
North Bengal	1975	Tista, Jaldhaka and Diana rivers were flooded. Widespread landslides and floods rendered 4500 people homeless.
Sikkim and Darjeeling	1976	Landslides in Sikkim and Darjeeling area due to heavy rainfall and consequent floods in Tista Valley due to which several people died.
North Sikkim	1983	Widespread incidences of landslides and damages occurred. A number of bridges were washed away and highways were blocked. Traffic could not move for two months on the affected stretch. Extensive loss of property and life also occurred. An army camp belonging to Boarder Roads Organisation was completely washed away.
Arunachal Pradesh	1993	Heavy damaged of life and property
Gangtok	1997	Lost of life and property
Sikkim	2005	Damaged of houses and lost of life
Jammu & Kashmir	1971	Wide spread landslide caused disruption of traffic and communication systems.
Jammu & Kashmir	1972	Wide spread landslides caused damage to life and property.
Jammu & Kashmir	1973	Landslides cut off Kashmir valley from rest of the country
Jammu & Kashmir	1975	Landslides caused death of people and disrupted transportation system for three days.
Jammu & Kashmir	1977	Srinagar-Leh road was blocked due to landslide.
Jammu & Kashmir	1979	Extensive damages due to landslides created problems to the traffic
Jammu & Kashmir	1986	Extensive incidences created severe problems in Jammu and Kashmir area along NH-1A.
NH-22, H.P.	1986	Landslides incidences on NH-22 causing severe to roads and property. Landslides at Nathpa, Urni, Dhang, Wangtu, Poweri, Panginala and Malling are recurring every year in rainy and snow melting season subsequently.
Kinnaur	1993	Jhakri landslide on NH-22 occurred on 25 <sup>th</sup> February 1993, affected the highway (450m), blocking for two months.
Uttar Pradesh	1970 (July & Sept)	Alaknanda river caused considerable loss of life among pilgrim. Many bridges, houses and entire villages were washed away. More than 233 people were killed.
Uttar Pradesh	1971	Heavy rainfall and erosion of hill slopes causing damming of river and burst involving loss of life, property and disruption of communications. One village Belakuchi was completely washed away. This is termed as Alaknanga Tragedy.

Source: Generated various sources.

The inherently unstable nature of mountain areas of the Eastern Himalayas is well recognized. The steep slopes, unstable geology and intense monsoon rains combine to make the region one of the most hazard-prone regions in the world. Although geohazards of varying intensity have occurred frequently in the past in the eastern Himalaya, more recently there has been an increase in human settlement in hazard-prone areas as a result of population pressure as well as improvement of transport and communication systems and other infrastructure development. Consequently, natural and man-made hazards are on the increase and each event affects an even greater number of people than before, and covers larger area than before. Landslide and slope failures during the monsoon season are the most common hazards affecting this region, often resulting in substantial economic and environmental losses and causing great suffering to many people.

#### **4.2 LANDSLIDES GEOHAZARD IN GANGTOK**

It is worth mentioning that the different hill settlements in India, including Gangtok, are prone to different types of landslides and avalanches. Starkel and Basu (2000) have edited a volume on Rains, Landslides and Floods in the Darjeeling Himalaya. Landslides and mass movement is a common feature in Sikkim Himalaya, and magnitude and damages caused every year in many parts of the state is very large (Mehrotra et al., 1996). This region being a part of Eastern Himalaya consists mainly of sandstone, slate, schist, gneiss, quartzite, etc. which are in disintegrated conditions in many places and associated with folds, fault planes and thrusts is always leading to enormous erosion, landslides and avalanches. Altogether 115 landslides were recorded

between 1953 and 1997 in the inventory of landslides prepared by Yudhbir and Gergan (2004).

**Table 4.5 Some important landslide events in the East District of Sikkim**

Sl No.	Slide Name/Location	Lithology	Types of Material/ Regolith	Causative factors	Activated since
1.	Burdang Slide 20 <sup>th</sup> Mile	Phyllite Quartzite of Daling Group	Disintegrated boulders of Quartzite phyllite Quartzite mixed in sandy silt matrix	Very high Weathering strong tow cutting presence of shear Zone. Heavy precipitation/ Cloud burst	First activated in 1968, Reactive in 1970 and 1996
2	9 <sup>th</sup> Mile Slide 14.4 km from Gangtok	Biotite Schist and Highly fractured slates.	Sandy clay with fragment of rock pieces	Debris/Soil slump due to prone pressure increase	-
3	Song Khola Slide 22.0 Km from Gangtok	Schist	Soil debris with weathered rock	Mainly due to road cutting in weathered rock mass	1957
4	Kue Khola Slide 31.7 Km from Rishi	Garnetiferous Gneiss	Garnetiferous gneiss, hill slope covered with Talus.	Creep debris slid	1966
5	Padamchen Slide 33.7 KM from Rishi	Schistiferous rugen Gneiss	Thick deposit of talus materials	Excessive saturation increased in gravity.	1968
6	Samsing Slide 33.1 Km from Gangtok	Weathered Schist	Disintegrated rock with clayey soil	Highly weathered rock mass unfavourable foliation plane	-
7	Nam chang Slide 24.8 Km from Gangtok	Weathered Phyllite	Disintegrated rock clayey soil	Highly weathered rock. Unfavourable bedding plane.	-

8	Pache Slide 31.0 Km from Gangtok	Weathered Schist	Rock pieces with silt clay soil	Highly weathering unfavourable bedding plane.	-
9	Pachak Slide I 55.9 Km from Gangtok	Quartzite Schist	Highly weathered gauge material	Highly weathered gauge material, fault/shear zone road cutting	-
10	Pachak Slide II 57.4 km from Gangtok	Phyllite	Boulder and rock pieces embedded in sandy soil	Steep slope highly crushed and sheared rock mass tow erosion	-
11	Tsochen-pheri slide, 23km from Pakyong	Rerriginous Quartzite with intercalation of phyllite, quartzite and Agurn.	Highly weathered bed rock material	Unusual rain fall and cloud bursts	June 1995
12	10 <sup>th</sup> Mile slide 5.0 km from Gangtok	-	-	-	Started in September 1970
13	Gangat Slide 5.0 km from Rangpo	Schist	Weathered rock mass	Weathered rock mass, fault/shear zone, folded strata unfavourable beds, toe erosion.	-
14	Bhasme Slide 9.4 km from Rangpo	Phyllite	Weathered schist	Weathered foliated phyllite unfavourable bed road excavation, tow erosion	-
15	Pachekhani Slide 13.4 km from Gangtok	Schist	Weathered Schist	Weathered schist folded strata unfavourable discontinuity planes.	-
16	Tarkin Slide 17.6 km From Rangpo	Schist	Weathered rock mass	Weathered rock mass, shear zone tow erosion	-

17	Suntalatar Slide 17.9 km from Rangpo	Weathered Phyllite	Highly weathered and Pulverized material	Highly weathered and pulverized material road excavation.	-
18	Rongli slide 26.4 from Rangpo	Garnet ferrous Schist	Rocky pieces with sandy soil and fault breccias	Highly weathered schist fault zone	-
19	Tathanchen Gangtok	Schists	-	1960	-
20	Chandmari	Gneiss	-	-	-
21	Panchmile Slide I 8.5 km from Gangtok.	Hornblende gneiss with mica flakes	Boulders and weathered rock fragments embedded in clayed soil	Weathering of micaceous material steep slope.	-
22	Dosmile slide 20 km from Gangtok	Augen gneiss	Weathered gneiss, Rock pieces and boulders of varying sizes.	Weathered gneiss failure along fissures, heavy rainfall.	-
23	Majadhari slide 8 km from Gangtok	Gneisses boulders no orientation	Large boulders with sandy soil	Perennial water flow, steep slope, road cutting	-
24	Khamdong Slide -I 36.2 km from Gangtok	Quartzite schist	Boulders of varying sizes coarse sandy soil.	Highly weathered formation fault zone, tow erosion	-
25	Sirwani Slide 32.0 km from Gangtok	Quartzite Schist	Boulders and rock with clayey soil	Highly weathered fault zone, sheared rock mass, steep slope, toe erosion	-
26	7 <sup>th</sup> Mile slide 12 km from Gangtok	Biotite gneiss covered with thick slope wash material.	Slope wash with disintegrated rock pieces.	Thick talus deposit failed under heavy saturation by rain	Activated Since 1966
27	Development Area Gangtok.	-	-	Weathered rock mass, steep slope pore pressure increase, heavy rain	Activated June 1997
28	Pani House 5 <sup>th</sup> Mile, Tadong etc. Gangtok	-	-	Cloud burst, heavy rain	Activated Sept. 2005

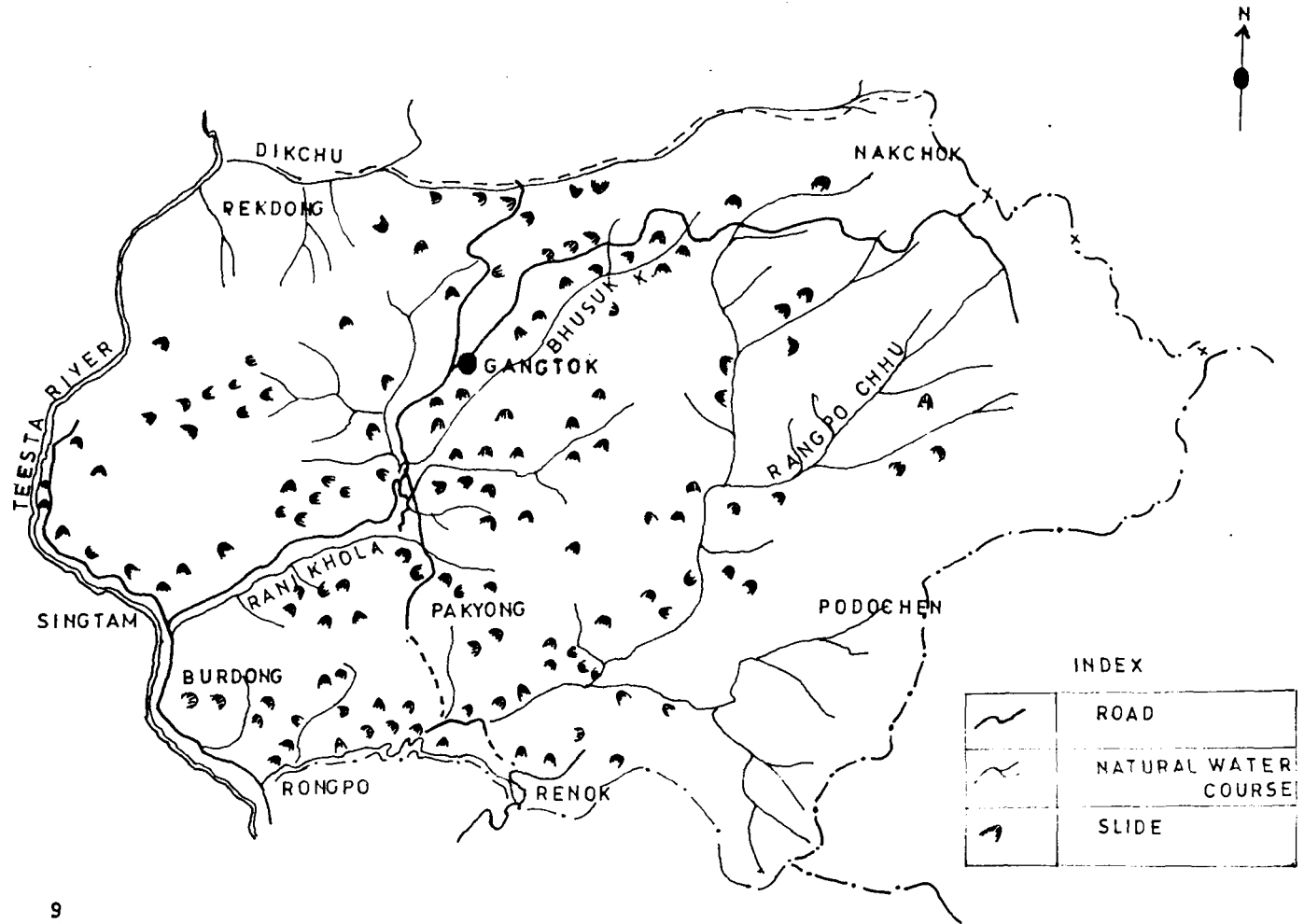
Source: Status Report form Initiating Landslide Studies in Sikkim, 2004, and *Now Daily*,

About 134 landslides have occurred during 1960 to 2005 in East District (Fig. 4.2). The distribution pattern of the landslides mainly along the river valleys clearly shows that they occur mostly along the roads (includes N.H. 31-A) where hill slopes are disturbed mainly due to cutting of toes. The 28 landslides which occurred between 1960 and 1997 in the East District of Sikkim, where Gangtok is located, are enlisted in Table 4.5. From the Table 4.5 and Figure 4.2 it is clear that a mark number of landslides events have taken place in the East District of Sikkim, particularly in an around of Gangtok during the last 50 years.

A number of landslides have occurred in Gangtok and its suburbs in the last 55 years. Records since 1950 show sharp acceleration of devastating landslide occurrences, leading to loss of life and heavy damage to land and property (Sarkar and Deb, 1998). For example, devastating landslides occurred at Rangpo-Dikling Road on 23<sup>rd</sup> July, 1993; landslides in Development area and Chandmari in June 1997, where about 50 people lost their lives and fifty houses were devastated; and landslides at Deorali and Syari in September 1990, where the human casualties was recorded at 25 besides loss of property of considerable dimension etc. Table 4.6 reveal incidences of landslides in the study area.

Spatial distribution of the landslide events (Fig. 4.3) in Gangtok clearly indicate the fact that most of the landslides have taken place in and around built up area and along the roads. One point should be highlighted here and that is that it is the human interference in the geoenvironment that has led to increased number of incidence of landslides in the study area. The areas where landslides are most common have been

# LANDSLIDE MAP OF EAST DISTRICT, SIKKIM



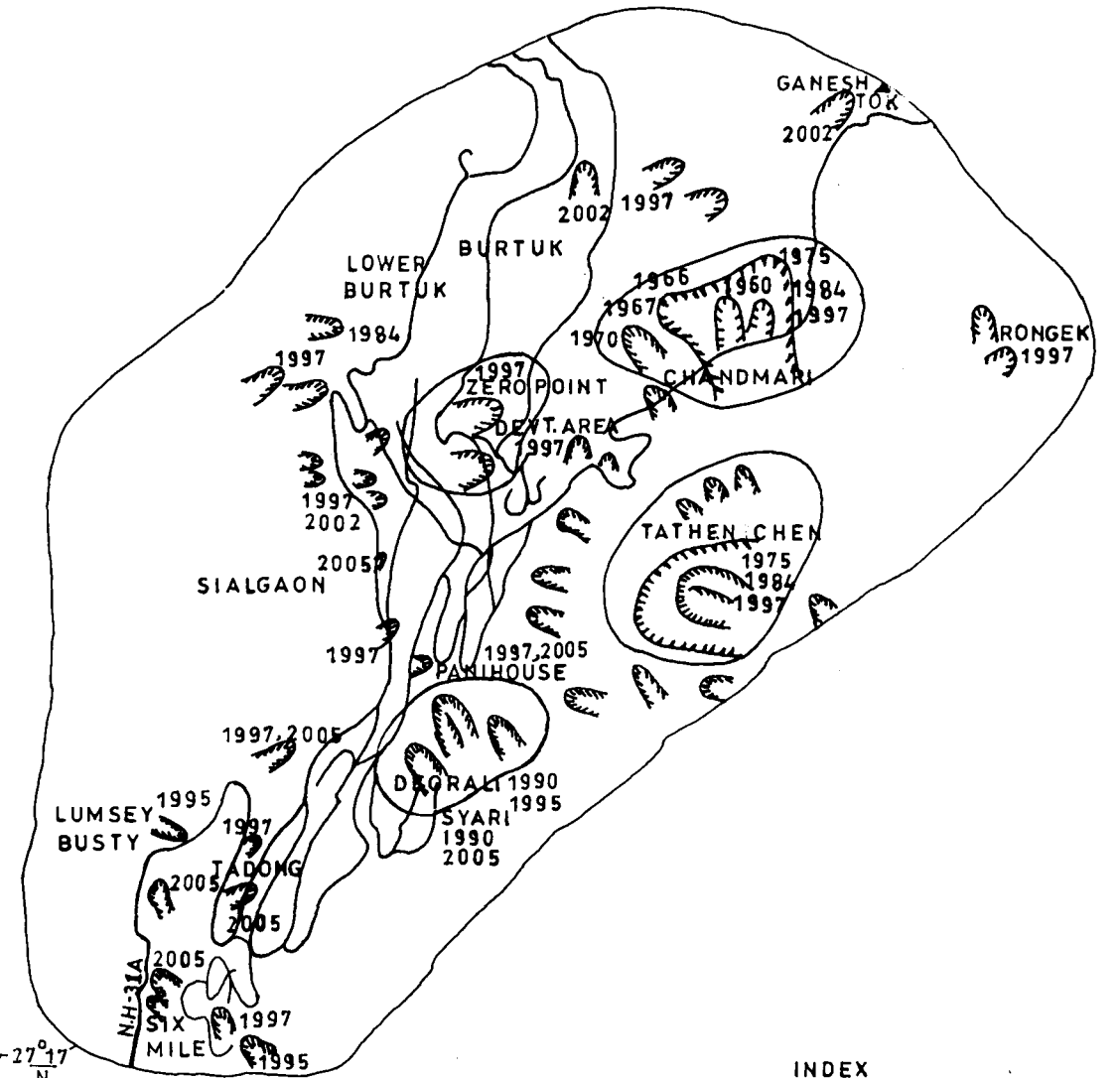
0 3 6 9  
KM

SOURCE : FIELDWORK, 2004-05  
DIFFERENT LITERATURE




FIG.4.2

# GANGTOK LANDSLIDE INCIDENCE MAP

27° 22'



27° 17'  
N

- INDEX**
-  ROAD
  -  LANDSLIDE
  -  MAJOR SLIDING AREA



88° 35' E

88° 39' 55"

FIG. 4.3

marked in the Figure 4.3. These areas are Chandmari, Tathenchen, Zero Point and Deorali.

**Table 4.6 Landslides of Gangtok (1960-2005)**

Sl.No.	YEAR	LOCATION	LITHOLOGY	CAUSATIVE FACTORS
1	1960	Chandmari	Gneiss	Heavy Rainfall
2	1966	Chandmari	Gneiss	Heavy Rainfall
3	1967	Chandmari	Gneiss	Heavy Rainfall
4	1970	Chandmari	Gneiss	Heavy Rainfall
5	1975	Chandmari	Gneiss	Heavy Rainfall
6	1975	Tathenchen	Schist	Heavy Rainfall
7	1984	Chandmari	Gneiss	Heavy Rainfall
8	1984	Tathenchen	Schist	Heavy Rainfall
9	1984	Lower Burtuk	Schist	Heavy Rainfall
10	1990	Deorali	Schist	Heavy Rainfall
11	1990	Syari	Schist	Heavy rainfall
12	1995	Deorali	Schist	Heavy Rainfall
13	1995	Lumsey Basty	Schist	Heavy rainfall
14	1995	Sumdur	Schist	Heavy Rainfall
15	1995	Deorali	Schist/Gneiss	Heavy rainfall
16	1997	Six Mile	Schist/Phyllite	Heavy Rainfall
17	1997	Tadong	Schist/Phyllite	Heavy Rainfall
18	1997	Arithang	Schist/Quartzite	Heavy Rainfall
19	1997	Upper Sischy	Schist/Quartzite	Heavy rainfall
20	1997	Diesel Power House	Schist	Heavy Rainfall
21	1997	Rongeyk	Granite/Quartzite	Heavy Rainfall
22	1997	Zero Point	Schist	Heavy Rainfall
23	1997	PaniHouse	Schist	Heavy Rainfall
24	1997	Devt. Area	Schist/Gneiss	Heavy rainfall
25	1997	Chandmari	Schist/Gneiss	Heavy Rainfall
26	1997	Tathenchen	Gneiss/Schist	Heavy Rainfall
27	2002	Ganeshtok Area	Schist/Granite	Heavy Rainfall

28	2005	5 <sup>th</sup> Mile	Schist/Phyllite	Heavy Rainfall
29	2005	Lower Tadong	Schist/Phyllite	Heavy Rainfall
30	2005	5 <sup>th</sup> Mile	Schist/Gneiss	Heavy Rainfall
31	2005	Syari	Schist/Phyllite/Gneiss	Heavy Rainfall
32	2005	Pani House	Schist/Phyllite/Gneiss	Heavy Rainfall
33	2005	Upper Arithang	Schist/Gneiss	Heavy Rainfall
34	2005	Six Mile	Schist/Gneiss	Heavy Rainfall

Source: Different Literature and Fieldwork

#### 4.2.1 Important Landslides of Gangtok

Some of the important landslide events which have occurred in and around Gangtok in the recent years have been discussed as follows:

**1. Syari and Deorali Landslide of September 1990:** A hazardous landslide took place in Syari and Deorali areas of Gangtok on 16<sup>th</sup> September 1990. This landslide took about 25 lives and heavy loss of property. Due to this landslide Army Cantonment area was badly affected. Moderate to steep hill slope covers this area with fragile rock formation such as schists and granite gneiss. September 1990 landslide was the direct result of the continuous rainfall for few hours. The rainfall was recorded 85 mm on 16<sup>th</sup> September, 1990.

**2. Deorali Area Landslide of September 1995:** This landslide occurred on the night of 5<sup>th</sup> and 6<sup>th</sup> September 1995 in Deorali area. Due to this 30 people lost their lives and there was heavy damage of property. This area falls in moderate to steep hill slope with weak rock formation such as schists with transition to granite gneiss on the upper

portion. This landslide event was also triggered by high intensity rainfall in short duration. The recorded figure of rainfall was 95 mm in the same night (Krishna, 1997).

**3. Devastating Landslides of June 1997:** A disastrous series of landslides took place on the night of 8<sup>th</sup> and 9<sup>th</sup> June 1997 in different parts of Gangtok, particularly in Chandmari and Development Area where about 50 people lost their lives and fifty houses were damaged. Results of the heavy rains for the last several days culminated on the night of 8<sup>th</sup> June 1997 triggering extensive landslides in Development Area, Tathenchen, Chandmari, Tadong, below the Palzor Stadium, Rongyek, and Lingding localities of Gangtok (Plate 9). The meteorological department has confirmed that from 5 pm to 9 pm on 8<sup>th</sup> June, 1997 an amount of 210 mm of rainfall lashed Gangtok and its surrounding areas (Sikkim Herald, 20<sup>th</sup> June 1997). According to Sikkim Express News Service (1997), more than sixty people lost their lives and more than hundred people got injured in the worst ever landslide in Sikkim. The landslide occurred in the early hours of 9<sup>th</sup> June and the worst hit areas places were the Development Area, Tathenchen, Tadong, Syari, Burtuk, 7<sup>th</sup> Mile, J. N. Road, Raj Bhawan, Pani House, Arithang, Sichey, and Palzor Stadium. In all 5000 families were affected in 20 sq km area in Gangtok. A five-storied building in Development Area was swept away by this landslide. In all 14 *pucca* buildings were destroyed or damaged in Gangtok due to this devastating landslide, and over 2000 people were given shelter in the relief camps set by the State Government. Water supply, electricity and road communication, from different parts of the country as well as within the state, to Gangtok was disrupted for two days. All government offices and schools were declared closed for two days. According to a preliminary assessment by

the state government the loss of property due to these landslides was to tune of Rs. 100 Crore. State Government had also immediately announced a relief of Rs. 50,000 for each of those killed and Rs. 10,000 for each of those injured, and Rs. 5000 for reconstruction of each damaged house. After this sliding event Chandmari was declared as dangerous and landslide prone area by the state government. Report also reveals that due to this disastrous landslide one person lost his life at Zero Point. The debris of the landslide composed mainly of coarse sandy soil with schist and gneissic rocks slid from below Raj Bhawan area and reached up to the office complex of Handloom and Handicraft. The office complex was badly affected by the movement of debris (Plate 10). Again, in the same night another slope failure had occurred in the Rongey area where about 20 houses collapsed and heavy damaged to property and livestock was reported. Road communication with Gangtok was severely affected in this area for many days. Besides Gangtok, many landslides and slope failures were reported from different parts of Sikkim during the same night of 8<sup>th</sup> and 9<sup>th</sup> June 1997. Due to these landslides heavy damages of property was reported. As such, landslides and land-slips are common in the study area but this disaster was the worst in recent memories (Krishna, 1997). The disaster of 1997 still haunts the people of Gangtok, who lost their near and dear ones and properties worth several crores of rupees.

**4. Landslide of June 2002:** Gangtok experienced 131.6mm of rain in 12 hours from 7:30 pm of Sunday to 7:30 am Monday (2nd and 3rd June, 2002), 188.9 mm between June 3 and 4 and 70 mm between June 4 and 5. A major landslide near Tadong (Fifth Mile) cut off all communication for a few hours. Two people lost their lives in Ganeshtok Area on the night of 3<sup>rd</sup> June. Landslides also occurred near Vajra Cinema

Hall and also near Garrison Reserve Engineering Force at Burtuk. Several roads to and fro Gangtok were closed as a result of these landslides and the northern by-pass was also closed.

**5. Landslide of September 2005:** Recently in the night of 24<sup>th</sup> September, 2005, the people of Sikkim, particularly the residents of Gangtok and surrounding areas, faced very tragic landslide geohazard. The torrential rain coupled with thunder and lightning stretching for about ten hour commencing from the evening of 24<sup>th</sup> September proved to be a nightmare for the people of Gangtok and its suburbs. Heavy landslides and landslips triggered by the continuous downpour damaged National Highway 31-A in several places and damaged standing crops and cattle of nearby villagers. Telecommunication, power and water supply were disrupted causing a lot of trouble to the residents of Gangtok, particularly of Rumtek, Ranipool and Ranka localities. Major landslides occurred on the National Highway near Pani House. Besides, different parts of Gangtok including Syari, 6<sup>th</sup> Mile, 5<sup>th</sup> Mile, lower Tadong, Lumsey, Ranipool etc. were severely hit by slides, where property and houses destroyed immensely (Plate 11 to 16). The slides were of such magnitude that the basement of a five-storied building at 5<sup>th</sup> Mile was affected (Sikkim Express 27.09.2005). More than 50 people lost their lives in these disastrous landslides.

#### **4.2.2 Case Studies**

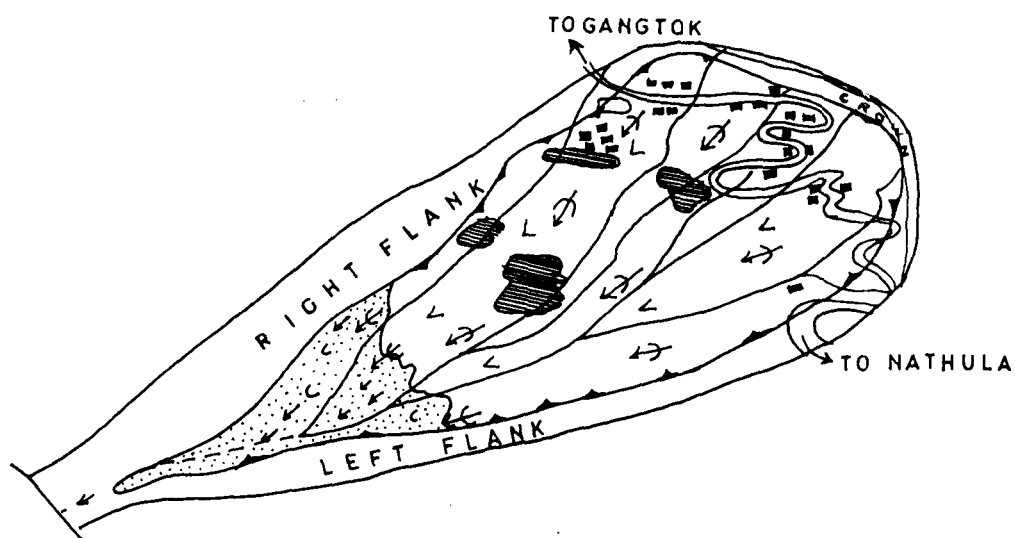
Details of few landslides of Gangtok are given under the following case studies.

**(1) Chandmari Landslide in June 1997:** Located on the eastern slopes of Gangtok ridge, Chandmari (Upper Chandmari and Chandmari proper) is an important

locality. According to 2001 Census the total population of Chandmari was 3,744 with 817 households. It has already been mentioned that a series of disastrous landslides took place in different parts of Sikkim on the night of 8<sup>th</sup> June 1997, but most badly affected was the Chandmari area of Gangtok, where around ten numbers of people lost their lives apart from heavy damage of property ( Fig. 4.4 and 4.5). Relevant to mention that Chandmari area has been prone to landslides from 1960s as recurring landslides hazards have occurred in the years 1960, 1966, 1967, 1970, 1975, 1984, and 1997. The Chandmari landslide is a chronic hazard giving constant trouble to the people and road communication of the area. In 1966 subsidence of road also took place here after heavy rains (Sinha 1975, Sinha et al., 1975), as the lower slope material slipped away. According to Cruden and Varnes (1996) classification of landslides, the Chandmari landslides have been dominated by earth slide and debris flows, which originate in Upper Chandmari area. Bhasin et al., (2002) estimated that between 15,000 and 20,000 sq m of soil mixed with weathered rock fragments was released in the Chandmari landslide of June 1997.

The Chandmari landslide was the direct result of continuous down pour of 233 mm within five hours of night of 8<sup>th</sup> June 1997. Basu and Dey (2003) reported that the old subsidence zone composed of gneissic rock with thick overburden of soil collapsed damaging a number of houses, schools complex, a temple, a government vehicle workshop and large number of parked vehicles.

DIAGRAMATIC SKETCH OF CHANDMARI LANDSLIDE



INDEX

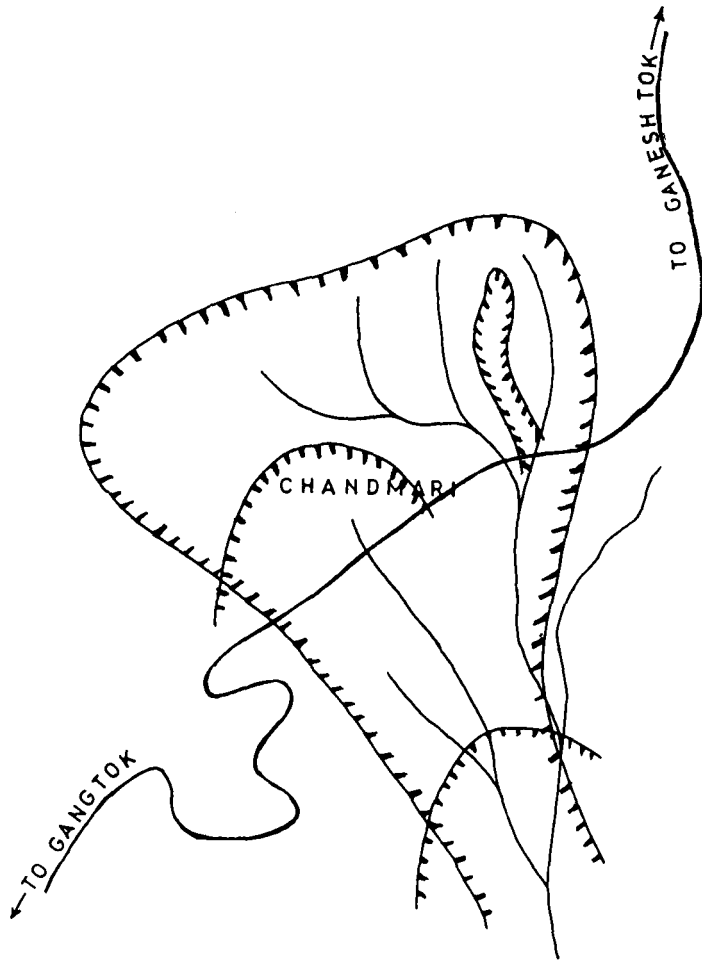
	ACTIVE LANDSLIDE
	NEW SCAR DEVELOPED DUE TO UNDERMINING
	FLOW
	SPRING
	WATER COURSE
	UNDER GROUND DRAINAGE
	CONCAVE SLOPE
	CONVEX SLOPE
	SLIDING
	HOUSES
	TERRACED CULTIVATION

(NOT TO SCALE)

SOURCE : RAWAT , 2005

FIG. 44

# CHANDMARI LANDSLIDE



## INDEX




-  SLIDE
-  NATURAL WATER COURSE
-  ROAD



FIG.4.5

Relevant to mention that Chandmari is situated in the higher elevation (between 1610 m to 2400 m altitude) of the northeastern slopes of the Gangtok ridge. Absolute slope of the area ranges from  $45^{\circ}$  to  $75^{\circ}$ . Whereas, the average slope ranges from  $12^{\circ}$  to  $24^{\circ}$  and the uphill slope angle is comparatively steeper than the downhill slope. The geology of Chandmari area is dominated by the rocks of banded gneiss (Darjeeling gneiss) and unclassified Daling group of rocks (i.e., mostly quartzite, phyllite and schist). The Chandmari landslide falls in the inner belt of Lesser Himalayan region and comprising highly metamorphosed ortho- and para-gneissic formation of older Precambrian complex of Darjeeling formation (Banarjee et al., 1983). These rocks are essentially migmatites streak, and banded gneiss alternating with quartzo-feldspathic and micaceous layers (Schwan 1980, Bhattacharya et al., 1987).

Slope instability and failure analysis is one of the most important aspects relating to the study of causes and consequences of landslide hazards in mountainous areas, especially in the Himalayan Mountain region. Indeed, slope stability study is a complex phenomenon which always requires the theoretical understanding of the geoenvironment of an area. Slope instability analysis generally involves two basic approaches viz., a) limit equilibrium analysis, and b) deformation analysis. Rawat (2005) has mentioned that the shear strength of Chandmari landslide is not uniform within the slope and the slope instability in Chandmari area is caused due to following two main reasons- i) The tropical humid climate, which is conducive to deep weathering of rocks causing strength losses and permeability changes, that lead to reduction in shear strength of slope material consequently decreases the stability of slope, and ii) high intensity rainstorm in short

duration results and rapid erosion of the weathered material, raising the ground water level and saturation of overburden soil.

In fact, 233 mm rain in a single day in the month of June in Chandmari area of Gangtok was the highest during the ten years (1987 to 1997). Moreover, the intensity of rains in Chandmari area is so high that it sometime reaches as high as 75 mm per hour. Recurrent cloud bursts are another important feature of this region. Besides, high surface run off causes rapid erosion of the debris. Presence of the Chungthang thrust near by the Chandmari area may also be a causative factor in the recurring occurrence of landslides at this chronic site. Soil forming materials of the area are highly weathered permeable debris and slope wash material. The area is mostly covered by sandy loamy skeletal soil with medium to fine grain and non-plastic in character. Soils of Chandmari are over saturated, having the normal to low value of shear strengths i.e., around 5 to 30 KPa and from  $14^{\circ}$  to  $28^{\circ}$  (Bhasin et al., 2002).

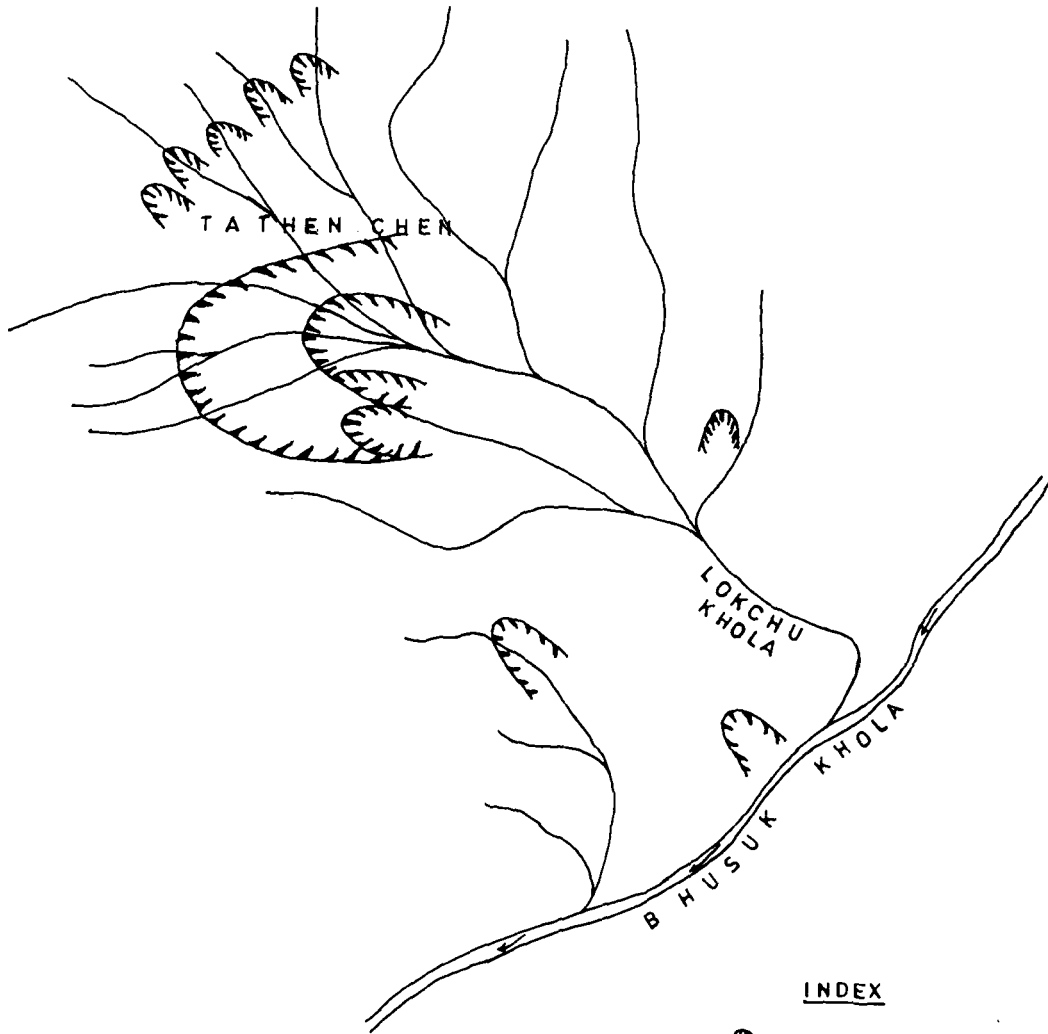
The high drainage density (2-6/sq km) and drainage frequency (10-15/sq km) found in Chandmari area may also be a contributing factor in the landslides. Further, the area is covered by open forest, while the dense forest is found in only a few small pockets. Nearly 30 per cent area of Chandmari is covered RCC houses.

It is equally important to mention here that in June 1998, a series of landslides occurred in Ranipool area, which is only 11 km from the main hub of the Gangtok. Due to these landslides a number of people lost their lives and property of thousands of rupees

was damaged. This slide area has been reactivated again in September 2005. However, it is clear from the above discussion that banded gneiss rocks with major thrust, high drainage density and frequency, high angle of slope, low vegetation cover, high seismicity and low cohesive sandy loamy soil are played crucial role in the landslide hazards at Chandmari area. According to Rawat (2005) the weight surcharged slope material in conjunction with reduction in shearing resistance along the failure zone due to excessive pressure and continuous removal of the toe support all along the radial watercourse are leading to frequent slope movements in Chandmari area, particularly during short duration intense rainstorm.

**2. Tathenchen Landslide in June 1997:** Tathenchen area is located on east facing slope of the Gangtok ridge at an elevation of 1200 to 1800 m, having a total population of 3,098 persons and 809 number of households as per 2001 Census. The average slope in Tathenchen area ranges from  $12^{\circ}$  to  $24^{\circ}$ . This area has been experiencing the rotational failure of slope with thick soil cover leading to some deaths, and destruction of houses, livestock and properties. First landslide event in Tathenchen area was reported in 1975, followed by in the years 1984 and 1997. Major landslide hazard in Tathenchen area occurred in the night of 8<sup>th</sup> June, 1997, which killed 10 people and damaged number of houses. According to Bhasin et al., (2002) the total surface area of the Tathenchen landslide is about 50,000 sq m (Fig.4.6) and the Royal Palace of the king of Sikkim is located very close to this landslide. The lower part of the area has been partly affected by sliding along the foliation planes in the phyllite rocks and partly by down slope sliding of the over lying soil.

# TATHENCHEN LANDSLIDE



## INDEX



SLIDE



NATURAL WATER  
COURSE

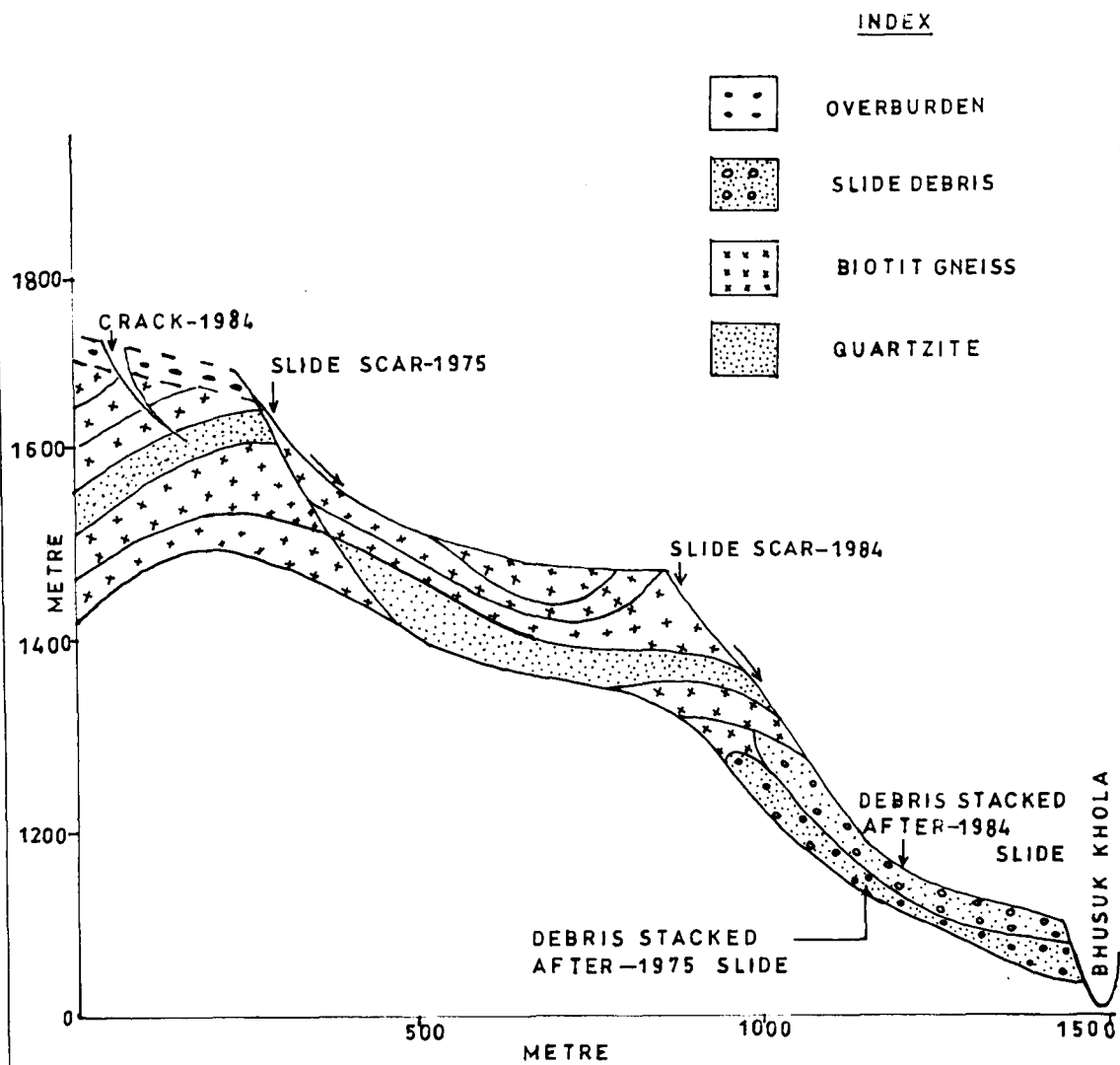


FIG. 46

The rocks found in Tathenchen area are mainly of banded gneiss and Dailing Groups of rock formations i.e., quartzite, phyllite, granite and mica schist (Fig. 4.7). The rocks of the area are partly having smooth joints, and the coarse loamy soil, which is very low caustic/cohesion in nature. However, the slope failure is mainly dominated by composite debris with rockslide. The vegetation cover in the area is not much and only 20 per cent area is under forest cover. The Lukchu Khola is the main drainage of the area, which is a small right bank tributary of the Bhusuk Khola. Apart from it, there are a number of small streams, which are locally known as '*Jhoras*'. Therefore, the area has very high drainage density and drainage frequency (4- 6/sq km and 10-15/sq km, respectively). Three landslides have occurred in the area which are known as Palace Jhora slide, Tathenchen minor slide and Tathenchen major slide (Basu and Dey, 2003). In fact, all these slides got reactivated on the night of 8<sup>th</sup> June 1997, and still get reactivated now and then during the monsoon period.

Important to remember that the landslide of the night of 8<sup>th</sup> June, 1997 has been regarded as one of the worst slides of Gangtok. Basu and Dey (2003) reported that Tathenchen major slide severely affected the lateral extension of the old slide of the area. Roughly, an area of around 400 sq m was badly affected by this major slide. It is worth mentioning that all the slides occurred in Tathenchen area mainly due to down pour during the monsoon season. Besides, instability of entire the eastern steep slope of Gangtok ridge is also another triggering factor in the landslide events of Tathenchen area. It can be said that the landslides of Tathenchen area are due to combination of a number of factors, which include high rainfall, steep instable slope, coarse sandy loam soil, soft

# GEOLOGICAL SECTION OF TATHENCHEN SLIDE



SOURCE : AFTER VERMA, 1993

FIG.4.7

rocks (phyllite, schists and micaschist), high drainage density and frequency, small forest cover, seismic activity, deforestation and unplanned growth of constructional activities.

#### **4. 3 CAUSES OF LANDSLIDES IN GANGTOK**

It is clear from the study of the landslides in Sikkim, especially in Gangtok that inherent geologic structure, geotechnical instability, seismic activity, excessive rainfall sometimes as cloud burst, deforestation, and unplanned construction activities are the main causes of landslides in the study area. Without doubt, incessant or heavy rainfall and cloud burst can be considered as the main cause of almost all the landslides in the Sikkim Himalaya in general and Gangtok in particular.

Development activities like building of roads and housing in mountainous terrain can induce instability depending on the way such development works are carried out. In the context of Sikkim all the above factors seems to be operative in causing landslide hazards. The intensity of tectonic deformations of the rocks and rainfall conditions have direct bearing on the landslide hazard experienced in the state (Yudhbir and Gargan, 2004). Major slope failures of Sikkim have been reported invariably during monsoon period. Whatever may be causative factors the old and fossil landslides are often reactivated (Singanengam, 1999). The slope instability of Gangtok falls under two categories- i) the fully erosion type, and ii) the slope failure type. The erosion type is mostly concentrated in the schistose rocks, whereas the slope failures are mostly concentrated at and near the litho-contact zones (Singanengam, 1999).

In fact, cloud burst itself is one of the natural atmospheric hazards associated with triggering of the mass wasting process in the mountain of the world including the mighty Himalaya. Several areas of the Himalaya have been severely affected by cloud bursts followed by debris flow in which number of lives have been lost (Joshi and Maikhuri, 1997). The natural calamities occurred in Himachal Pradesh, Uttaranchal and Sikkim in the year 1997 are some of the examples of cloud burst creating a colossal loss of lives and property in respective regions (Joshi, 1997). Thakur (1996) has considered frequent cloud bursts with rainfall intensity of 600 mm in a day and at times 200 mm for a period of two to four hours as a common landslide triggering factor in the Sikkim Himalaya. Anabalagan (1991) also considered rainfall the main triggering factor for the landslides in the mountainous regions, especially in the Himalayan Mountain.

Rainfall induced slope failure is the most common geohazard in Gangtok. Saturation of soil not only increases the pore water pressure but also reduces soil strength parameters. There is a direct correlation between the amount of rainfall and the incidence of landslides. Figures 4.8 and 4.9 have been prepared to reveal relationship between incidence of landslides and rainfall. For this purpose, June and September months have been selected as most of the landslides have occurred during these two months monsoon. Undoubtedly, the month of June is very crucial because the monsoon rains are most vigorous in this month, and this is causing landslides in the area. For example, in June 1990 more than 1000 mm of rainfall was received, when landslide occurred in Deorali area of Gangtok. It is to be noted here that it is not the total rainfall of month that triggers landslides, but the intensity of rainfall with in a short period of time that causes

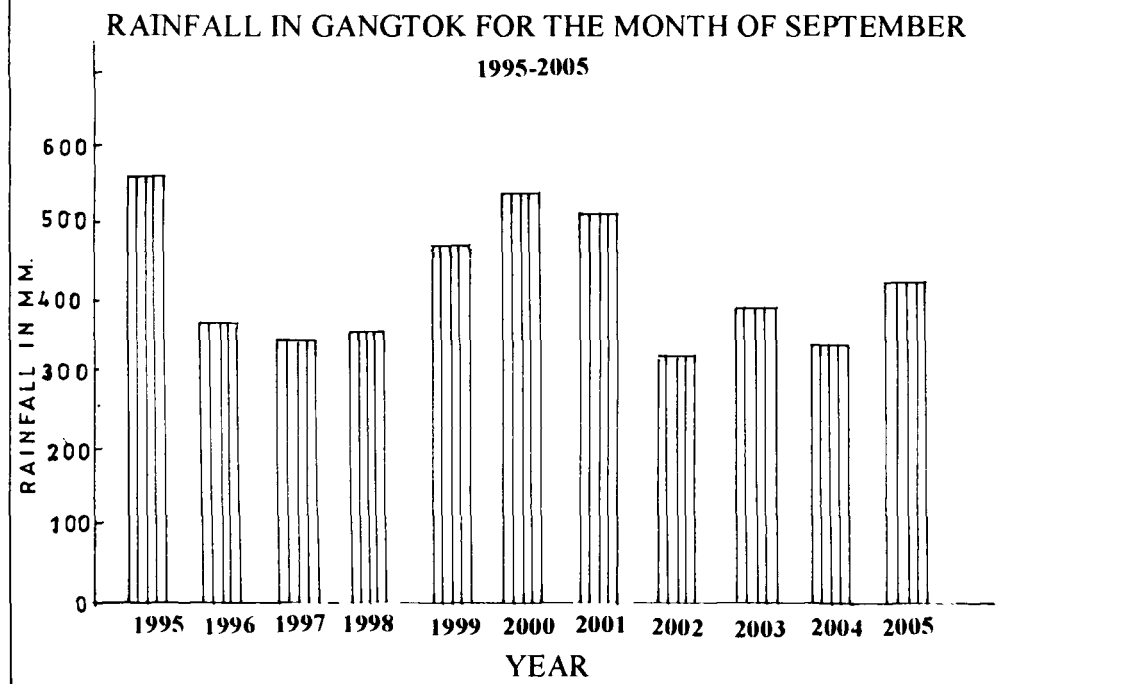
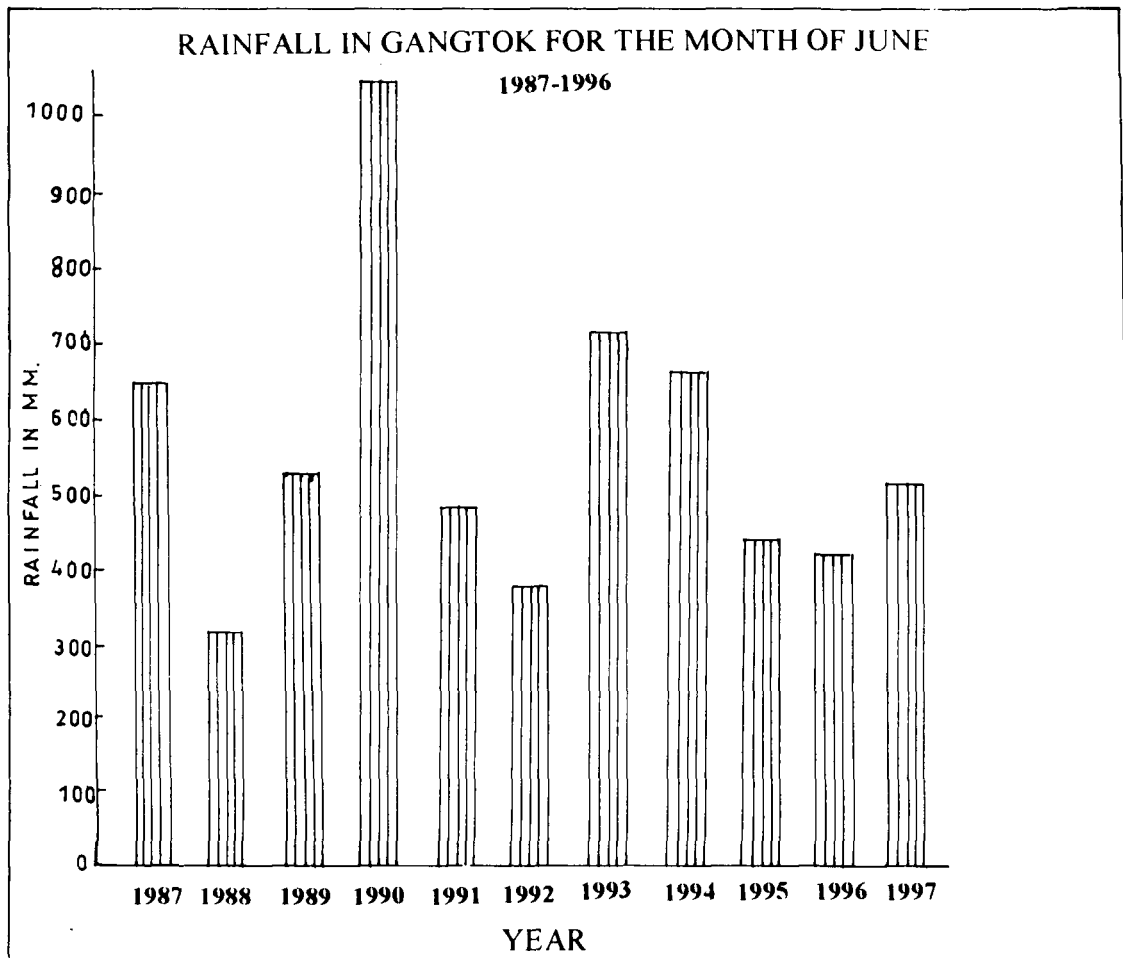
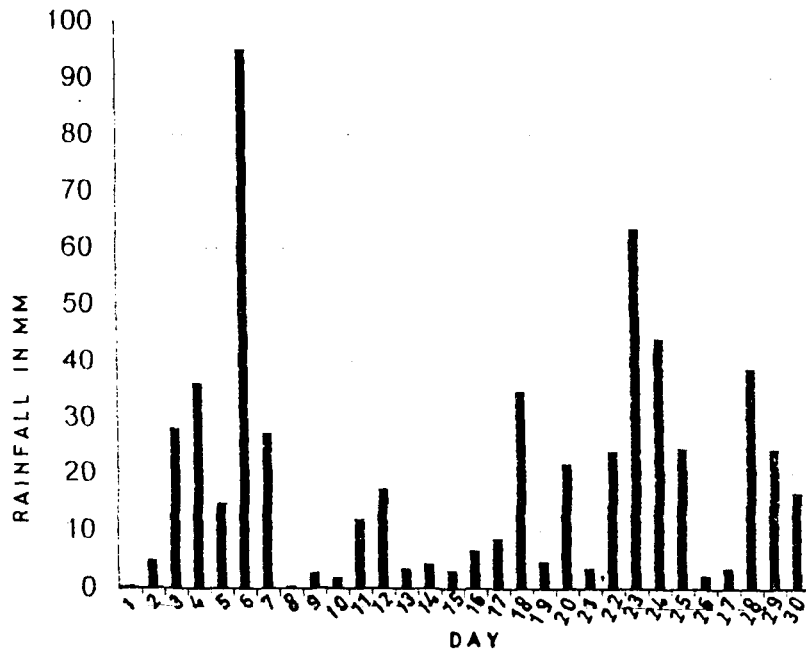


FIG. 4.8

Rainfall in Gangtok in the month of September 1995



Rainfall in Gangtok in the month of September 2005

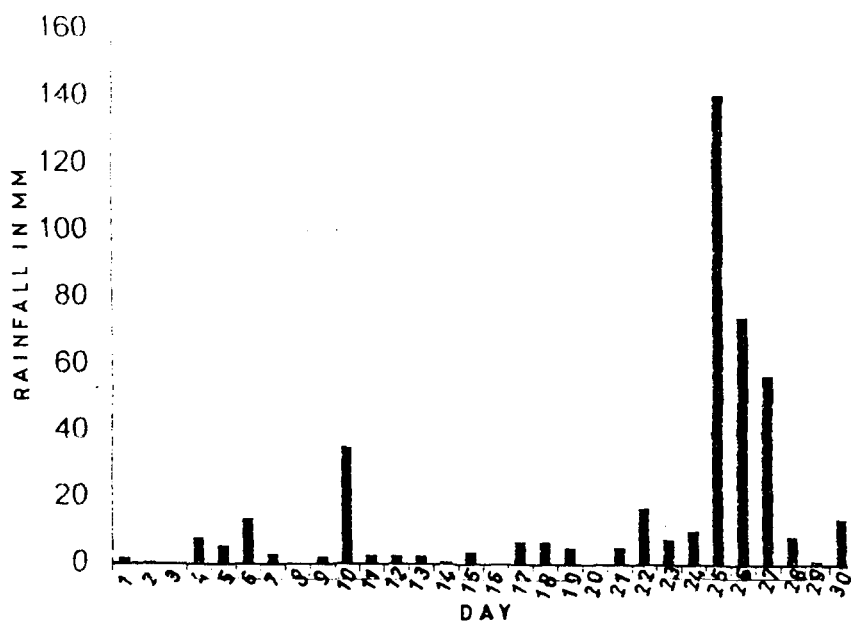


FIG.4.9

landslides. Gangtok also receives high amount and intensity of rainfall during the month of September because monsoon is still active by that time. No doubt, in comparison to June the total monthly rainfall in September is low. In the year 1995, 2000, and 2001 about 500 mm of rainfall in the month of September was recorded in Gangtok, when landslides occurred in Deorali and Syari areas of Gangtok. Compared to September of 1995, rainfall in September 2005 was very low.

Gangtok is most prone to rainfall induced slope failures in the heavily fractured and weathered rocks of phyllite and schists that contain high amount of clay minerals. According to Mehrota et al., (1996) the main reason for the landslide hazards in Sikkim Himalaya, including Gangtok, is the geological set up along with the rainfall intensity and different constructional activities. The *in situ* soil is seen over the hill slopes whereas the valleys are characterized by transported soil. The soils developed over the gneiss are silty to sandy, while clayey soils have developed over the schist, which hold lots of water.

It is worth mentioning that the haphazard growth of multi-storied RCC buildings at different parts of Gangtok are vulnerable and at risk, as geoenvironmental setting coupled with unplanned development activities can trigger off greater losses during landslides (and even during earthquakes). Physical vulnerability is also related sometimes to the technical capacity of the buildings and structures to resist the forces acting upon them during such events. For example, the two most vulnerable areas of the study area viz., Chandmari and Arithang below Church may slide down at any time after a torrential rain. If timely protective measures are not taken then the whole Gangtok may face tragic

landslide hazards in near future. Besides, the removal of vegetation, intensive use of forest for fuel, fodder and timber, modification of slope by construction of buildings and roads, and improper land use planning etc. are the main causes of landslides in the study area. The high rise buildings on steep hillsides beyond their bearing capacity, roads constructions and sub-standard drains without paying heed to the natural drainage, use of explosives in road constructions beyond the permissible limit are some of the follies that have aggravated the natural calamities in recent decades (Lama, 2004). As it has already been mentioned that the study lies in active seismic belt, any type of tremors could be the cause of the landslides in Gangtok. A different study by the Geological Survey of India (GSI, 1989-99 and 2001) on Gangtok has strongly recommended not overburdening Gangtok with more constructions in view of the future impending danger of landslide hazards. Due to the faster growth of the population during recent past in Gangtok and its suburbs, even the steeper slopes have been occupied by the residents of Gangtok, which are more vulnerable to the slope failures and landslides.

Krishna and Kundu (2002) in their study on landslides in Sikkim Himalaya have reported that the factors generally found to contribute in most of the landslides events are as follows:

**a. Internal Factors**

- i. Presence of weak, sheared rock, vulnerable to weathering and erosion such as slates, phylites, schists and soft sedimentary rocks.
- ii. Increasing pore water pressure and decrease in cohesion of the slope material.

- iii. Presence of ground water, which reduces the normal stresses and increases the shear stresses along a potential slip surface.
- iv. Pressure of clay minerals like Kaolinite, and montmorillonite in the soil of slope exaggerated slipping in wet condition.

**b. Structural factors**

- i. Presence of thrusts and faults.
- ii. Presence of multiple sets of joint planes and fracture planes.
- iii. Presence of other discontinuity surface, which present planes of weakness within rock masses across which the rock material is structurally discontinuous.
- iv. Rock anisotropy governing the mechanical development of the slope movement.
- v. Contrast in permeability of the rocks.
- vi. In a bedded and jointed rock mass with inclined bedding planes, the critical slope angle depends upon their orientation in relation to the slope and the orientation of joints.
- vii. When joints, bedding planes, sensitivity planes and faults dip down-slope, they often give rise to slides. Closed joints free of clayey infillings may often allow a high degree of stability in hard rock slopes even when dipping at angle of  $35^{\circ}$ . The slope movement occurs even when the beds are dipping at an angle of  $110^{\circ}$  if the slope is flat and the colluvial cover is thin, so that surface water can easily penetrate into the rock along the steep

transverse joints. In this case the slope failure spreads very rapidly and far from the cutting even when only few meters of it were excavated at the time of road cutting for making a new road in a mountainous region.

**b. Triggering factors**

- i. Gravity of the slope materials and other structures present on slope acting vertically downward.
- ii. Prolonged heavy rainfall which is very common in the monsoon.
- iii. Rapid melting of snow in the high altitude areas.
- iv. Seismic waves propagation both natural shocks (earthquakes) and blasting give rise to included landslides.
- v. Excavation/undercutting of toe portion of landslide body, either due to river erosion or man made action.
- vi. Violent storm and cloud burst with heavy and persistent rain.
- vii. Supersonic sound waves produced by thunderbolts in a period of heavy and prolonged rain.

**d. Anthropogenic factors**

- i. Intensive deforestation for fuel wood, fodder for livestock, timber and non-timber forest produce (NTFP) extractions.
- ii. Improper land use: agricultural practices on steep slopes, overgrazing, and irrigation on steep and vulnerable slopes, quarrying for construction material without considering the condition of the terrain.
- iii. Improper planning in infrastructural construction activities

The geoenvironmental factors responsible for landslides in Gangtok are as follows:

**A. Geomorphic Factors**

1. Highly weathered rocks
2. Rapid surface runoff on the steep and deforested slopes
3. Soil erosion and development of rill and gullies
4. Steep slopes
5. Increase in pore water pressure and decline in cohesion of the slope material
6. High drainage density and frequency

**B. Geologic Factors**

1. Weak rocks- phyllite, gneiss, schist etc
2. Structure of rocks- joints, cracks, fractures, inclined bedding planes, dip, faults, fractures, etc.
3. Seismic activities

**C. Pedologic Factors**

1. Water holding clay loam soils
2. Sandy clay loam soils allowing high infiltration of rainwater

**D. Hydrological Factors**

1. Presence of numerous streams on the hill slopes
2. Saturated clay loam soils due to retention of subsurface water

#### **E. Forest**

1. Lack of thick forest cover

#### **F. Atmospheric/Climatic Factors**

1. Incessant rain in short period: 600 mm/day or 200 mm/hour
2. Cloudburst
3. Prolonged heavy rains

#### **G. Anthropogenic Factors**

1. Haphazard and unplanned construction activities
2. Undercutting of toes of stable hill slopes
3. Deforestation

If the landslide hazards are not properly studied and adequate measures not taken, their frequency and extent will gradually increase causing innumerable problems. Therefore, efforts have to be made to control happening of such unfortunate events, which affect man, his property, and development. Of course, the local geoenvironment is also degraded leading to uncongenial conditions. In this context landslide hazard zonation of an area is a prerequisite, first to mitigate the geohazard, and second to help in the planned development process. So that, developmental works should not aggravate the geohazard phenomenon on one hand, while on the other geohazards do not affect the development of an area. Despite thorough research on landslides in different parts of the world, the causative factors that should be considered for landslide hazards are not all unanimously accepted. Different scholars have given their views on it, a few to mention

are- Stvenson (1977), Carrara et al., (1978), Lakhera (1990), Seshgini et al., (1982), Choubey and Litoria (1990), Pachauri and Pant (1992), and many others.

#### **4. 4 LANDSLIDE HAZARD ZONATION OF GANGTOK**

Analysis of landslide hazard is a complex phenomenon that is always related with a numbers of factors. In order to identify high and very high hazard zones and taking proper precautions, the use of micro hazard zonation map and risk assessment techniques will definitely help in mitigation of the hazards and in achieving sustainable development in the study area. The hazard zoning maps are prepared on various scales and dimensions depending on the utility and propose. These maps are generally prepared by integrating the various triggering factors which have already been mentioned in the foregoing text.

A landslides zonation map divides the land surface into zones of varying degrees of stability, based on an estimated significance of causative factors in inducing instability. In fact, traditional methods of landslide hazard mapping have been based on extensive fieldwork by the geoscientists in potentially dangerous areas. This is slow, expensive and very labour intensive operation, and as such can not be widely applied. With the increasing availability of high resolution spatial data sets, mostly derived from the satellite imagery, GIS and computers with large and fast processing capacity, it is becoming possible to partially automate the landslide hazard and susceptibility mapping process and minimize field work.

In the last three decades, various scholars round the world have made attempts to prepare the landslides zoning maps in different parts of the world. Out of them the names

of Nilsen and Barbb (1973), and Varnes (1981, 1985) are worth mentioning. In the Himalayan region landslide zonation map has been attempted by several scholars, viz., Majumdar (1980), Chatterjee (1986), Gupta (1988), Gairola and Shukla (1990), Chandra (1992) and others. It is important to note that Mehrotra et al., (1996) have carried out detailed landslide hazard zonation mapping of entire East Sikkim based on concept of landslide susceptibility Index (LSI) and landslide susceptibility value (LSV). Besides, Singh et al., (2001) have also prepared micro-landslide hazard zonation map of some parts of Gangtok. In order to keep the environmental degradation to minimum due to developmental activities it is essential to identify hazard prone zones in the hilly terrain and classify these zones in terms of instability for their various uses. A landslide hazard zonation map is basically a predictive tool providing information about the causes/factors that trigger landslides, frequency of occurrences of landslides and possible impacts on natural environment and present land use. The importance of such a map lies in their utility for techno-economically feasible land use, location of dams, housing, bridges, complexes, alignment of roads, and in undertaking measures for mitigation of hazards and ecology of Himalayan region (Anonymous (1992)).

From the Table 4.7 and landslide incidence map of Gangtok (Fig. 4.3) it is clear that altogether 48 landslides have occurred in the last 50 years in Gangtok. Figures 4.10 and 4.11 show relationship between the frequency of occurrence of landslides in the study area and various geoenvironmental elements. Lithology of the study area represents three main units, viz, Gneiss (Granite), Quartzite, Phyllite and Schist. It need not mention that lithology of an area always determines the shear strength, permeability, susceptibility to weathering and other characteristics of rocks which are responsible for slope failure.

**Table 4.7 Geoenvironmental theme units and landslide susceptibility classes**

	Theme Unit	FRQ	LHF	WHT	Area (KM <sup>2</sup> )	% Area Covered	INCID / Km <sup>2</sup>	Susceptibility
<b>Lithology</b>								
a	Gneiss (Granite)	4	0.25	1	9.5	23.28	0.42	Low
b	Quartzite	10	0.75	2	7.9	19.36	1.26	Moderate
c	Phyllite/Schist	34	2	3	23.41	57.36	1.45	High
<b>Slope (Average)</b>								
a	> 24 <sup>0</sup>	3	0.31	1	3.2	7.84	0.38	Low
b	18-24 <sup>0</sup>	28	2.92	3	16.6	40.68	1.69	High
c	12-18 <sup>0</sup>	15	1.56	3	16.3	39.94	0.92	High
d	6-12 <sup>0</sup>	2	0.21	1	4.5	11.03	0.44	Low
e	<6 <sup>0</sup>	-	-	1	.21	0.51	-	Low
<b>Drainage Density</b>								
a	>6	1	0.01	1	1.96	4.80	0.51	Low
b	4-6	29	2.42	3	19.9	48.76	1.46	High
c	2-4	11	0.92	2	12.05	29.53	0.91	Moderate
d	<2	7	0.58	2	6.9	16.91	0.01	Moderate
<b>Drainage Frequency</b>								
a	>15	2	0.17	1	3.91	9.58	0.51	Low
b	10-15	16	1.33	3	14.8	36.26	0.08	High
c	5-10	20	1.77	3	13.9	34.06	1.44	High
d	<5	10	0.83	2	8.2	20.10	1.22	Moderate
<b>Landuse</b>								
a	Urban Cluster	10	0.83	2	10.1	24.75	.99	Moderate
b	Dense Forest	6	0.5	1	16.8	41.17	0.36	Low
c	Open Forest	6	0.5	1	4.9	12.00	1.22	Low
d	Crop Land / Open Space	26	2.17	3	9.01	22.08	2.88	High
<b>Soil</b>								
a	Fine Loamy	3	0.31	1	5.3	12.98	0.75	Low
b	Fine Loamy Fragmented	-	-	1	2.1	5.14	-	Low
c	Sandy Loamy Skeletal	17	1.77	2	12.41	30.41	1.37	Moderate
d	Coarse Sandy Loamy	28	2.91	3	10.9	26.71	2.57	High
e	Unclassified	10	1.04	2	10.1	24.75	0.99	Moderate

\* FRQ: Frequency, LHF: Land Slide Hazard Factor, WAT: Weightage, INCID: Incidence of Landslide per km<sup>2</sup>

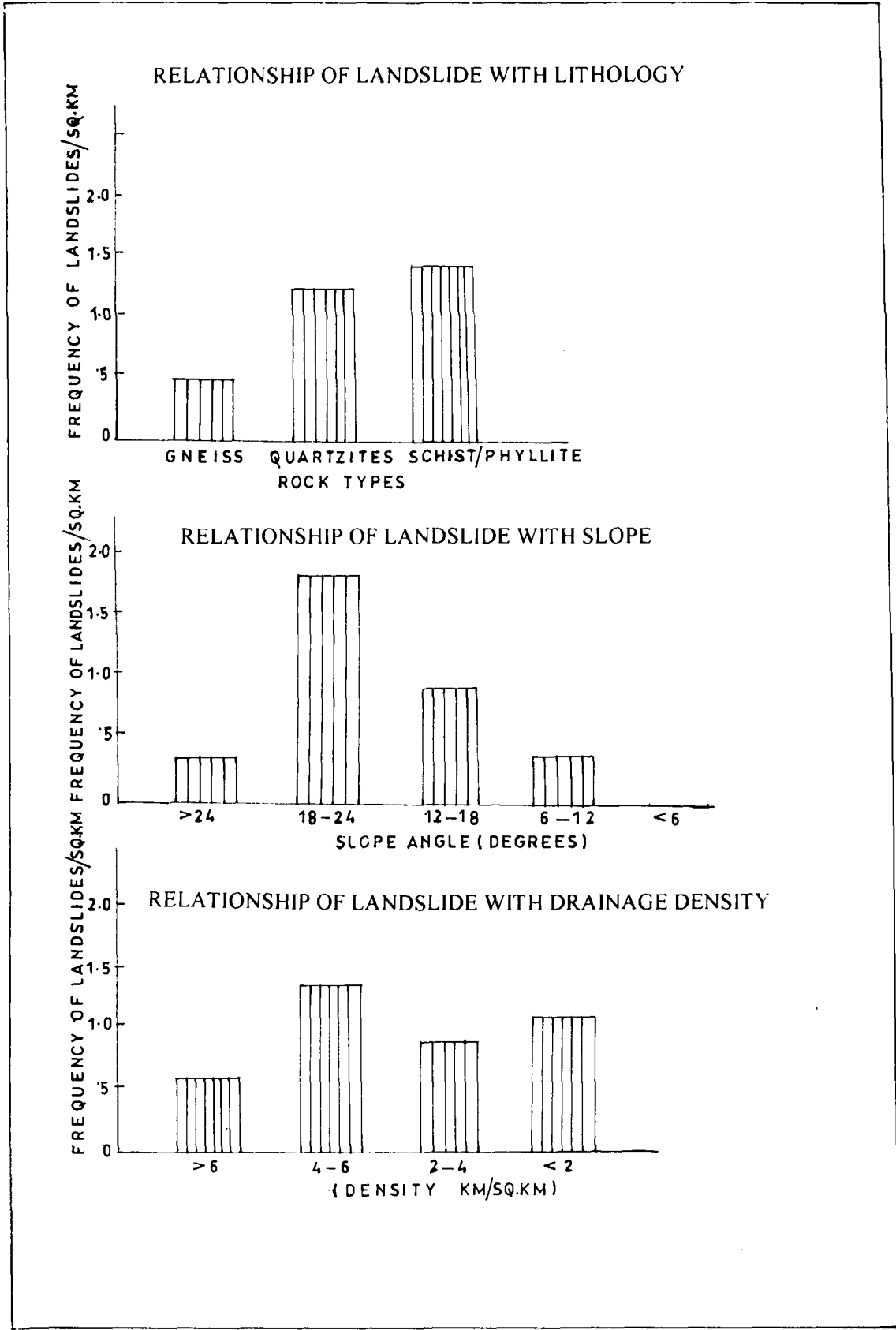


FIG. 4.10

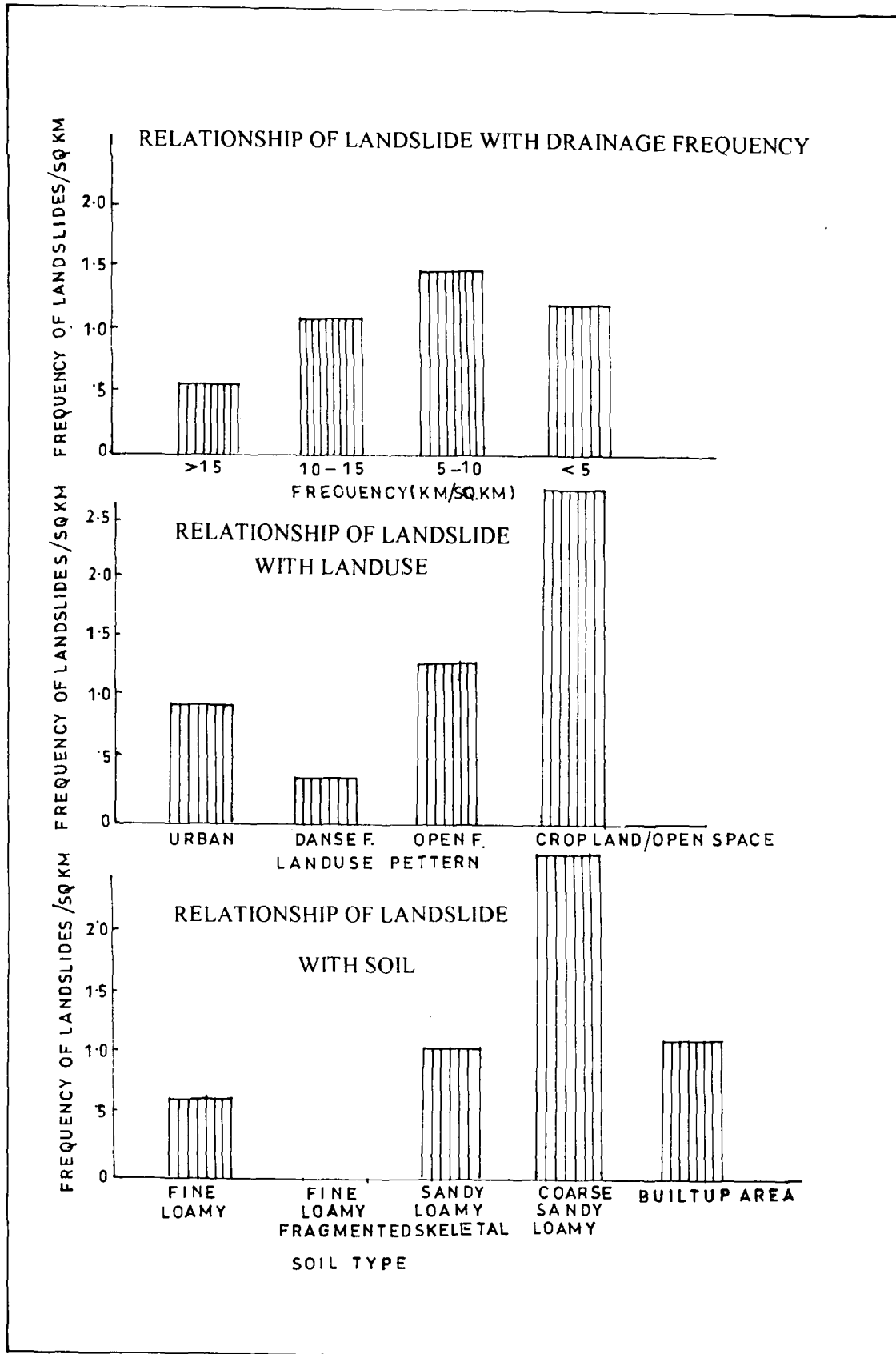


FIG. 4.11

Schist is found in 57.36 per cent, quartzite in 19.36 per cent, and gneiss (granite) in 23.28 per cent of the study area. The frequency analysis of landslides occurrence according to rock types reveals that out of 48 landslides, 34 occurred in schist, followed by 10 in quartzite and 4 in gneiss (Fig 3.16). Clearly schist is found to be highly susceptible to landslides. The flaky and brittle nature of the schist make it prone to sliding incidence by triggering factors like sudden down pour and haphazard and unplanned growth of constructional activity in and around of Gangtok.

The average slope of Gangtok represents five categories i.e.,  $<6^\circ$ ,  $6-12^\circ$ ,  $12-18^\circ$ ,  $18-24^\circ$  and  $> 24^\circ$ . It is important to note here that after field survey with the help of Abney level the actual degree of slope of the site of landslide ranges from  $30^\circ$  to  $75^\circ$ . However, from the analysis of average slope map it is revealed that 40.68 per cent area falls in the category of  $18^\circ- 24^\circ$ , followed by  $12^\circ-18^\circ$  (39.94%),  $6^\circ-12^\circ$  (11.03%),  $> 24^\circ$  (7.84%) and  $<6^\circ$  (0.51 %). The steepness of slope of an area always indicates a state of potential instability. It is also clear from the study that out of 48 slides, 28 landslide have occurred in the average slope angle varying between  $18^\circ$  to  $24^\circ$ , followed by 15 in  $12^\circ-18^\circ$ , three in above  $24^\circ$  and one in  $6^\circ-12^\circ$  (Fig 3.8.). No slide has occurred in the below  $6^\circ$  angle of slope. Further, the density of landslides per square kilometre has been seen highest in the slope angle ranging  $18^\circ$  to  $24^\circ$ .

Drainage density and drainage frequency analysis has always been playing a very vital role in analysis of landslide hazard incidence. Generally, the highest values of drainage density or frequency indicate the probability of highest frequency of sliding

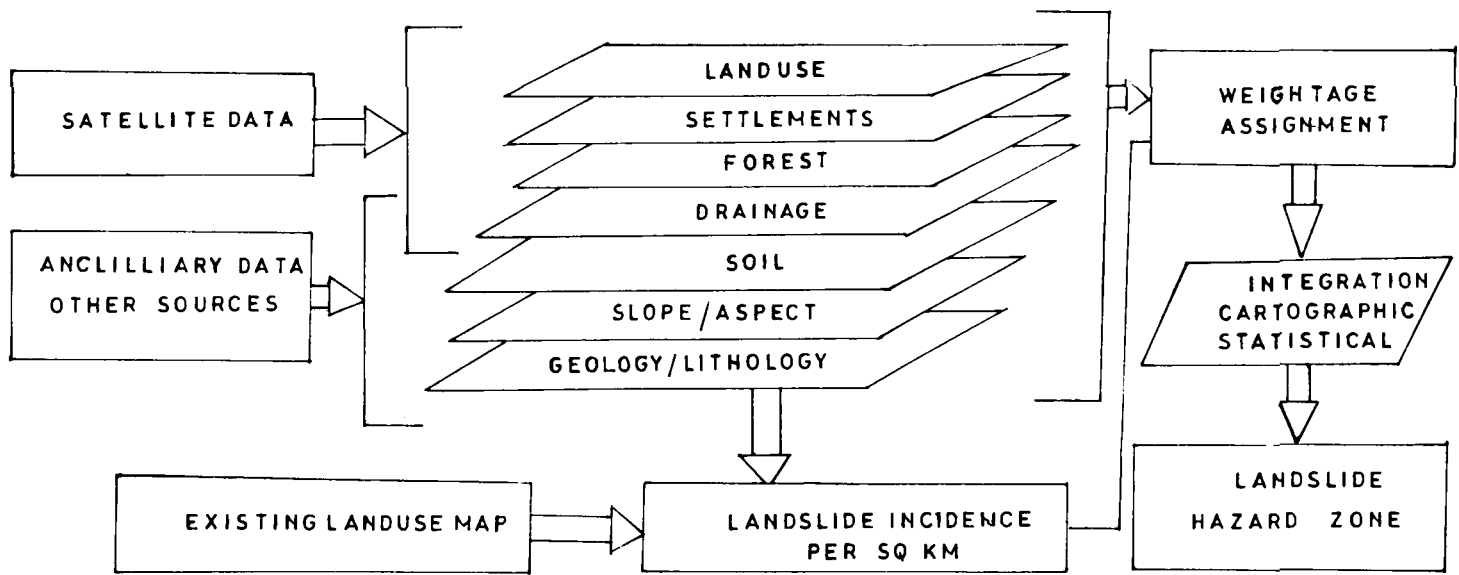
events in an area. The drainage density maps of the Rani Khola and Bhusuk Khola have been classified into four categories i.e.  $>6/\text{km}^2$ ,  $4-6/\text{km}^2$ ,  $2-4/\text{km}^2$ , and less than  $2/\text{km}^2$ . Their analysis reveals that 29 slides has occurred in 4-6 categories, which covered the highest percentage of the area i.e., 48.76, on the other hand, 11 slides occurred in the categories of  $2-4/\text{km}^2$  followed by 7 in  $<2$  and one in  $>6$  (Fig. 3.11 and 3.12 ). It is obvious that the slides per sq km are highest in the drainage density range of 4-6. Landslides incidence map compared to the drainage frequency maps of Rani Khola and Bhusuk Khola ( Fig. 3.13 and 3.14) indicate that highest number of slides (i.e., 20) have occurred in 5-10 category, followed by 16 in 10-15, 10 in  $>5$ , and two in  $>15$ .

Preparation of land use map is an important step towards the scientific study of landslide incidence and micro hazard zonation. Land covers, especially the vegetation/forest, play an important role in the stability of slopes and in the occurrence of landslides. The land use map of Gangtok (Fig. 2.3) represents four main categories of land use viz., urban cluster, dense forest, open space, and crop land. The open space covers an area of 22.08 per cent. It has been observed that the lowest number of landslide events occurred in dense forest and open forest area. Whereas, 10 slides occurred in urban cluster, which covers 10.1 sq km area. It is obvious that haphazard and unplanned construction activity (without considering the geoenvironment) in Gangtok is the main triggering factor of sliding events in urban cluster. On the other hand, forest coverage is playing a protective role for the low sliding events in different parts of Gangtok, particularly in the areas of dense and open forests.

It is worth mentioning that soil is another very important variable to prepare landslide hazards zonation map of an area. Joshi, et al., (2002-03) have given a flow diagram (Fig. 4.12 ) showing different steps involved in the preparation of landslide hazard zonation map. Keeping the matter in mind, soil map (Fig. 3.22 ) of the study has been prepared which represents five categories of soils- fine loamy, fine loamy fragmented, loamy skeletal, coarse loamy and unclassified (i.e., urban cluster or built up area). However, from the analysis it is seen that highest number of landslide events (i.e., 28) took place in coarse sandy loam soil followed by 17 in sandy loamy skeletal soil, 10 in unclassified (i.e., soil under the built up area), and three in fine loamy soil. Sandy loamy skeletal soil covers an area of 30.41 per cent, followed by 26.71 per cent under coarse sandy loam. Sliding phenomena per square kilometre is highest in coarse sandy loam soil (i.e. 2.27/km<sup>2</sup>).

After detailed and in-depth discussion and analysis of different geoenvironment thematic maps of Gangtok and on the basis of above analysis a Landslide Hazard Zonation Map of Gangtok has been prepared (Fig. 4.13) according to the guidelines proposed by the Bureau of Indian Standard (BIS) 1998, i.e., on 1: 50,000 scale (Toposheet No. 78 A/11). Landslide Hazard Factor (LHF) factor and weightage of different geoenvironmental elements have also been taken into consideration for the same. Finally, a composite micro-landslide hazard zonation map (MLHZ) has been prepared. The study area has been divided into three different hazard zones, i.e., High Hazard (HH), Moderate Hazard (MH) and Low Hazard Zone (LH). The landslide hazard factor (LHF) value has been grouped into three landslide susceptibility classes as given in Table 4.8.

# LANDSLIDE HAZARD ZONZTION MAPPING

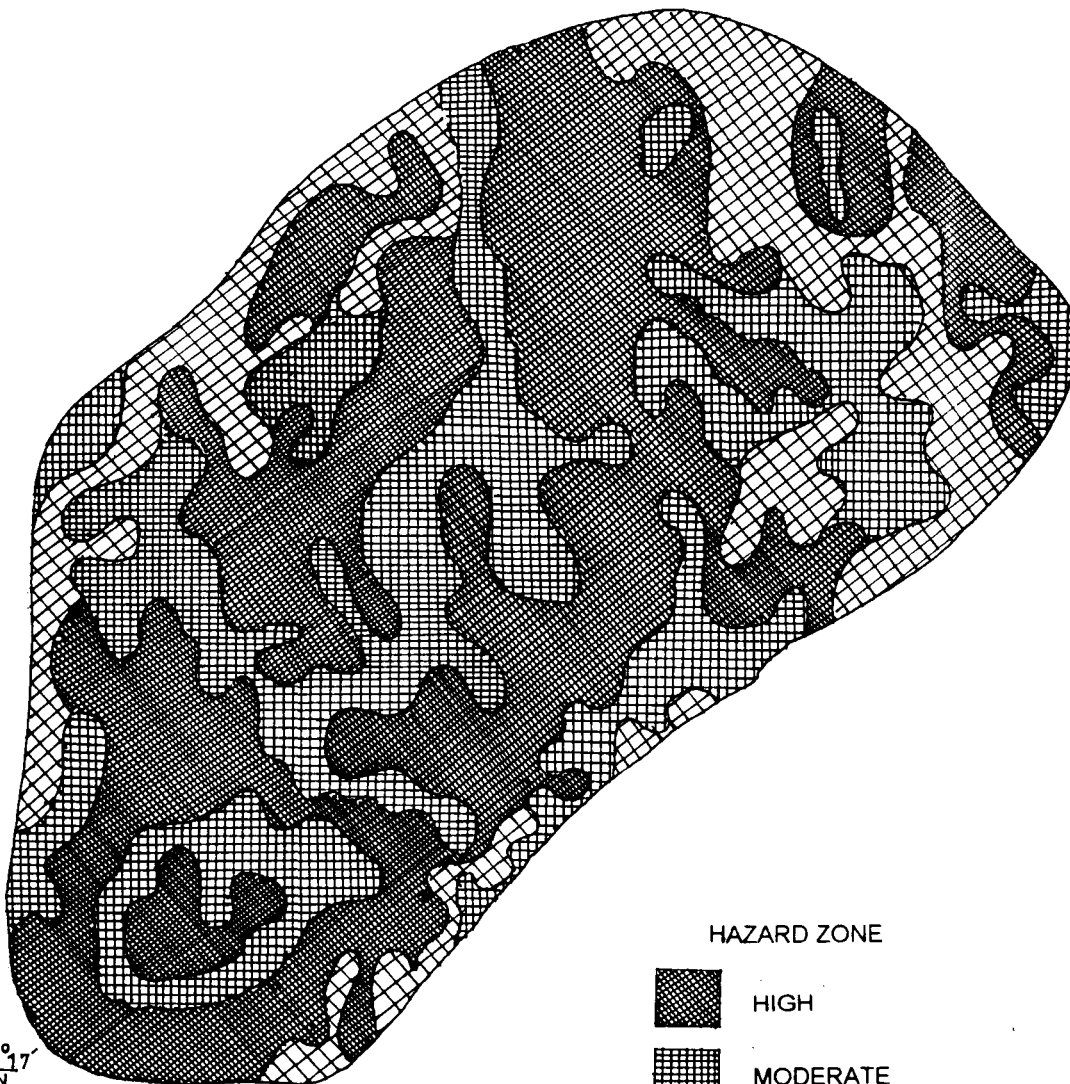


SOURCE : AFTER JOSHI et al., 2002-03

FIG.4.12

GANGTOK  
LANDSLIDES HAZARD ZONES

27°22'



27°17'  
N

HAZARD ZONE



HIGH



MODERATE



LOW



88°35' E

88°39' 55'

FIG. 4.13

**Table 4.8 Landside Hazard Factors (LHF), Weightage and Susceptibility Levels**

LHF	Weightage	Susceptibility
<0.57	1	Low
0.58-1.32	2	Moderate
>1.32	3	High

It is clear from the landslide hazard zonation map that 22.15 sq km area of Gangtok falls under high hazard zone, followed 11.41 sq km in moderate hazard zone, and 7.25 sq km is low hazard zone. It means out of total 40.81 sq km area of Gangtok 22.15 sq km or 54.27 per cent is in high susceptibility zone and needs immediate attention for making remedial measures. Therefore, in the following lines landslide methods and techniques of hazard management and mitigation have been discussed.

The high hazard zone covers a number of localities of Gangtok including Ganeshtok Area, Chandmari, Tathenchen, Rongek Area, Burtuk Area, Baluwakhani, Zero Point, Palace, Secretariat, Deer Park, Pani House, Deorali, Syari, Sichey, Diesel Power House, Arithang, Tadong, Fifth Mile, Six Mile and Sumdur. In the moderate hazard zone come localities like VIP Colony, part of Chandmari, Cantonment Area, Convey Ground, Krishi Bhavan Area, Sialgaon, MG Marg, Lower Burtuk, Below Deer Park, part of Rongek area, Amdogolai and Lumsybasty Area. While the low hazard zone covers areas of Upper Burtuk, Tashi View Area, below Rongek area, part of Arithang, eastern part of upper Sichey, Phawabasty valley, eastern Ganeshtok area, part of Cantonment area, near Government of India Press and northern Tathenchen.

Correlation between the geoenvironmental units and landslides indicate that all the seven units of Gangtok are affected by various degrees of landslide goehazards. However, in the units namely- Middle Steep Deforested Ridge, Lower Central Deforested Ridge, Deforested Rani Valley and Southwest Deforested Moderate Slope occurrence of landslides is most common. Therefore, no further expansion of Gangtok should be allowed particularly in these four units.

#### **4. 5 GEOHAZARDS MANAGEMENT AND MITIGATION**

Hazards management can be defined as the body of policy and administrative decision and operational activities that pertain to the various stages of hazards and disasters at all levels. In fact, the management of geohazards is a critical part of overall management of the environment. It has already been mentioned that tens of thousands of people are affected by natural hazards every year, which not only damages the economic base of a region but also leads to enormous loss of lives and property. Overall, the morbidity, which results from the hazardous situation, can be divided into: (i) injuries, (ii) emotional stress, (iii) epidemic of disease, and (iv) increase of indigenous diseases. Therefore, managing hazards is one of the key elements of an effective health and safety system. There are three fundamental aspects of hazard management: (1) hazards response, (2) hazard preparedness, and (3) hazard mitigation.

Hazard management process can also be presented as follows:

##### **1. Pre-event measures:**

###### **i. Mitigation of Hazards**

**Hazard Assessment**



- Data collection and Analysis — Vulnerability Assessment
- Vulnerability reduction — Risk Assessment

## ii. Preparation for Hazards

- Prediction
- Emergency Preparedness
- Education and Training

## 2. Measures during and Immediately after Hazards

- i. Rescue
- ii. Relief

## 3. Post- Hazard Measures

- i. Rehabilitation
- ii. Reconstruction

Further, the hazard management systems need to be able to:

- Identify all hazards in the institution or academic research level
- Record those hazards
- Assess the seriousness of each hazard
- Develop appropriate control measures, and
- Monitor the known hazard

method, salt velocity method, radiotracer method, hydraulic model etc. However, for the present work following area-velocity method has been adopted:

$$Q = AV$$

Where, A = Area (width x depth)

V = Velocity

**Table 3.4. Discharge in the Rani and Bhusuk Khola**

River	Catchment Area (Km <sup>2</sup> )	Average daily discharge (m <sup>3</sup> /s)	Daily maximum discharge (m <sup>3</sup> /s)	Daily minimum discharge (m <sup>3</sup> /s)
Rani Khola	22.61	57	83	31
Bhusuk Khola	18.2	36	49	23

Source: Field Work, 2004-05.

The mean daily discharge of Rani Khola is 57 cumec and of the Bhusuk Khola is 36 cumec (Table 3.4). Compared to it the Teesta has the average daily discharge of 850 cumec. All three forms of discharge are more in the Rani Khola basin compared to the Bhusuk Khola basin. This is because of large basin area and number of streams in the Rani Khola basin.

Hazard mitigation embraces all measures taken to reduce both the affect of the hazard itself and the vulnerable conditions to it, in order to reduce the scale of future hazards. Therefore, mitigation activities can be focused on the hazard itself or the element exposed to the threat (Anonymous, 2001). Mitigation of hazards usually entails reducing the vulnerability of the element at risk, modifying the hazard- proneness of the sites, or changing its function. Hazard mitigation concept, indeed, include the basic assumption that the impact of disaster can be avoided or reduced when they have been anticipated during development planning. So, recognizing the need of the hour, the decade 1990-99 was declared as 'International Decade for Natural Disaster Reduction' by the United Nations with an objective to focus on disaster and hazard management, planning for prevention, reduction, mitigation, preparedness and response to reduce the loss of life and property due to natural hazards and disasters.

Hazard mitigation is very important step in hazard management to reduce the vulnerability of the system. Mitigation is always related with the process of reducing the severity of the hazard through proper planning. Each disaster or hazard requires a specific type of mitigation. In some cases, engineering solutions can be used to at least temporarily reduce the impact of a natural disaster or geohazard, for example, earthquake resistant buildings. However, hazards mitigation can be achieved in one of the two principal ways: either by modifying the hazard event itself or by reducing its impact on man (Pandey, 2000). Data collection is a very important step towards the management and mitigation of different types of hazards. Collection of data generally involves three kinds of studies- i) hazard assessment, ii) vulnerability assessment, and iii) risk assessment.

Hazard assessment is a process by which an attempt to specify the 'hazard occurrence probability' of an event of a given proportion occurring in a certain area within a specific time period. Indeed, hazard assessment process heavily rely on the available scientific information on geologic, topographical, geomorphic, pedologic, climatic, and hydrological aspects, even by using aerial photographs, satellite imagery etc. Ideally, a geohazard assessment promotes an awareness of the issue in a developing region, evaluates the threat of hazards, identifies the additional information needed for a definitive, and recommends appropriate means of obtaining it (Anonymous, 2004). Concisely, hazard assessment process includes important dimensions like- a) typology of hazards, b) physical characteristics of hazard occurrence, c) temporal characteristics of hazard occurrence, d) hazard assessment considerations, and e) elements of risk to the affects of hazards. Furthermore, hazard assessment process may consider important points, viz., i) history (both written reports, documents and oral accounts), ii) probabilities of various intensities, iii) maximum credible threat, iv) necessary to consider secondary hazards, or 'knock-on' affects of primary forces or main triggering event, and v) the more rare hazards are in a given area, the less historical or statistical information there is to work with. Therefore, they present a less confident opportunity for prediction or common awareness and they can be a greater liability.

Vulnerability assessment is a process which results in an understanding of the types and levels of exposure of persons, property, and the environment to the affects of identified hazards at a specific time period:

**i.e., Vulnerability = People + condition + place + time + event**

Vulnerability can be estimated for selected geographic areas, e.g. areas with the greatest developmental or already developed areas in hazardous zones. The techniques employed include lifeline mapping and sectoral vulnerability analysis for sectors such as energy, transport, agriculture, tourism and housing (Anonymous, 2004). However, vulnerability analysis process involves the following steps:

**1. Types of vulnerability:**

- i) Physical vulnerability**
- ii) Economic vulnerability**
- iii) Social vulnerability, and**
- iv) Cultural attributes affecting social vulnerability.**

**2. Capabilities, and**

**3. Vulnerability analysis considerations:**

- i) Need to focus on degrees of loss, damage**
- ii) Focus attention on important elements, concentration analytical resources on critical or significant items, and**
- iii) Essential to consider relationships of factors that determine social and economic systems and processes over time management and assessment.**

The risk management and assessment is an important step towards the management and mitigation of geohazards. Risk management is a process of analysis which leads to the estimation of the magnitude of a given risk and the determination of

how important such a risk is to matters of 'our' concern (Sharma, 1999). Risk assessment is very important for planner, researcher for incorporating and taking the initiative measures towards the mitigation strategies of geohazards. According to Pirazizy (1992) the analysis of risk involves estimation, identification and assessment of- i) nature and degree of hazard, ii) damage and its socio economic eventualities, and iii) probability of hazard occurrence.

Further, hazard prediction, forecasting and warning system are some others important dimensions towards the management and mitigation of different types of geohazards. Smith (1996) has illustrated the relationship between hazards forecasting and warning system (Fig. 4.14 ).

The micro-zonation approach or hazard mapping is one of the best modern options towards the management and mitigation of geohazards of a region. According to Kuroiwa et al., (1978) micro zonation approach is one of the major strategies for mitigation of natural hazards or their retrenchment. Pirazizy (1992) also explained that by dividing the area of investigation into different sections of incongruous hazard occurrence, and using this information for location of anthropogenic activities, there is immense possibility of drastically reducing future human and material losses.

It is a fact that in the rush for urbanization, the geoenvironment of Gangtok has neither been given due consideration in the development and management of Gangtok nor in its master plan for the future. The understanding of the geoenvironment as a

natural system and the processes operating in it is necessary to guarantee better use of the land and its attributes. The role of geoenvironment at a particular place for proper land use is much wider, involving the evaluation and mitigation of natural and man-induced hazards. The proper understanding of the earth's materials and dynamic processes is essential for comprehending geoenvironment of a particular place, especially where large settlements like Gangtok have come up in the hills and mountains. It is equally very important to study, and manage and mitigate various geohazards in such areas. It is important to note that there has been constant geoenvironmental degradation in different parts of Gangtok. Fragility as well as vulnerability is being aggravated by anthropogenic onslaught together with natural calamities. It is true that nobody can stop catastrophic events like the earthquake, landslides etc. Nature has its own way to balance her dynamic systems.

As mentioned earlier an accurate and timely prediction and management of hazardous event can save human lives and limit the losses of economy and social disruption. To avert losses from earthquakes and landslides in Gangtok, and check occurrence of landslides a multidimensional approach is the need of the hour. The choice of the approach to the problem for consideration should include points like location, duration and accessibility. It should also include a very detailed micro-hazard zonation mapping for the same, which has already been prepared. Besides, enquiries about the risk knowledge and awareness among the people who live at high-risk zones are essential. Stress should be laid on the fact that both microzonation and empirical enquiries should be closely undertaken at the same time, distinguishing previous knowledge, existing

consciousness, and risk perception to forecast the behaviour of the people and community for better risk management and livelihood security. The geohazards management strategy for Gangtok can be taken up on pre-event measures (mitigation and preparation for geohazards during and immediately after hazards); and post-hazard measures (rehabilitation and reconstruction).

The mitigation of geohazards usually entails reducing the vulnerability of element at risk, modifying the hazard proneness of the site or changing its function. Non-structural mitigation measures may be the only affordable alternatives. To manage and mitigate geohazards in Gangtok, Government and Non-Governmental Organisations may take steps like:

1. Identification and assessment of risk programme
2. Undertake data dissemination and Public Awareness Programme
3. Manpower development and training, and
4. Linkage between investigation and user agencies.

Disasters and hazards management and mitigation education (in both formal and non-formal way) to each level of the society may be the best solution in this regard. In this connection it would be important to mention that in 2005 a Hazard Management Cell was been set up under the Ministry of Home, Government of Sikkim, Gangtok. Preliminary works like preparation of inventory of hazards has started, and it is believed that more fruitful works shall be taken up in future.

An integrated approach should be adopted for every phase of hazard mitigation, i.e., pre, during and post hazard event. But it should be noted that 'prevention is definitely better than cure'. Instead of spending cores of rupees on rescue, relief, rehabilitation and reconstruction, it is much desirable to take care of the human actions that accelerate and trigger occurrence of geohazards. Because, it will require much less money and time than what is required after the hazard takes place. Actually, practical and prudential endeavours should be taken by man while managing and mitigating the geohazards of a mountainous region, which have typical environment and fragile ecosystem.

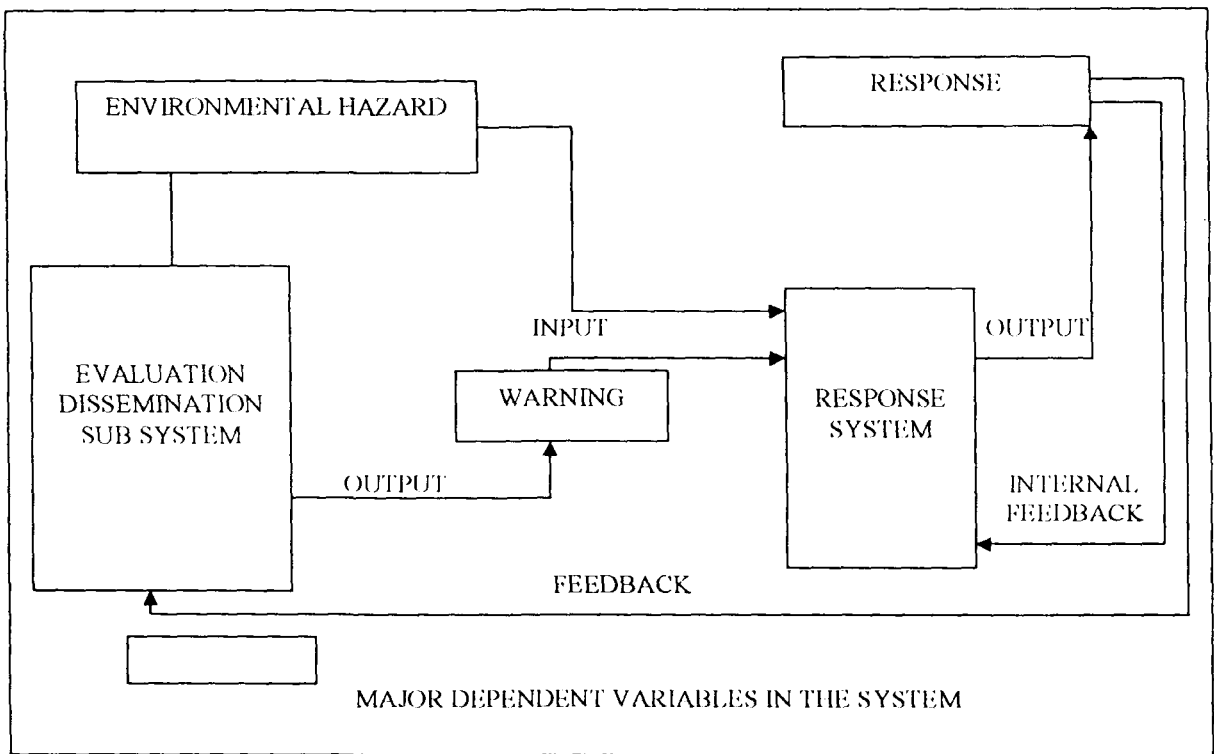


FIG:4.14 RELATIONSHIP BETWEEN HAZARDS FORECASTING AND WARNING SYSTEM (SMITH, 1996).

## CHAPTER- V

### SUMMARY AND CONCLUSION

The present thesis pertains to an appraisal of geoenvironment of Gangtok, the capital of Sikkim state, with special reference to geohazards. Gangtok is a hill station perched on one of the many ridges of the Middle Himalaya Range. Alike most of the hill settlements Gangtok has typical mountain geoenvironment characterised by a long and narrow crest, steep slopes, forests, swift flowing streams interspersed with small spurs, presence of a number of geohazards, especially landslides, etc. Being in the Himalaya Mountain, the geoenvironment along with geohazards of Gangtok exhibit unique characteristics associated with the young folded mountain system of the world, particularly in the tropical belt. Proximity to the sea i.e., Bay of Bengal, has its own influence on the geoenvironment of Sikkim in general and Gangtok in particular, notably in terms of heavy rainfall from the southwest monsoon, making it a wetter part of the Himalaya in comparison to the western parts. The uninterrupted passage of the Bay of Bengal branch of southwest monsoon through the Malda gap results in the high rainfall, which is directly or indirectly related to the recurring problem of landslides in Sikkim.

Geohazards and natural disasters often strike countries, both developed and developing, all over the world. Every year a number of geohazards and natural disasters, occur through out the globe claiming more than two million lives and affecting about one billion people. Over the last two decades, natural disasters have claimed nearly three

million lives and adversely affected more than 800 million people world wide, and 90 per cent of the victims were from the developing countries. Countries like India, particularly the Himalaya is affected every year by different types of geohazards such as earthquakes, landslides, avalanches, floods, etc. On an average about 5000 people are killed and 59 million are affected annually from various types of geohazards and natural disasters in the Indian sub-continent. It is heartening to note that the frequency and dimension of natural hazards have increased in the recent years, which, in fact, is destroying the abilities of the people to survive and prosper. Moreover, these hazards and disasters are always hindering the developmental activities of respective regions and the country as a whole. The Sikkim Himalaya, particularly Gangtok, has been experiencing a number of geohazards like earthquakes, landslides, avalanches, floods etc. Hence, a proper understudying of different types of geohazards is necessary to save lives and property, and to maintain the pace of development by managing and mitigating the natural hazards, particularly the geohazards. In the following lines first a summary of the research has been given, which is to be followed by major findings derived from the study.

## **5.1 SUMMARY**

The whole study has been organized into five chapters. The First Chapter presents introduction to the thesis, where theoretical background is also given in the form of literature survey, apart from other basic details like objectives, research questions, database and methodology. In the Second Chapter, origin, growth and development of Gangtok have been discussed. The crux of the thesis is given in the Chapter Three in

which various components of the geoenvironment of Gangtok have discussed first, then on the basis of them geoenvironmental units have been delineated. This Chapter covers the first objective. Then occurrence, extent, causes and mitigation of the landslide geohazards have been analysed in the Chapter Fourth. An important part of this Chapter is preparation and analysis of landslide hazards zonation map of the study area. This Chapter fulfils the second and third objectives. The conclusions of the thesis are given in the Fifth Chapter in which after summary of the work major findings have been presented.

First of all origin and development of Gangtok has to be seen as this is the study area whose geoenvironment with reference to geohazards has been dealt with in this research, because both are related to each other. Geoenvironment has its own potential and constraint for the development and growth of this hill settlement on one hand, while on the other the latter create interference in the geoenvironment and that causes disturbances in the stability of the geoenvironment system, quite often manifesting in aggravating occurrence of geohazards, especially landslides which in turn affects the very development and closely related with the various developmental activities first under the growth of Gangtok. That is why hazards are now given special attention in the planning process as it not only destroys the development but also hinders the pace of development. In this context lies the relevance of present research work on understanding of geoenvironment of Gangtok.

The origin and development of Gangtok has been closely connected with the development works undertaken firstly by the different Chogyals of Sikkim, who ruled the state until 1975, and then secondly and significantly too taken up by the different governments elected democratically after the merger of Sikkim with the Union of India as its 22<sup>nd</sup> state. Actual development of Gangtok started when it was made the capital of Sikkim in 1894, until then there were only a few wooden houses around a monastery and palace. In fact, it was a halting place of mule caravans travelling on the ancient trade route between the mainland India and Tibet through the famous pass Nathula and Chumbi valley. Of course, in the surrounding area there existed some hamlets like Lingding, Syari, Tadong, Burtuk, Deorali etc. which were later merged in the expanding Gangtok. Among the Chogyals mention may be made of Thutob Namgyal, Tashi Namgyal and Palden Thotub Namgyal, during whose reigns Gangtok grew from a small hamlet to a modern imposing capital with all cosmopolitan functions and services. Expansion of Gangtok in terms of area reveals that it had 2.10 sq km by 1947, which increased to 6.11 sq km between 1947 to 1975, but the largest area was added (34.70 sq km) between 1975 and 2005 and now it is spread over 40.81 sq km.

After 1975 very rapid development and growth has been registered in Gangtok. Before that Gangtok was governed by a Bazaar Committee, but after 1975, the state has introduced the municipal form of local self- government, unfortunately it did not last for long. After few years the Department of Urban Development and Housing Development (UD & HD) has taken over the charge of governance of Gangtok. In fact, under the umbrella of UD & HD, the landscape of Gangtok and its suburbs has drastically changed.

Expansion of Gangtok is also related with the growth of its population. Over the years the population of Gangtok has increased, however, rapid growth of population by 207.13 per cent was recoded during the decade of 1971-1981. As per 2001 Census Gangtok has 75,112 persons, belonging to the Nepali, Bhutia, Lepcha, Tibetan and people different communities from various states of India. Though the expansion and development of Gangtok is mainly controlled by the slope factor, haphazard constructional activities have been seen in different parts of Gangtok after the implementation of the Five Year Plans. Though, during the Chief Ministership of Kazi Lhendup Dorji a number of developmental activities took place in Gangtok, a rapid development has been seen after 1980s.

Definitely, Gangtok has typical geoenvironment specific to a hilly terrain. As it is spread over a ridge almost all micro-level landforms of a ridge are found here. It has a narrow crest right from the base of the highest area to the confluence of the two rivers, which bound the study area in the east and west. The eastern steep slopes of the ridge descend to Bhusuk Khola, while not so steep western slopes merge with the Rani Khola. Both the drainage basins have high drainage density and frequency, whose relation has been found with the occurrence of landslides. The most common range of slope in the area is  $40^{\circ}$  to  $60^{\circ}$ . Most of the settlement has come up on the crest and western slopes of the ridge right up to the Rani Khola. Even further sprawl is possible as the northeastern and eastern steep areas put a constraint on it. Apart from these there are small spurs in between which flow numerous streams, steep and gentle valleys, escarpment and saddle.

Altitude ranges from 900 m in the southwest to 2500 m in the northeast where the Ganeshtok peak lies. The main hub of Gangtok lies between 1200 m to 1800 m altitude.

Phyllite, schist, banded gneiss, quartzite and granite rocks exist in the study area, which are considered weak from the point of view of landslides. Most occurrences of landslides have been found in schist and phyllite rocks. The structure is dominated by joints, cracks, bedding planes, faults and thrusts. The SSE-NNW running Gangtok fault just passes across the study area. While one of important tectonic features of the Himalayan i.e., Main Central Thrust (MCT) passes just 5 km northeast of the Gangtok. On the other hand, another dislocation zone the Main Boundary Fault (MBF) lies far in the south. All these structural characteristics along with its location in the mobile belt put the area in seismic zone IV. A number of earthquakes have struck the study area along with Sikkim as a whole. The occurrence of earthquake triggers landslides as well, hence both can be seen as extreme geoenvironmental phenomena of Gangtok.

Seismicity has been described as a part of geologic environment, which is also a cause of major landslides in the hills. Hence, earthquakes have not been discussed as one of the geohazards in Chapter IV. In this context presence of the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT) in Sikkim Himalaya close to the study area is point of great concern. The Indus Tango Suture Zone (ITSZ) is also lies not very far from the area. All these discontinuities and other structural features are active sites of seismic activities, and in the event of any tremor, unfortunately entire Gangtok will be affected. Data show that around 30 earthquakes have hit Gangtok in last 50 years. Almost

all the earthquakes of the region have the maximum magnitude ranging from 5.0 to 6.5 on Richter scale. Recurrence of big earthquakes in the region is believed to be at an interval of 15 to 20 years.

Various types of loamy soils are found in the study area, which have different percentage of clay particles, which is relevant from the point of view of holding the infiltrating rainwater. When these clay particles are wet enough they act as lubricant on which the land can slide. From hydrological point of view the Rani Khola and Bhusuk Khola are the two main rivers of the area. Of course, number small streams originate from the slopes of the Gangtok ridge and meet the two rivers. Gangtok water supply system solely depends on surface water sources. About 80 per cent population of Gangtok is presently covered by the Gangtok water supply system and remaining 20 per cent population depend on sources like '*Jhoras*' (streams and springs). Analysis of water samples and data from pollution control board reveal that water is free from marked pollution, hence, suitable for drinking.

Gangtok experiences the sub-tropical and temperate continental types of climate. It gets an average annual rainfall of 300 cm to 400-cm. winter is generally dry, except some occasional drizzle and rare snowfall. Maximum and minimum annual ranges of temperature vary from 26<sup>0</sup>C to 2<sup>0</sup>C, respectively. Both dense and open forests are found in the study area. The dense forest covers 41.17 per cent and open forest 12 per cent area of Gangtok. The remaining part is built either up area or open space or cultivated fields.

Tropical and temperate forests are found in the study area due to altitudinal variation. Different varieties of trees, shrubs, herbs and grasses are seen in and around Gangtok.

Based on different geoenvironmental elements seven units have been identified in Gangtok. Layers of different variables have been overlapped to demarcate geoenvironmental units. The main purpose of the geoenvironmental units is to see the totality of the geoenvironment and variations within it within the study area. Names of the geoenvironmental units are as follows

- i) Northeast Higher Steep Forested Ridge (7.21 sq km),
- ii) Middle Steep Deforested Ridge (8.32 sq km),
- iii) Eastern Deforested Steep Ridge (5.11 sq km),
- iv) Lower Central Deforested Ridge (5.10 sq km),
- v) Western Forested Moderate Slope (7.75 sq km),
- vi) Deforested Rani Valley (4.50 sq km),
- vii) Southwest Deforested Moderate Slope (2.82 sq km).

The unit two is the largest in area, while unit seven is the smallest. Geoenvironmental unit one- Northeast higher steep forested ridge and the units three Eastern deforested steep ridge have constraints for the development in Gangtok. In other words, no further expansion should take place in these units, as first one is the area to be kept free from any disturbance, while the second area is too steep to develop, otherwise more geoenvironmental problems will be invited. On the other hand, location of the main settlement on unit two- Middle steep deforested ridge is a matter of great concern, for it is

a steep slope area on which thousands of RCC buildings have come up which are at great risk in the event of an earthquake or a landslide. It appears that entire area may slide down one day either during a cloud burst, which are very common, or may crumble and collapse during an earthquake, as it happened recently on 14<sup>th</sup> February 2006. Keeping characteristics of geoenvironmental units in mind it can be suggested that no further expansion should take place on the steep slopes and in forested areas. These two places should be kept free from human interference, otherwise more problems will follow. Moreover, on the steep slopes and sites of landslide fast growing vegetation should be grown which can hold the slope material. Channels in the upper parts of the landslide area should be diverted to check role of runoff and infiltration of rainwater in triggering landslides.

A number of landslides have occurred in Gangtok and its suburbs in the last 45 years. Records show sharp acceleration of landslides in and around Gangtok, causing loss of life and property. It is also clear from the study that most of the landslides have taken place in and around built up area and along the roads, indicating that it is the human interference which is main cause behind occurrence of landslides. Some of the most devastating landslides took place in Syari (1990), Deorali (1990, 1995), Tathenchen and Chandmari (1997), Ganeshtok area (2002), Pani House, Lower Tadong and Syari area (2005). Most number of landslide events has been reported from Chandmari, Tathenchen, Deorali and Syari localities. Significant to mention that most the devastating landslides in the study area have taken place during the monsoon months of June and September. The main cause of landslides in Gangtok is direct result of continuous down pour. However,

lithology and structure, geotectonical instability, seismic activity, coarse sandy loam soil, high drainage density and frequency, deforestation and unplanned constructional activities as human interference in the geoenvironmental system are other main causes of landslides. In the context of rainfall as triggering factor of landslides one point is perplexing and that is that rainfall is an area specific phenomenon, not a point specific phenomenon like the landslides. Whereas rainfall occurs over an area, but the landslide takes place at only a few sites, and not in the entire area where the same intensity of rain has precipitated, and that is the intriguing point to mind. Though rainfall as cause of landslide has been accepted widely, still there are some more intricate and complex processes, factors and causes unexplained, because some unique process operates under the influence of a multiple of factors that triggers landslides on a part of a hill slope, and not on the entire slope. Probably here comes the human interference in the hill slope system, which leads to slope failure. The human disturbance to the stability of the slope is first, then comes the heavy rainfall which triggers the mass movement. However, this argument can not be applied to landslides occurring in the wild areas, almost free from human interference. Some natural processes are definitely involved in the landslides caused due to human interference in the geoenvironmental system. But this is a well established fact that landslide occurs whenever the rain comes, and probably never occurs in dry periods, and that establishes the fact that rainfall is crucial cause of landslides in the world.

Relationships between the frequency of occurrence of landslides in the study area and various geoenvironmental elements (Fig. 4.10 and 4.11) reveal the following points. The frequency analysis of landslides occurrence according to rock types reveals that out of 48 landslides, 34 occurred in schist, followed by 10 in quartzite and 4 in gneiss. Clearly schist is found to be highly susceptible to landslides. The flaky and brittle nature of the schist make it prone to sliding incidence by triggering factors like sudden down pour and haphazard and unplanned growth of constructional activity in and around of Gangtok. It is also clear from the study that out of 48 slides, 28 landslide have occurred in the average slope angle varying between  $18^{\circ}$  to  $24^{\circ}$ , followed by 15 in  $12^{\circ}$ - $18^{\circ}$ , three in above  $24^{\circ}$  and one in  $6^{\circ}$ - $12^{\circ}$  (Fig 3.8.). Surprisingly, no slide has occurred in the below  $6^{\circ}$  angle of slope, and that shows that steepness of slope plays important role in the occurrence of landslides. Therefore, the density of landslides per square kilometre has been seen highest in the average slope angle ranging  $18^{\circ}$  to  $24^{\circ}$ .

Drainage density and drainage frequency analysis has always been playing a very vital role in analysis of landslide hazard incidence. Generally, the highest values of drainage density or frequency indicate the probability of highest frequency of sliding events in an area. The analysis reveals that 29 slides have occurred in 4-6 km./sq km category of drainage density which covers the highest percentage (48.76) of the study area. On the other hand, 11 slides occurred in the categories of  $2-4 \text{ km}/\text{km}^2$ , followed by 7 in  $<2$  and one in  $>6$ . It is obvious that the slides per sq km are highest in the drainage density range of 4-6 km/sq km. Landslides incidence map compared to the drainage

frequency maps of Rani Khola and Bhusuk Khola indicate that highest number of 20 slides occurred in 5-10 category, followed by 16 in 10-15, 10 in < 5, and two in > 15.

The land use of Gangtok has urban cluster, dense forest, and open space and crop land. The open space covers an area of 22.08 per cent. It has been observed that the lowest number of landslide events occurred in dense forest and open forest area. Whereas, 10 slides occurred in urban cluster, which covers 10.1 sq km area. It is obvious that haphazard and unplanned construction activity (without considering the geoenvironment) is the another main factor of sliding events in Gangtok. On the other hand, forest cover plays a protective role hence few sliding events have been reported from forested areas, particularly in the areas of dense and open forests. Finally, a composite micro-landslide hazard zonation map (MLHZ) has been prepared depicting three categories of viz., High Hazard (HH), Moderate Hazard (MH) and Low Hazard Zone (LH). For this purpose the landslide hazard factor (LHF) values have been grouped into three landslide susceptibility classes.

The high hazard zone covers a number of localities of Gangtok including Ganeshtok Area, Chandmari, Tathenchon, Rongek Area, Burtuk Area, Baluwakhani, Zero Point, Palace, Secretariat, Deer Park, Pani House, Deorali, Syari, Sichey, Diesel Power House, Arithang, Tadong, Fifth Mile, Six Mile and Sumdur. In the moderate hazard zone come localities like VIP Colony, part of Chandmari, Cantonment Area, Convey Ground, Krishi Bhavan Area, Sialgaon, MG Marg, Lower Burtuk, Below Deer Park, part of Rongek area, Amdogolai and Lumsybasty Area. While the low hazard zone covers areas of Upper Burtuk, Tashi View Area, below Rongek area, part of Arithang,

eastern part of upper Sichey, Phawabasty valley, eastern Ganeshtok area, part of Cantonment area, near Government of India Press and northern Tathenchen.

It is clear from the landslide hazard zonation map that 22.15 sq km area of Gangtok falls under high hazard zone (HH), followed 11.41 sq km in moderate hazard zone (MH), and 7.25 sq km is low hazard zone (LH). It means out of total 40.81 sq km area of Gangtok, 54.27 per cent is in high susceptibility zone (HH) and needs immediate attention for taking remedial measures.

Some methods and techniques of landslide hazard management and mitigation have also been given to fulfil objective three. Emphasis is placed on preventive measures for landslides geohazards, which include avoiding interference in the geoenvironmental system through the construction and other development works, deforestation, too much RCC buildings on steep slopes, and many such human activities leading to alterations in geoenvironmental set up of Gangtok. Even in preparing the master plan of Gangtok geoenvironmental potentialities and constraints have not been given due recognition. As the higher central Gangtok ridge is already saturated with construction works, no further construction should be allowed there. The northeastern and eastern steep slopes are suitable for any sort of sprawl, a satellite township, small in size, seems to be best remedy to solve geoenvironmental problems of the capital of Sikkim. The phrase 'small is beautiful' is more suited to hill settlements. Hills and mountain regions owing to their inherent characteristics do not allow large size growth of human settlements. Therefore, it has rightly been said earlier that mountains exhibit their own typical potentiality and

constraint for the establishment, size and expansion of human settlements. If the geoenvironmental characteristics are properly understood while developing and managing big settlements then various problems would not arise actually.

Management of hazards is one of the key elements of an effective health and safety system. The three fundamental aspects of hazard management are: i) Hazard response ii) Hazard preparedness and iii) Hazard mitigation. Besides, it may also be presented as i) pre-event measures ii) measures during and immediately after hazards and iii) post-hazard measures. On the other hand, hazard mitigation is also very important step towards hazard management to reduce the vulnerability of the system. Based on detailed studies of geohazards, simulation models can be generated on computers that will help in prediction of landslides in given geoenvironmental and human conditions. All means and ways should be employed to check of landslides as they cause great loss of life and property, disruption of communication network and transport system, tension and misery in the affected people and many other unimaginable difficulties. Slope failure causes failure of various natural and human systems. Hence, it is must to reduce occurrence, intensity and extent of landslides, and for that understanding of geoenvironment and preparation of hazard zonation map is a must. Here also lies relevance of this study.

## **5.2 MAJOR FINDINGS**

From the foregoing on the geoenvironment and landslide geohazards of Gangtok following main finding have been derived.

1. Gangtok, the study area, has grown to present size and status from a tiny hamlet.
2. Main development and expansion started when Gangtok was made capital of the then kingdom in the year 1894, and the process got accelerated from 1975 when Sikkim become the 22<sup>nd</sup> state of the Union of India. That is why exponential population growth of 207.13 per cent was recorded during the decade 1971 and 1981.
3. The growths of Gangtok have been identified in three phases, viz., 1894 to 1947, 1947 to 1975 and 1975 to 2005. During the last phase it has seen phenomenal expansion of area by 568 per cent, and it is spread over 40.81 sq km area today.
4. Land use/ land cover show that it still has 53.17 per cent area under forest cover, while built up area is 24.75 per cent. The later is mostly at the cost of forest cover, and that indicate the amount of deforestation in the study area.
5. Much of the development has caused alterations in the geoenvironment of Gangtok, and this human interference has led to emergence of number of geoenvironmental problems/ geohazards, including the landslides.
6. Gangtok is perched on a ridge, running northeast to southwest, of the Eastern Himalaya Mountain, hence its geoenvironment is characterised by all facets of mountain environment.

7. Eastern and northeastern slopes of the ridge are steeper than rest of the slopes, hence landslide prone. While most of the settlement has grown on the relatively less steep western slopes.
8. Geoenvironment of Gangtok is characterised by steep slopes of angle mostly  $40^{\circ}$  to  $60^{\circ}$ , weak rocks, structural discontinuities in the vicinity of MCT, MBT, ITSZ, and Gangtok fault right across the study area, part of seismically active zone IV, high drainage density and frequency, decreasing forest cover, sandy loam to sand clay loam soils with clay minerals, tropical to temperate climate with heavy monsoon rainfall that is responsible for triggering landslides, and hydrological conditions with numerous rivers, streams and *jhoras* (small streams and springs).
9. Landslides occur in almost all the geoenvironmental units but they are most common in four units namely the Northeast Higher Steep Forested Ridge, Lower Central Deforested Ridge, Deforested Rani Valley and Southwest Deforested Moderate Slope, mainly due to steep slopes, construction works and deforestation.
10. Landslide is the most common geohazard of the area, occurrence of which has accelerated after 1950s. About 48 major landslides have occurred between 1960 and 2005.
11. Most landslide affected areas are Chandmari, Tathenchhen, Deorali, Zero Point and Arithang, where geoenvironment is characterised by steep slopes, weak rocks, high drainage density and frequency, and open forest, while human factors are high number of RCC buildings, deforestation, and disturbance in slope stability due to different construction works.

12. Most of the landslides occur during the monsoon period, especially in June and September, when the southwest monsoon is strong.
13. Out of 48 landslides, 28 occurred in average slope category of  $18^{\circ}$  to  $24^{\circ}$ , and 15 in  $12^{\circ}$  to  $18^{\circ}$ . While 28 in coarse sandy loam porous soil, 17 in sandy loamy skeletal soil, and 10 in the built up area.
14. Undoubtedly, incessant rainfall is the main triggering factor in the landslides.
15. Over all main geoenvironmental causes of landslides are- steep slopes, considerable percentage of clay minerals in the sandy clay loam soils, weak lithology, geotechnical instability, excessive and heavy rainfall during short duration, and human interference in the form of deforestation, construction works and slope alteration.
16. Alarmingly, more than half, i.e., 54.27 per cent of Gangtok falls in the High Hazard Zone, while another 25 per cent come under the Moderate Hazard Zone.
17. It can be said that Gangtok has been suffering from the recurring and chronic landslide geoenvironmental problem, and that invite attention of the geoscientists to understand the processes and mechanism involved in it to suggest remedial measures for checking frequent and devastating occurrence of landslides to save Gangtok and its inhabitants.
18. Taking care of the geoenvironment of Gangtok while developing it further, avoiding interference in the geoenvironmental system and planting of faster growing trees, bushes and grasses in the already landslide affected areas and will be the best solution of the problem.

### **5.3 RECOMMENDATIONS**

Though this research has been able to comprehend the geoenvironment of Gangtok with special reference to geohazards, still there is scope to carry out more detailed work on the following aspects of the research problem.

1. In-depth studies on the old and new landslides to find out site-specific geoenvironmental characteristics and reasons of landslides.
2. Such studies will include geomorphic features, processes and factors responsible for slope stability and its failure as well. Nuances, intricacies and complexities of mass movements are still not fully and truly understood, particularly on landslides, despite plethora of research, publication, and laboratory and computer simulations. This is because laboratory simulations can not create the natural conditions and processes, simply impossible. Field is the best and true laboratory of a geoscientist in general and geomorphologist in particular, and the results and findings of the only field based research should be accepted.
3. Though rainfall is considered the most accepted triggering factor of landslides through out the world, its actual role in the processes leading to break of the threshold on a stabilised slope are yet to be fully comprehended. No doubt the rainwater acts in many ways, like lubricating the plane of slide, increasing weight of the slope forming material through saturation of it leading weakening of shear strength etc., but all are happening every where wherever the same nature and amount of rainfall has taken place, but landslides occur at only a few sites and not in the entire area. This question has to be answered, why not at all places or why at only a few sites. Generally, the entire slope forming material gets wet under

rainwater, which increases its weight, but slope does not fail as the balance between the downward stress/ gravity pull and vertical force is still maintained. The vertical force is responsible for slope stability, contrary to it the gravity generates downward mass movement causing slope instability. Therefore, it is interesting to investigate that when downward gravity pull will overwhelm the vertical force, leading to slope failure.

4. In studying slope stability slope should be taken as a system in which its different geoenvironmental components are working together harmoniously towards stability of slope. Hence, systems approach should be applied while studying slope instability and mass movement, especially the landslides. ,
5. As man has become dominant geomorphic agent at some places, human interference and alterations should also be examined thoroughly and critically. In this connection interface between natural and human systems must be studied to know the reality that who is responsible for landslides, nature or man, or both. Truth in this regard has to be searched and brought to the knowledge of the posterity. .

These are the relevant research problems to be investigated to enrich the understanding of geoenvironment and geohazards, especially the landslides. It is very much possible with the tools and techniques available at the disposal of the geomorphologists and geoenvironmentalists. If required, more can be borrowed from other geosciences.

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**Plate 1 Gangtok**



**Plate 2 Main settlement on steep slope**



**Plate 3 The Gangtok Ridge (Viewed from Ganesh tok)**



**Plate 4 The Tashilling (Secretariat) on the Gangtok ridge**



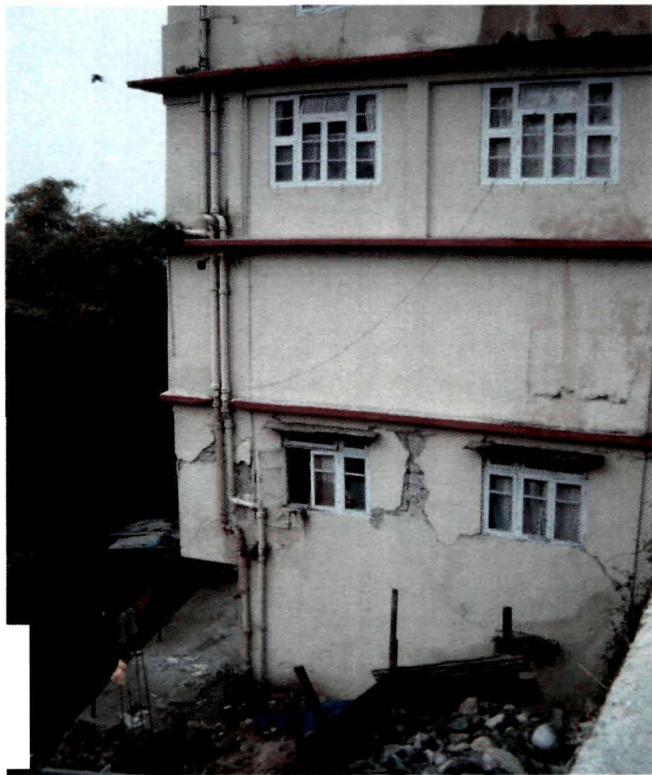
**Plate 5 Cracks developed in a RCC building after the tremor of 5.7 intensity on 14.02.06**



**Plate 6 Cracks developed in a RCC building after the tremor of 5.7 intensity on 14.02.06**



**Plate 7 Cracks developed in a  
RCC building after the tremor  
of 5.7 intensity on 14.02.06**



**Plate 8 Cracks developed in a  
RCC building after the tremor  
of 5.7 intensity on 14.02.06**



**Plate 9 A major landslide near Chandmari in 1997  
(Courtesy: Bhasin, et al.)**



**Plate 10 Debris of landslide filled compound of a government office  
near Zero Point**



**Plate 11 House and property damaged by minor landslide**



**Plate 12 Vehicle under the debris of landslide**



**Plate 13 Road blockage due to landslide**



**Plate 14 Road blockage due to landslide**



**Plate 15 Road blockage due to landslide**



**Plate 16 Landslide near 6<sup>th</sup> Mile locality**

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