SIKKIM

STUDY SERIES

Geography & Environment

Volume - I

By

KC Pradhan, Eklabya Sharma,
Gopal Pradhan and AB Chettri

Chief Editor
Mahendra P. Lama

Sikkim
Study Series

Geography & Environment

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Volume 1

by
K.C. Pradhan
Eklabya Sharma
Gopal Pradhan
A.B. Chhetri

Chief Editor
Mahendra P Lama

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Pawan Chamling
(Honoris Causa)
Chief Minister of Sikkim

Foreword

Sikkim has a long and interesting history of its own. There are several historical accounts written by travelers. Many of the historical records are not opened as yet. I am told that the National Archives in New Delhi has opened the archival materials to the readers and scholars only upto 1913. It would be of great interest to the readers in general and Sikkimese people in particular to know from these precious archival records various events that marked Sikkimese historico-political development, socio-cultural milieu and environmental and economic dynamics.

When I took over the august office of the Chief Minister of Sikkim in 1994, I seriously wanted to read as much literature on Sikkim both old and new alike. This was to broaden my own horizon of knowledge of Sikkim and also to assess how much we have gained and lost in terms of both institutional memories. As compared to such huge and rich events and accomplishments that characterized Sikkim over the centuries, I found very little literature on Sikkim. They were mostly on the political history of Sikkim that too primarily focusing on the genesis of merger with India.

We have a rich cultural history that have been very assiduously developed and conserved by well integrated and finely woven co-existence of three major ethnic groups viz., Bhutia, Lepcha and Nepali communities. Our political history has been laden with and influenced by varied events and unfolding of major events in and around Sikkim. The constant fracas with British India, long colonial rule in India and its effort to spread its tentacles to neighbouring Himalayan countries including Bhutan, Nepal

and Sikkim and through them to China all influenced the course of Sikkimese political history. The Chinese occupation of Tibet and later its acceptance by India as an autonomous region of China and the Sino-India war of 1962 added new geo-political dimensions to Sikkim.

We have unique environmental management system that called for a sustainable balancing between human needs and nature's capacity to cope with such contingencies. This has been well ingrained in the present management of our natural resources. Economically the subsistence farming characterized the system for long which was largely driven by a feudal land order. This made the system economically not only exploitative but brought in in-built elements of inequality, disparity and deprivation. All these together helped in some kind of political collectivization among the have-nots which were later indicated in their utmost willingness to move to a more open and democratic regime. The post-merger Sikkim did authenticate and vindicate their hopes and aspirations in this regard.

A major gap in the published literature on Sikkim has been too much of emphasis on its political history which are at times repetitive. There has been very insignificant published literature on other equally vital areas. Whatever has been published in these areas has remained both scanty and scattered. Sikkim is known for its cultural varieties and rich ethnic lineages. We have a bountiful of literary history based on both creative literature, religious teachings and travelogues. Our economic development has very strong elements of what we today call 'sustainable development'. It has been a paradise for natural scientists and a major destination for travelers and explorers.

However, in all these critical areas nothing has been recorded. Both records and memories have remained scattered. As a result we have tended to lose very precious and useful knowledge, information and historical-intellectual properties. We have felt that if we do not start the process of recollecting, examining, recording, writing and disseminating these memories, information and knowledge in right earnest, it would be rather too late and

deleterious for both present and future generation. We may, as a result, steadily lose all our institutional memories and even the sources of oral history.

My government remains unwavering in its resolve to improve not only the living condition of the people but also to develop them intellectually and broaden their outlook. In this direction, a beginning has already been made by bringing out a number of enlightening and inspiring publications that broaden their horizons and sharpen their inner faculties. To promote language and culture Sikkim Akademi has been set up and Libraries have been established in every Gram Panchayat Unit to cultivate reading habits among the rural people. This new tradition and culture of elevating the intellectual level of the people is aimed at strengthening the civil society and knowledge society so that people could utilize their potential to the full and absorb the best that is happening in the world.

It is in this regard that we have conceived the idea of bringing out *Sikkim Study Series* on various issues and discipline which have mostly remained neglected. More importantly we decided to commission these studies to the writers and scholars who have been studying Sikkim for long and who have known Sikkim intimately. It was a challenging task to put together writers and scholars with varied background and more so discipline them to write in a kind of required format. I am impressed by the way the commissioned volumes are emerging one by one.

This volume on *Geography and Environment* in Sikkim co-authored by Shri KC Pradhan, Dr Eklabya Sharma, Dr Gopal Pradhan and Dr AB Chhettri is the first volume in the series. The authors have been consistently working on the environmental issues in Sikkim. This volume is a crucial contribution to the discourse on sustainable development. Sikkim has a fragile eco-system and the question of environmental security has always been upper most in our minds while initiating any development interventions. In order to tread the path of balanced development we have to sacrifice many forthcoming benefits. As a result our options and alternatives become narrow. This means we will have to provide limited choices to the people.

However, the Sikkimese people are devout nature lovers. They have the wholesome tradition of conservation of natural resources. This is our strength which could even defy the agents and instruments of globalisation.

Our Government has vowed to make Sikkim an organic State by 2015. We are seriously working towards this. I am sure this volume will be found useful by a range of people both in India and abroad. The bringing out of these volumes is a well thought out action yet an arduous task. Besides a high level of standard and quality which need to be maintained for a wider readership, the authors needed to be given constant advices and guidelines. Many of the authors have had to go back to the archival sources and also based their writings on oral history from various corners of Sikkim. More than this, the monitoring of the project and the assessment of the volume by independent referees and the editing needed have been carried out in a very professional manner. In all these Prof Mahendra P Lama, Chief Editor of the Series played a very critical role and deserves high accolade.

The Information and Public Relations Department coordinated this work all through. I must express by gratitude for this to the past Secretaries of the Department and the former Secretary Shri V B Pathak, present Secretary Shri Girmi Goparma and the officer in-charge of this project Ms Jabi Thapa and also to those who worked from behind the scene to accomplish this project.

Pawan Chamling
Chief Minister of Sikkim

Preface

Gazetteer of Sikhim with an introduction by H.H. Risley is one of the important documents reference of which is more than often taken in understanding Sikkim upto early part of Twentieth Century. Thereafter, Sikkim has seen many ups and down in all fields. After a lapse of many years, in 1986-87 the Sikkim Government, attempted to document the changes encountered by Sikkim in many fields in the Second Gazetteer of Sikkim. The task was gigtantic with numerous formidable challenges. The work could not be put through for various reasons. For some years it was forgotten altogether. The pressing need of such document has continuously been felt in the arena of general readers, scholars, planners and many others.

Dr. Pawan Chamling dreamt to have authentic documents on Language and Literature, Art and Culture, History, Politics, Environment and Geography, Economy and Development of Sikkim in the name and style of the *Sikkim Study Series* in his second term of Chief Ministershipi.e.1999-2004. The same dream is being realised in the very first few months of the thrid term of his Chief Ministership. It is his vision and sagacity to direct the Department of Information and Public Relations to publish such important documents for the posterity.

A careful study was done to locate and select subject experts and those selected experts were assigned the job. In depth research have been done by the authors in their respective field with full freedom.The hallmark of the *Sikkim Study Series* is that the eminent authors, teachers,scientists and bureaucrats of this region, who have understood Sikkim in depth, have contributed to it.

We sincerely hope that this Series will adequately address the long felt

need of the Second volume of *Gazetteer of Sikkim*. We welcome comments, suggestions from our esteemed general readers, research scholars and subject experts to improve upon the Series.

G. Goparma, IAS
Secretary to the Government of Sikkim
Department of Information and Public Relations

Gangtok
Dated: 5th July 2004

Chief Editor's Note

It was a casual discussion meeting with the Chief Minister Pawan Chamling that led to the idea of Sikkim Study Series. *While we were all enthused and encouraged by the extensive acclamations the State of Sikkim received in publishing the* Sikkim Human Development Report 2001, *we were quite aware of inherent difficulties one faces in conducting research based on primary sources in the State. There are not many publications based on primary sources in Sikkim and hence most of them cannot serve as reference material. At the same time, not many studies of general interest are conducted in the State sourcing their inputs and analysis on field surveys and primary resources. As a result, we tend to question the authenticity of some facts, figures and other accounts.*

Who will fill up this gap between peoples need and crave for some reliable sources of references and the absence of well researched volumes ? This question though often asked had even reeled the mind of the Chief Minister. On this pleasant- nice autumn day when we broached on this issue, Pawan Chamling in his usual serious style proposed a series of books on various aspects of Sikkim and offered all the institutional support required for such a venture. He delightfully imposed the duty of bringing out the volume on me. The project Sikkim Study Series *is therefore, essentially his brainchild that would go a long way in linking the past-present-future generations, sensitizing the masses about their rich and magnificent heritage and providing people with intellectual inputs and food for thoughts.*

We decided to publish a series of an authentic and well researched reference volume on crucial fields of study like Sikkimese History, Geogra-

phy and Environment, Economy, Literature and Culture, Society and Food habits and Political development. The primary objectives were set at collecting historical documents and putting them together in a scientific manner in each field of study; filling the knowledge and information gaps on each field of study and presenting a cogent and comprehensive analysis of the issues. This also meant ultimately providing some firm basis for preparing a vision of *Naya Sikkim Sukhi Sikkim* (new and prosperous Sikkim) based on historico-politico-cultural and social background.

From the very beginning we were quite clear that these volumes were to be written by persons, may not be exactly academics, possessing good knowledge about how Sikkim steadily emerged from a pre-merger fledgling protectorate to the modern day robust State of India. We had rounds of discussion particularly identifying the individuals who could write on various themes. We wanted to make the initiative more inclusive by assigning the tasks to individual based in Sikkim for long.

Since it is a serious and sensitive project we had to very clearly lay down the criteria that would make each volume both a stand alone and qualitatively unquestionable one. Therefore each title of the series needed to be reviewed by a group of experts and copy edited before its publications. These group of experts are drawn from among eminent writers/scholars /professionals located in various institutions.

The methodologies we adopted included that a detail outline of each title of the series to be prepared by the prospective author and each theme of the series to be thoroughly discussed before they were developed into a full fledged volume. We started the process in 2001 and it took us full three and half years to see the first volume in place.

The present volume on *Geography and Environment* in Sikkim written by KC Pradhan, Eklabya Sharma, Gopal Pradhan and AB Chhettri makes a substantive effort in putting together the major topographical, demographic, climatic and ecological features of Sikkim. It devotes a significant section on the issues related to management of natural resources, concerns about

The authors have worked in Sikkim for many years now and have brought forward those issues that directly impinge upon the common people. For instance, the exploitation of the medicinal plants and herbs many a times without the knowledge of the governmental agencies, absence of any regulatory authorities on the use of non-forest produce, haphazard constructions of high rise buildings and unprecedented rise in the number of transport vehicles could all accumulate to become a major threat to the otherwise serene and magnificent environment of Sikkim. There is not much of awareness about the impact of the provisions of the World Trade Organizations particularly on the biodiversity in the State. Therefore, the preparedness to cope of with these provisions is at a very infant stage.

I am personally grateful to GS Yonzone and Shrawan Acharya two very well known experts on the geographical and environmental issues of the Eastern Himalayas for reviewing the first two drafts of the volume. Though a careful check has been made into the factual correctness and the references in the text of this volume, given the comprehensive nature of this volume it is quite possible that there remains errors and omissions which are beyond the control of the undersigned. They would certainly be the responsibility of the author. I am sure in course of time we shall find a mechanism to correct and put them in order. It is a massive, serious and at times strenuous to edit volumes of such a variety, depth and quality. This was more so as majority of the authors are not trained academicians and scholars and loved to write in their own 'free' style.

My locational disadvantage apart, the Information and Public Relations Department did play a major role in facilitating the coordination between authors-me-reviewers. Being a typical government department, the system would move in a very slow and tardy manner. I noticed that even with such a beautiful edifice of physical and human infrastructures the Department will not move an inch when it comes to taking any initiatives. What is more intriguing is that the institutional memory was always lacking. It was difficult to connect the outgoing Secretary with the incoming

one as the former used to take away idea, interest and commitment also. It always remained however an interesting encounter. The Chief Secretary Sonam W Tenzing did provide very many useful suggestions for which I am very grateful to him. However, I must acknowledge the support I received from AK Pradhan, RS Basnet and Pathak all former Secretaries and present Secretary Girmi Goparma. I should particularly thank P Thondup former Director, Jabi Thapa and Kuber Chandra Dahal of the IPR Department for their constant support. I would also acknowledge the keen interest shown by the printer M/s Kwality Stores, Gangtok in bringing out a well produced volume.

Since these volumes cover large range of issues, long period of historical and contemporary accounts and very many anecdotes, many of them have been written in more descriptive rather than analytical mode. I am sure, picking up threads from these volumes, other scholars and individuals from both within and outside Sikkim will add to the series by providing more in-depth account and analysis .

1 March 2004

Mahendra P Lama

CONTENTS

List of Tables

List of Figures

SECTION – 1

Sikkim : An Overview


TIBET
GREAT HIMALAYA
Tsho-Lhamu
Gurudongmar
Yumesamdong
Hot Spring
Yumthang
Muguthang
Thangu
Thechu
Longbo
Phuni-Tshokha
Greenlake
Jackthang
Yabuk
Mt Khangchendzonha
Lachung
Kyishongla
Lachen
NEPAL
Goecha Peak
Gochela
Tholung
TIBET
Pandim
Kabru
Thangsing
Narasingh
Dzongu
Chungthang
Singhik
Kasturi Oral
Chaurigang
Dzongri
Samartek
Mangan
Boktok
River Rangit
River Teesta
Nathula
Tshoka
Phodong
Garakhet
Labdang
Khecheopalri
Yuksam
Dhond
Chewab
hanjang
Ralang
Tashiding
Meanam
Rumtek
Tsomgo
Lake
Gangtok
Uttaray
Pemayangtse
Ravangla
Khedi
Yangyang
Pa-Shing Teng-Kha
Dentam
Singtam
Pakyong
Vershey
Rinchenbong
Damthang
Temi
Kaluk
Hilley
Soreng
Tendong
Rangpo
Rhenock
Bermoik
Sombaria
Nayabazar
Namchi
Parbing
BHUTAN
Melli
Kalimpong
Algarah
Lava
Teesta
Kafer
Darjeeling
West Bengal
Siliguri
SINGALLILA RANGE

Fig. 1

Sikkim is a small Indian state in the eastern Himalayas, lying between 27°04'46" and 28°07'48" north latitude and 88°58" and 88°55'25" east longitude covering an area of 7096 sq km. Mount Khangchendzonga located in Sikkim is the third tallest mountain system in the world. Sikkim is a part of the upper Tista basin. The main tributary of the Tista river is the Rangit river. It is a unique mountainous state encircled by three different international boundaries. To its west lies Nepal, Bhutan and the Chumbi Valley of the Tibetan Autonomous Region of the People's Republic of China are in the east, Darjeeling Gorkha Hill Council of West Bengal is in the south, and the Tibetan Plateau of the Tibetan Autonomous Region of the People's Republic of China is in the north (Fig.1.1) It extends approximately 114 km from north to south and 64 km from east to west with altitude ranging from 300 to 8598m. It has 447 villages with a population of 5,40,493 (2001 census), comprising mainly of the ethnic groups the Lepchas, Bhutias and Nepalese. The Lepchas are considered the original inhabitants of Sikkim. The *lingua franca* of the state is Nepali and it is included in the VIII Schedule of the Constitution of India. At the state level, however, there are, besides Nepali, seven other languages recognised by the Government of Sikkim. They are Bhutia, Lepcha, Limbu, Rai, Newari, Gurung, and Tamang.

The (Amendment) Act of the Indian Constitution, 1974 made Sikkim 'an associate state of India' doing away with its earlier position of 'Protectorate Status'. The merger of Sikkim as the 22nd state of Indian Union took place after the establishment of the first popular government on 16 May,1975. In the 2001 census, Sikkim had a total population of 5,40,493 of whom of 53% male and 47% female. The sex ratio was 875 in 2001. Decadal growth rate of 32.98% was recorded between 1991–2001. Population density was 76 persons per sq km. There are four districts namely, the North, South, East and West and eight sub-divisions. The state capital is Gangtok.

The state remains highly dependent on agriculture, which, accounts for

nearly 26% of gross domestic product (GDP) at current prices. As an agrarian state, Sikkim's and main workers are categorized into cultivators, agricultural labourers, worker in the household industry and other workers. In 1991, 65.6% of the main workers were dependent on agriculture, either as cultivators or as agricultural labourers (Lama, 2001).The 2001 census shows that 48.72% of the population were workers and the remaining 51.28% were non-workers. Out of 48.72% of the workers, cultivators comprised 49.9%, agricultural labourers 6.4%, workers in household industry 1.2% and other workers 42.4%. There is a gradual shift from cultivators to other workers in recent decades.

Per capita availability of different types of land has declined rapidly over time as a consequence of the mounting population pressure. The landholding distribution among the people is skewed in the state; some have large holdings while most have marginal holdings. The increasing inequality of landholdings were marginal or below 1 hectare, whereas their share in the total area was only 10.30% in 1991–92. In comparison, 2.38% of the holdings at the top of the land distribution hierarchy accounted for as much as 20% of the total area.

The state has 12.3% of cultivable land and the percentage increase of cultivated land was by large cardamom, oil seeds, vegetables, oranges, pulses, ginger and potatoes followed by cereals, maize and paddy during the 20 years from 1975–76 to 1995–96. Percentage increases in state production during this period clearly show that crops such as cereals, vegetables, ginger and potatoes performed well. The percentage contribution of large cardamom production was proportionally small, as it is a low–volume crop that nevertheless has high economic returns. Large cardamom's share in the state's gross income from all crops was proportionally very high: 16.58% in 1995–96, which was second to 31.14% contribution of cereals. There is great scope for improving the yield, add value to the products and increase economic return from cash crops like cardamom, oranges, ginger and flowers.

Livestock farming is another important economic activity. There has been an increase of 66% in livestock number between 1977 and 1992; cattle population has increased by 27%, while it was 34% for yaks. About 22% of the area in Sikkim is available for fodder production and pasture development. Feed and fodder alone constitutes between 60 to 70% of total cost of production of various livestock products. This sector has great potential and a comprehensive programme on feed and fodder development is required that ensures both environmental safety and economic progress.

Tourism is continuously growing. The state has become one of the most important for nature and culture destinations in eastern India. Religious, recreational, trekking, adventure and nature tours are promoted in Sikkim. The concept of ecotourism has already been introduced in tourism planning and a successful pilot project on Sikkim Biodiversity and Ecotourism has laid down participatory development process for stakeholders. Committed state and village level Non government organizations (NGOs) can carry forward the concept of ecotourism development. This sector has high potential and the Government has shown full commitment to develop it.

Sikkim is endowed with rich natural resources. Biodiversity elements here are of global importance. This region is listed among the world's most critical centres for biodiversity and endemic species with 150 species of mammals, 550 species of birds, 650 species of butterflies and moths, 33 species of reptiles, 16 species of amphibians, 48 species of fishes, 4500 species of flowering plants, 36 species of rhododendrons, nine species of conifers, 450 species of trees, 480 species of orchids, 362 species of ferns and allies and 175 species of wild edible plants. Of these 19 species of mammals, 11 species of birds and 65 species of plants are threatened and endangered. Conservation of these species and their habitat warrants special attention in the state and it has taken conscious initiatives of conservation and has brought 41% of its area under protected area management network, which is very significant amongst the mountainous

states of India. Participatory management of forests has been adopted in the state and Joint Forest Management is under implementation Though which more communities are getting involved in protection of forests while sharing the benefits.

High altitude medicinal plants and floral wealth have great potential for cultivation, value addition and commercialization in the state. These natural resources need judicious state planning for both conservation and development. Rhododendrons form the key species for environmental stability especially in the sub-alpine to alpine ecotone between 2800 to 4000 m. Their conservation would allow ecological stability and promotion of more diverse communities of both plants and animals. They are also sources of great attractions for trekkers. However, proper energy planning is the need of the hour with a view to wean away the trekkers from using rhododendrons as fuel wood.

A biotic resources of the state are equally important. The vast mountain ranges, glaciers, lakes, waterfalls are of great geo-morphological interest. An imaginative programme to market them consistent with well planned conservation is of utmost importance. The mineral wealth of the state also needs systematic exploration and utilization.

Water, the most important natural resource is plenty in Sikkim. This resource being renewable and most valuable has great potential for development in the state. Hydropower potential assessed and projected until now for both Rangit and Tista amounting to 2766 mw should be harnessed keeping the environmental security intact. This would provide the state self-sustainability in terms of power generation. The total hydel power potential is estimated at over 8,000 mw.

Large scale changes in the mountain environment by way of extensive road construction works, hydel power projects, urbanization, increased flow of tourists beyond its carrying capacity would have widespread human miseries. The miseries are not restricted to the mountain areas alone but have also socio-economic impacts on the plains. What is needed is an

integrated approach to sustainable development in which farmers are in the forefront, reconciling their socio-economic needs and aspirations. Such development programmes also need to be gender sensitive and socio-culturally in harmony with the taboos and traditions of the local system. In these activities, the promoters of development programmes should act as facilitators and catalysts of development processes.

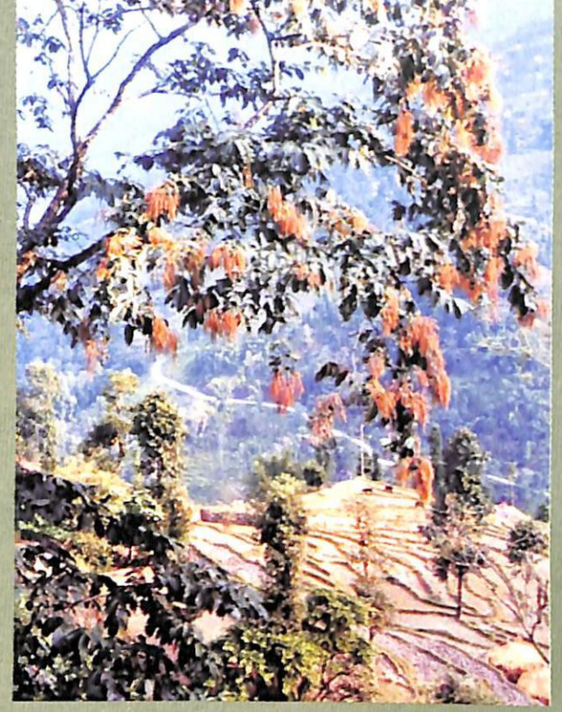
Environment and public health is are important aspects of sustainable development. The Department of Forests, Environment and Wildlife and Department of Public Health and Engineering (P.H.E.) has been implementing various programmes on environment and health related issues in the state. Regular monitoring is carried out on management of solid waste, management and handling of bio-medical waste, noise pollution, ambient air quality and water quality in the state by the State Pollution Control Board, Sikkim and Urban Development and Housing Department (U.D. & H.D.). Various acts and laws on the environment, forests and wildlife have provisions for their effective protection and management.

Sikkim is a unique state where sustainable development can be perceived only with due consideration of environmental security. In any development efforts, be they on agriculture, horticulture, floriculture, livestock farming, industry, tourism, management of natural resources, power or construction, environment becomes the core issue. This is true because of fragility of the mountain slopes and vulnerability of the rural people. The state is prone to many natural disasters such as landslides, drought, hailstorms, flashfloods, glacial lake outburst floods, avalanches at high altitudes and is vulnerable to earthquakes. Mountain risk engineering and disaster mitigation are areas where the state should develop enough skills and build preparedness. Planning and development in recent years are rightly starting to mainstream environment and related issues. Sikkim has a comparative advantage in being a small and natural resource rich state whose benefits should be harnessed for environmentally sound sustainable development.

Sikkim is an important catchment region to the plains of eastern part of India and also Bangladesh. By conserving biodiversity and protecting forests soil erosion is reduced thus decreasing flood frequency and thereby benefiting the downstream states and countries. Environmental services provided by the state thus should be compensated by down stream states and countries. Valuation of environmental services needs top priority in deciding compensation. Mechanisms of compensation are not worked out in India and it would be a pioneering effort and contribution if the state ventures on this line.

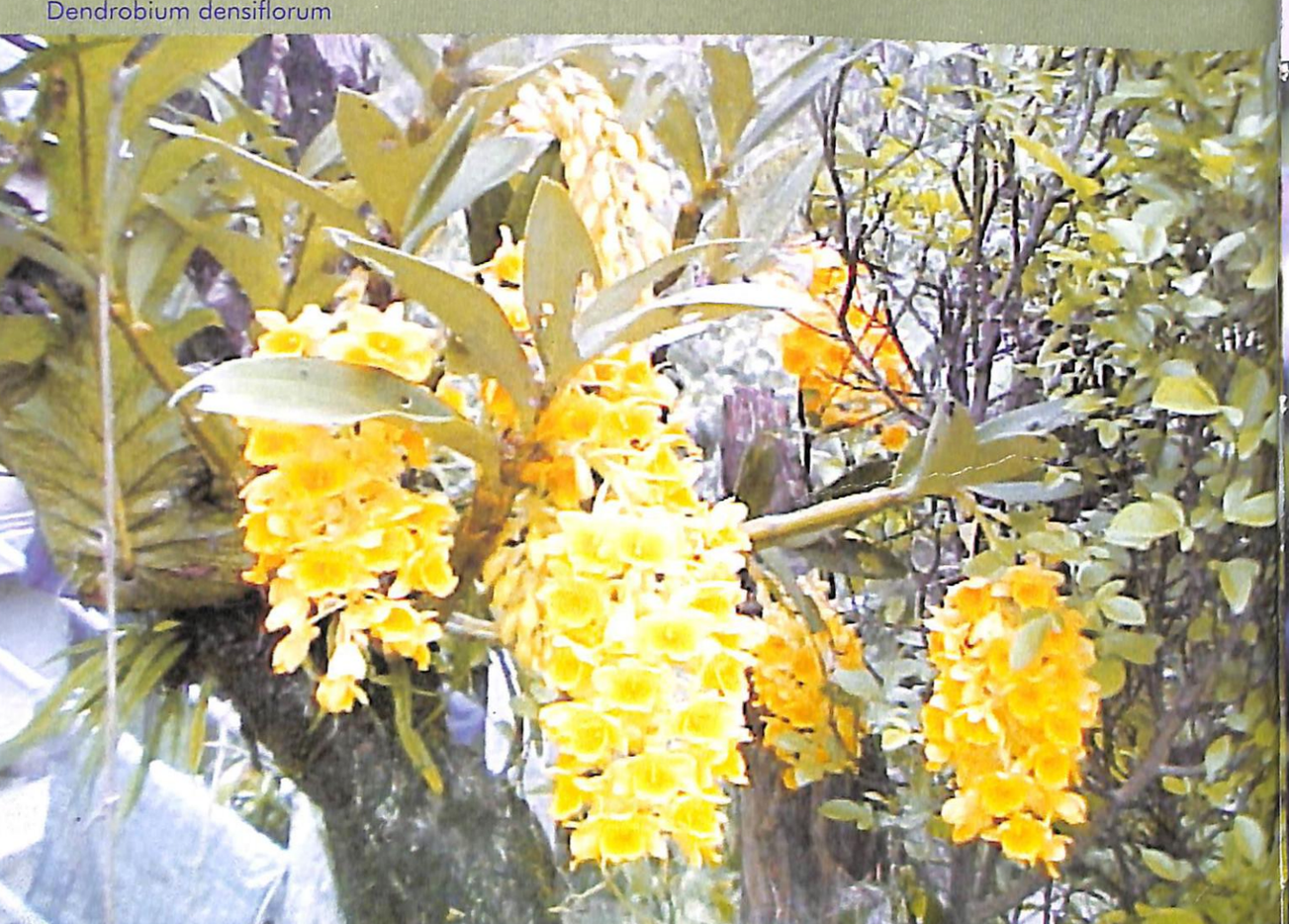
It is a matter of pride that Sikkim has fully recognized the importance of its exceedingly rich biodiversity and its natural resources well in time. In a democratic system of polity, this sort of political will is hard to come by when the aspirations of the people are far greater than what the environment can really support. There is need, however, to create conditions for greater involvement of people on the one hand and to inculcate the sense of love of nature and its conservation among the younger generation on the other.

Monal Pheasant *(Lopophorus impejanus)*
the State Bird

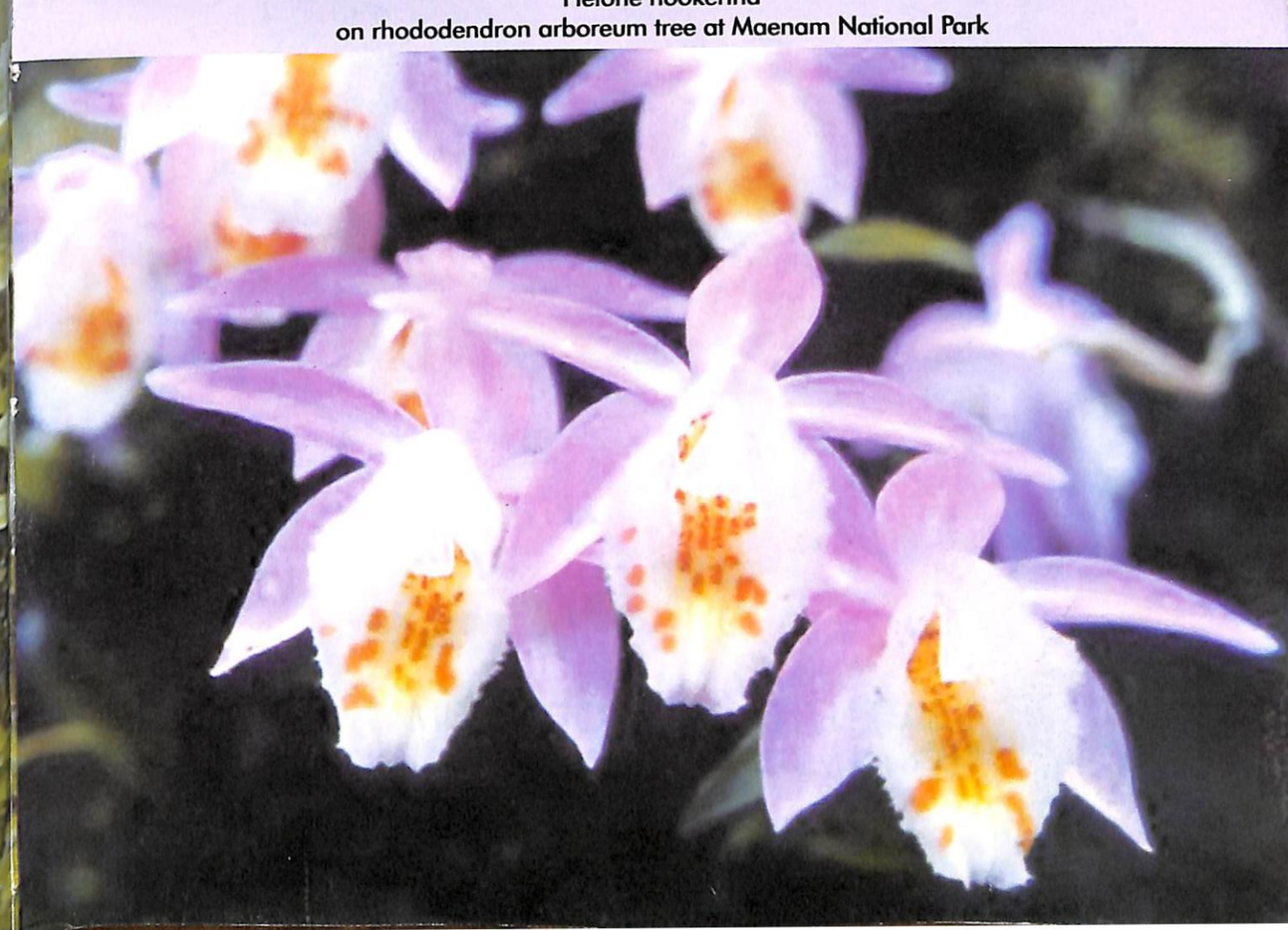


Terminalia myriosarpa
in flower

Dendrobium densiflorum



Pleione hookerina
on rhododendron arboreum tree at Maenam National Park



SATELLITE IMAGE OF SIKKIM

Courtesy: CISMHE, University of Delhi

SECTION – 2

Physical Background

2.1 Himalayan Context

The Himalayas are the greatest and youngest mountain system of the world. The Himalayas (Sanskrit for 'abode of snow') in Asia comprise a series of parallel and converging ranges and forms the highest mountain region in the world. More than 30 peaks rise to heights of 7,620 m or more, and one of these, Mount Everest (8848 m), is the world's tallest mountain. The vast Himalayan complex covers an area of about 5,94,400 sq km and extends in an arc of about 2410 km. It stretches from the Indus River in northern Pakistan eastward across the territory of Jammu and Kashmir; down into northern India; across part of southern Tibet (an autonomous region of China) and over most of Nepal, the Indian state of Sikkim and North-East region and Bhutan (Fig 2.1). About 150 million people inhabit this magnificent mountain system, out of which 0.36% resides in Sikkim.

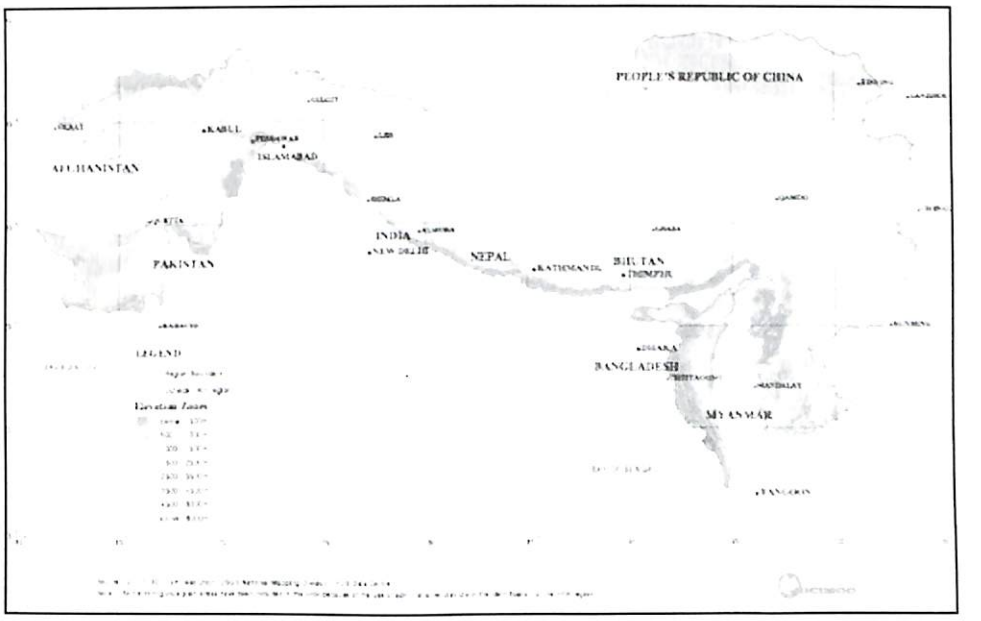


Fig 2.1 Map of Hindu Kush-Himalayan region

During the Paleozoic and Mesozoic eras (65 million to 570 million years ago) the area that is now the Himalayas occupied the floor of the

ancient Tethys sea on the northern part of the Indian plate of the earth's crust. The mountains were formed as the Indian plate, moving north, pressed against the stationary Asian landmass. The principal uplift occurred during the middle or late tertiary period (12 million to 65 million years ago). The ranges of the Himalayan system developed from north to south in a series of stages. Even today the system has not reached a state of equilibrium and earthquakes are frequent.

The Himalayas can be divided into four parallel, longitudinal mountain belts of varying widths. From south to north these belts are the Outer Himalayas, or Sub-Himalayas; the Lesser Himalayas; the Great Himalaya; and the Tethys, or Tibetan Himalaya. The passes in the Himalayas, which often lie along or across glaciers, are the highest in the world, with an average height of about 3,050 m. All passes above 4,880 m are closed due to snow from November to May.

The Himalayas are drained by several major Asian rivers, including the Brahmaputra, Indus, and the Sutlej, as well as by many of their important tributaries. The headwaters of the river Ganga are also in the Himalayas. Numerous small glacial lakes are found at the heads of gorges, but the largest lakes lie at comparatively low elevations. Above the snow line, in all parts of the Himalayan systems, small glaciers are found. Several glaciers are as much as 48 km long.The majority, however, are less than half that size.

Three seasons are generally recognizable in the Himalayas; a cold period from October to February, a hot period from March to June, and the southwestern monsoon season with heavy rains (particularly in the east) from June to September. The high main range of the Himalayas forms a vast screen that intercepts and condenses nearly all moisture carried by the monsoons winds. This moisture is deposited on the southern face of the mountains, which have a heavy annual rainfall; the northern slopes are semi-arid or arid.

The elevation of the Himalayas also affects its temperature range. The

climate on the southern side varies from subtropical at the base and valleys, through temperate at elevations of about 2,130 m to alpine at 3,660 m. The line of permanent snow lies at about 5,030 m. Strong winds prevail throughout in the high elevation areas.

Vegetation is generally more lush in the east where rainfall is heaviest. At elevations up to 610 m, a zone of grass is found in the west, and a dense, swampy subtropical forest known as the Tarai is found in the east. At lower elevations is a monsoon forest in which sal, a close-grained hardwood, is the most characteristic tree. Evergreen oak and rhododendron predominate at 1,524 to 2,743 m and the deodar cedar is also found here. Above this level, to an elevation of about 3,658 m are coniferous forests and at higher elevations, extending to the snowline, lies an alpine zone of low shrubs and grasses. During the second half of the 20th century, many regions of the Lesser Himalayas have been deforested for firewood and to make room for agricultural development, resulting in severe erosion. In the Lesser Himalayas, only in Bhutan and parts of eastern India are large regions still heavily forested.

The Indian Himalayan region, which is more than 2,800 km in length and 220 to 300 km wide, is spread over the states of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya and a part of Assam, along with the Darjeeling Gorkha Hill Council of West Bengal. It has a total geographical area of approximately 591 thousand sq km (18% of India) inhabited by 51 million people (6% of India) in 1991 (Anonymous, 1992a). The region in general is characterized by sparse population, undulating terrain, far flung small villages which are difficult to approach, tiny and scattered land holdings, more so on slopes with shallow and gravelly soil, an agro-pastoral economy, scanty irrigation; little use of modern technology and inputs; and low productivity. These, coupled with almost no industrial development, and thereby low employment potential, encourage the local young males to seek employment away from their homes.

The problem of youth moving away becomes aggravated in the areas where an inhospitable climate outweighs the sentimental attachment of people with their native land. Agriculture is the primary occupation of the people all through the region but the agricultural land use patterns vary from region to region. While in the north-eastern region shifting cultivation continues on the slopes, settled agriculture on terraced slopes dominates in the central and north- western region. Throughout the region, valleys are characterized by settled agriculture and intensive cropping. In the Himalayan region, agricultural systems and resource-use patterns which could sustain mankind under climatic constraints, difficult terrain and poor communications have evolved over the centuries. A close association of man, forests and the environment observed all across the Himalayas, implies a strong perception of ecological principles in the traditional management systems. These systems, however, are becoming weak and are being lost in critical areas. Historically, forests had been treated as a common property resource and thereby freely accessible to those inhabiting the region.

Sikkim, is unique in its geographical location, biological wealth, environmental settings and cultural diversity. It beholds one of the magnificent range of snow clad mountains popularly known as the Khangchendzonga group. A cursory glance at the location of Sikkim in the map of India reveals the extraordinary strategic importance of the state. Sikkim shares international boundaries with three neighbouring countries, viz., China, Nepal and Bhutan.

2.2 Physiography

2.2.1 Landscape

The topography of Sikkim is characterized by great variation in elevation, ranging from 250 m to 8,595 m. Most of Sikkim is in the Lesser and Greater Himalayan zone. The state is girdled by high ridges on the north, east and west and thus looks like an amphitheatre. To the north the

convex arc of the Greater Himalayas separates the state from the Tibetan highlands. A number of peaks built up of crystalline rocks accentuate the demarcation between Tibet (China) and Sikkim. The longitudinal Chola range separates the state from Tibet on the eastern side while the Singalila range, another longitudinal offshoot of the Himalayan arc, marks the boundary between Sikkim and Nepal in the west.

The girdling ridges on the three sides of the state contain some imposing peaks and high altitude passes. The exalted peaks of Khangchendzonga (8,595 m), Siniolchu (6,895 m), Pandim (6,706 m), and high altitude passes like Nathu La (4,728 m), Jelep La (4,040 m), etc., are all located within this Himalayan state. Important peaks and passes located in Sikkim are given in Table 2.1.

Sikkim is in the upper part of the Tista basin which virtually marks the state boundary. The present landscape of the state owes much to the drainage network of the river Tista. The structural slope of the land is from north to south, hence all the major rivers of the state have a southerly flow. However, small streams appear from almost every corner of the state and run on all directions. They have dissected the land so intricately that there is no sizeable piece of level land anywhere in the state. The northwestern part of the state is highly elevated and therefore, remains under snow cover almost throughout the year. The resultant topography is that of a typical glaciated one, characterized by cirques, aretes, glacial troughs, and morainic deposits. Besides, there are numerous glacial lakes which freeze during winter. The freeze thaw action at the shores of the lake give rise to typical periglacial features, such as patterned ground and solifluction deposits (rock wastes).

Similar landscape features are also found all along the northern and eastern highlands (Choudhury, 1998). The ongoing glacial, periglacial, glaciofluvial, fluvial and pluvial activities are continually reshaping the mountain topography. While the swift flowing rivers transport loads of eroded materials by chiselling the valley side slopes, many of the lakes

Table 2.1
Important Peaks and Passes

Sectors	Peaks (above 6000 m)	Passes
Northern Sector	Lhonak Sentinel Chorten Nyima Khora Khang Khora Tso Gna Khang	Chorten Nyima La Naku La Kongra La Tsak La Bam Tso La
Eastern Sector	Pauhunri	Say Say La Ghora La Khanchung La Pata La Thangkar La Nathu La Jelep La Batang La Doka La
Western Sector Langbu	Jonsang Khang La Pyramid Peak Tent Peak Nepal Peak Kanchenjunga Kabru Talung Rathong	Jonsang La Daiu La

Source: Choudhury, 1998

choke with sediments. In recent years, there is noticeable reduction in the size of some of the larger lakes of Sikkim including Khecheopalri lake in West Sikkim.

2.2.2 Glaciers

Glaciers are the perennial sources of fresh water that is discharged in the two major rivers, namely Tista and Rangit. A substantial area of Sikkim lies above the snowline which is around 5000 m. Quite an extensive area remains snowbound throughout the year, especially in the northern, eastern

and western parts. The snowfields of Sikkim give rise to several medium and small-sized glaciers. They include Tista Khangsa glacier (below Pauhunri Peak, North Sikkim), Khangpup Khangsa glacier (north Sikkim), Lhonak North and Lhonak South glaciers (below Lhonak Peak, north Sikkim), Langbu glacier (below Langbu Peak, north Sikkim), Chungsang glacier (below Pyramid Peak, north Sikkim), Tent Peak glacier (below Tent Peak, north Sikkim), Nepal gap glacier (below Nepal Peak, north Sikkim), Zemu glacier (below Kanchenjunga, north Sikkim), Hidden glacier (between Chungsang and Zemu glaciers, north Sikkim), Talung glacier (below Talung Peak, north Sikkim), Zumthul Phuk glacier (north Sikkim), Rathong glacier (below Rathong Peak, West Sikkim. (Choudhury, 1998).

Except the first two of these glaciers, all descend from the eastern slope of the Singalila range and thus can be called the Singalila group of glaciers. All these glaciers are cirque glaciers. Most of these glaciers extend eastward, almost parallel to each other. The largest and most important among them is the Zemu glacier. Almost all the glaciers of Sikkim give birth to some streamlets. The Tista Khangsa, as the name suggests, is the breeding ground of the river Tista. The melted water of this glacier accumulates in a tarn (glacial lake), the Chho Lhamo. The spill water of Chho Lhamo and a series of small glacial lakes ultimately forms the head water of the river Tista. The Lhonak glacier gives rise to the Goma Chhu or Lhonak Chhu, which is a sub-tributary of the Tista. From Zemu glacier rises the Zemu Chhu, one of the chief feeders of the Tista. Yet another important river, the Rathong Chhu, originates from the Rathong glacier and contributes to the Rangit river (Choudhury, 1998).

State Remote Sensing Application Centre in collaboration with Space Application Centre, Ahemadabad, have prepared a glacier atlas of Tista basin in Sikkim (State Council of Science and Technology, 2001). The investigation suggested as many as 84 glaciers in Sikkim covering an area of 440 sq km. The permanent snow fields measure around 251 sq km area which, when added to glaciers, cover an area of 691 sq km. It is reported that permanent glacial and snow cover stored 145 cu km of

water in Sikkim. Most of the glaciers of the Tista basin cover areas less than 5 sq km. Jayaram *et al.*, (1998) have analysed the glaciers of Sikkim using remote sensing techniques and have outlined potentials of water resources from these glaciers for the benefit of the state and downstreams regions.

2.2.3 River System

There is only one major river system in the state, that is the river Tista. The Chola range in the east and the Singalila range in the west determine the boundary of the Tista. The entire state is drained by the Tista, its numerous tributaries and innumerable sub-tributaries.

The master stream Tista originates from a glacial lake Chho Lhamo located at the north-eastern corner of the state. While it flows down to the plains, it has scores of tributaries on side of its course. The tributaries coming from the east are more in number but shorter in length and have less amount of discharge, while those coming from the west are fewer in number but are much larger and conspicuous. The latter, i.e., the rightbank tributaries of the Tista have developed their own elaborate drainage network and have formed second order drainage basins. Consequently, the amount of discharge of these tributaries is greater. The rightbank tributaries are more voluminous due to the fact that all of them have their feeders in the high mountain glaciers. The glaciers like Lhonak, Zemu and Rathong in the west heavily feed the rightbank tributaries. In comparison, many of the leftbank tributaries originate from seasonal rain and semipermanent snowfields, and hence are ephemeral in nature. The major tributaries of the Tista within the state of Sikkim are given in Table 2.2. The most important among all these tributaries is the Rangit. Other important tributaries include the Zemu Chhu, the Rangyong Chhu, the Lachung Chhu, the Dik Chhu, the Rongni Chhu and the Rangpo Chhu.

The Rangit Chhu, a rightbank tributary of the Tista originates from a comparatively low altitude area in the south district of Sikkim. However, its chief feeder, the Rathong Chhu originates from the Rathong glacier in the

Table 2.2
Major Tributaries of River Tista in Sikkim

Leftbank tributaries	Rightbank tributaries
Chhombo Chhu	Zemu (Lachen) Chhu
Lhasa Chhu	Rangyong Chhu
Kalep Chhu	Rangphap Chhu
Gyamthang Chhu	Rangit Chhu
Burum Chhu	
Gey Chhu	
Tarum Chhu	
Rabom Chhu	
Lachung Chhu	
Ong Chhu	
Chakung Chhu	
Dik Chhu	
Rongni Chhu	
Rangpo Chhu	

Source: Choudhury, 1998

west district of Sikkim. The Rangit receives quite a large number of tributaries on its way to the Tista. Apart from the Rathong Chhu, it is fed by the Rimbi, the Kalej, the Rishi, the Roathak, the Rammam and the Manpur Khola. It also receives some tributaries from the Darjeeling hills namely, the *chhota* (little) Rangit, the Jhepi and the Ragnu Khola. After its confluence with the Rammam, the Rangit river comes to be known as the Great Rangit or '*Bara* Rangit'. The combined course of the Rammam and the Great Rangit marks the southern boundary of the state. The Great Rangit ends its journey near Melli where it meets the master stream, the Tista.

The Zemu Chhu, another rightbank tributary of the Tista, originates from the snout of the Zemu glacier. Initially, the river flows down towards west and is known as Poke Chhu. After receiving the Lhonak Chhu from the northwest, it is known as the Zemu Chhu. The Zemu Chhu meets the Tista near Zema in North Sikkim. Another important rightbank tributary of the

water in Sikkim. Most of the glaciers of the Tista basin cover areas less than 5 sq km. Jayaram *et al.*, (1998) have analysed the glaciers of Sikkim using remote sensing techniques and have outlined potentials of water resources from these glaciers for the benefit of the state and downstreams regions.

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Most of the lakes are of glacial origin, hence, are confined to high altitude areas. Perhaps the only exception is the Khecheopalri lake which is located in a low altitude valley (1,945 m) in west Sikkim. Most of the small lakes in north Sikkim are still unnamed. In the western part of Sikkim too, a few lakes lie in the midst of wilderness, such as the Lam Pokhari, the Lachhmi Pokhari and the Kathok Lake. The most popular lake of the state is the Tshangu in east Sikkim. However, the most picturesque and one of the largest lakes of Sikkim is the Mey Mey Chhu, which is also located in east Sikkim, close to Indo-Tibetan border. Some other lakes worth mentioning are the Chho Lhamo (5,099 m) and Gurudongmar Chho (5,176 m).

Most of the lakes are not only the source of fresh water for various ecological and human benefits but are also of religious value and attraction for many tourists and pilgrims. The most famous ones are Tshangu and Khecheopalri lakes.

2.2.5 Hot Springs

Sikkim has a few mineral springs where warm water oozes out from beneath the surface with a strong sulphurous odour. Most of these are locally known as *Dabaipani or Tatopani*. The hot springs of Yumthang, Ralong and Phur-Cha-Chu are popularly known for their medicinal value. The Ralong hot spring is located on the western bank of the Rangit river near Ralong monastery in west Sikkim. The Phur-Cha-Chu is located on the eastern bank of the Rangit near Rinchingpong monastery in South Sikkim. Details on hot springs (thermal water) are given in Minerals and Mining under Section 4 of this book.

2.3 Geomorphology

Distinct micro-morphological features of Sikkim terrain include terraces and floodplains, valley-side slopes and landslide slopes, alluvial cones of different types and generations, tors, kettle-shaped depressions, terraceisles, sickle-shaped rags, bevelled plains, undulating plains with deeply dissected

valleys, glacial or periglacial deposits, related sedimentary structures, crevasses, soil series or polypedon, gorges, etc. The terrain also exhibits various climatically induced landform suites, and the landform assemblages containing relict elements in the profiles arising from the time lag in response to varied geomorphic and pedogenic processes and environmental changes. These micro-and other meso-topographic forms have been produced by the trunk stream Tista and its innumerable tributaries-one of the important agents of denudation and deposition which has been engaged in attacking and moulding the emerging forms in the upper and burying others mainly in the lower reaches (Mukhopadhyay, 1998).

As a potential control of form, prevalent climatic variation is as important as the existing structural variation in the attainment of differential weathering status and the four-tier terrace and floodplain formations in the Sikkim terrain. The orientation of the horseshoe shaped river, i.e., Tista basin and the location within the Himalayan mountainous landmass have controlled its relationship (*a*) to the trend of geological structure, (*b*) to the passage of glacier in the uppermost reaches and (*c*) to the headward communication of the effects of tectonic, isostatic and eustatic movements in sea level (the Bay of Bengal), specially in its lowermost reaches over the Great Bengal Plains. It is important to note that the slope to dynamic equilibrium is also largely controlled by those exogenous factors while dynamic equilibrium in morphological systems is to be found in most of the climatic zones.

Morpho-systems also include the events of slope-angle and its transformation which are related to the processes of linear erosion, slope wash, gravitative transfer etc. These processes are found to be reinforced by the changed climatic situations particularly associated with catastrophic meteorological phenomena viz., (*a*) rapid down pours of high intensity, mainly local in range and connected with convection currents or the passage of cyclones e.g. which occurred in the year of 1968 in Tista basin area, (*b*) long-lasting continuous rains of lesser intensity and regional extent

due to advection of oceanic air masses and (*c*) periods of rapid warming, bringing about quick melting of snow and ice as well as ground thaw often accompanied by precipitation. Mukhopadhyay (1998) has considered the distinctive components of form, of the main river Tista and its tributary-basins e.g. (*a*) channel net work, (*b*) suite of valley-side slope, (*c*) perimeter, and (*d*) outlet which are the basin characteristics in the morphological systems. These morpho-systems are closely connected with the litho-ectono-structural setting of the Sikkim region.

2.3.1 Morphogenic Systems

Mukhopadhyay (1998) has attempted to interpret the evolution of landforms on a geo-unit or zonal basis in association with climatic succession. It also includes the references of the prevalent relationship with the denudational and depositional processes responsible for fashioning the land surfaces of Sikkim-Himalayan area. The five climatic zones from upper to lower are: (*a*) frigid zone above 4,000 m (glacial, periglacial and fluvio-glacial processes); (*b*) cold zone between 2,500 to 4,000 m (periglacial, fluvio-glacial and fluvial processes at higher altitudes); (*c*) cool temperate zone between 2,000 m to 2,500 m (fluvio-glacial and fluvial processes at higher and medium altitudes); (*d*) warm temperate zone between 1,000 m to 2,000 m (fluvial processes), and (*e*) subtropical zone upto about 1,000 m (fluvial processes at lower altitudes).

The three geomorphic units - the frigid zone, cold zone and cool temperate zone— in combination have formed the major portion of the northern part coinciding with the upper Tista Basin. This upper section stretching about 100 km west to east signifies the presence of glacial, periglacial and fluvioglacial evidences indicating the occurrences of related fluctuations particularly in climate, timber line and other associated effects in the context of mountain ecology and environment.

Transporting rates of the debris become as high as 20 times the normal, particularly in a catastrophic environment. Huge amounts of silt

are also derived from the upper reaches of the elevated watershed areas. A number of glaciers of different sizes (Table 2.3) move over their beds in Greater Himalayan terrain, reducing to powder (rock flour) mainly by friction with large quantities of surface-rock. This variety of powdery rock flour when mixed with melted water form the so called glacier-milk which is transformed further to consistency of thin mud during the situations of the peak melt discharge in subsequent stages. However, this point of debris and silt production and their transportation relating to the occurrences of changes in the phase of these glaciers-advance, recession and stable conditions— like in the other parts of the Himalayas, needs our immediate attention. These changes in the glacial-phase of the upper Tista basin

Table 2.3.
Major Glaciers

Names of the Glaciers	Altitude(m) Upper and Lower	Location		Alignment	Magnitude (km)		Height of the snour (m)
		Latitude (N)	Longitude		Length	Breadth	
Pauhunri	7010	88"54'	27°57'	NE-N-SW	4.2	1.0	5150
(Tista-source)	6100	88°55	27°59'				
Zemu	6000	88°15'	27°41'	N-NE-E	26.0	1.7	4150
	4250	88°28'	27°46'				
Simvu	6800	88°17'	27°41	NE-NW-NE	9.5	1.4	5300
(Simvo Gl)	5500	88°18'	27°44'				
Green Lake	7100	88°11'	27°50'	SE-E	9.0	0.9	4720
(Tent Peak-Nepal Gap)	5000	88°17'	27°46'				
Lhonak	7320	88°14'	27°53'	N-NE-E	6.5	1.6	5020
(North and South Twin Gl)	5250	88°14'	27°56'				
Tumrachen	4870	88°21'	27°49'	NE-E-SE	4.8	0.8	4400
(Hidden Gl in SW)	4580	88°24'	27°50'				
Passanram	6100	88°20'	27°42'	NE-S-SE	8.0	0.7	3960
(Tong Shyong Gl in W)	4400	88°21'	28°38'				
Zumtu	6700	27°43'	88°23'	SE-E-SE	6.5	0.6	3660
(SE of Siniolchum)	3970	27°41'	88°25'				
Talung	6750	27°41'	88°21'	S-E-SE	14.5	1.2	4210
	4300	27°36'	88°18'				
Tong Shyong	5790	27°41'	88°15'	SE-S-SE	7.2	1.0	4420
	4570	27°37'	88°08'				
Alukthang	6790	26°36'	88°11'	SE-E-SE	6.4	0.6	4100
(NE of Forked Peak)	4420	27°34'	88°14'				

Source: Mukhopadhyay, 1998

section have extended the elated multifarious effects in the area of water management with a special reference to the landslides and floods towards the lower reaches. The Pauhunri, Zemu and Talung glaciers as the result of huge ice cover in this part of the Greater Himalayas have fluctuated between wide limits in the past and certain fluctuations are still going on even today. Such fluctuations are found to have accompanied many notable changes in the various fields like (*a*) the production and the transport of debris, (*b*) floods and siltation of reservoirs, (*c*) vegetation cover (timber line) and (*d*) others associated with the cooling effects of these groups of glaciers in Sikkim (Mukhopadhyay 1998).

The other features are entrenched meandering and straight channel patterns in the lower part, wide level surfaces (of various sizes and origin) with occasional cover of grasses and swamps or boggy areas in places, e.g., Green Lake plains and north western plains, varied drainage texture and complex type (deranged) of drainage patterns with swampy interstream areas in some places. Deranged patterns are marked by irregular stream courses which are found to have joined, for example, the Green Lake swamps and the like, and occasionally flowed out of the lake-swamps.

This drainage pattern is typified by the occurrence of a few short tributaries like mere threads of water which are intensified during rains or storms, cirque and nivation cirque (floor), in the Zemu, Talung glaciers, cryopediments, frost riven cliffs and scarps, cryoplains cryopediplain and the like relating to cryonival morphogenesis, e.g., patterned ground features, crevasses or deep cracks, over the Zemu-Talung-Pauhunri glaciers, lateral and end moraines, as found to the north west of Tomya chu-Yabuk, for example, glacial trough and sickle-shaped troughs (Sichelwannen) and other plastic scouring forms relating to sub-glacial erosion, truncated spurs, escarpment and tors (granitic), thermo-erosion gullies, as ice wedges (syngenetic ice wedges in loose deposits, epigenetic ice wedge in solid rocks) on slopes thaw out, pingo 5-100 m open system and scarps and the like. These long and relatively narrow glaciers feeding the Tista and its

tributaries are of distinctive types and exhibit the different sections with typical features relating to erosional and depositional activities.

Sections of ablation, valleys with shoulder and heads or high steps, basins and narrow sections, valley-side benches, U-shaped cross profile and steps in the longitudinal profile, tributary valleys, section of accumulation, glacial deposition including moraines— lateral and end moraine till, firn field, plastic section and glacier terminus section or snout of glaciers and others are found. These glacierized zones in the upper northern Sikkim Himalayas also contain features of glacio fluvial erosion and deposition particularly in the preglacial which were guided by the source of debris and the drainage which followed courses being influenced by the ice. It includes several episodes of glacio-fluvial activity (dead-ice wastage) during recession when distinct drainage systems came into being and found it, ways in the directions of the ice-surface slope with a beginning upon the ice from ice melt, snow melt and rain, and drainage also came from ice-free mountain terrain in subsequent stages. The sub-glacial erosion, for example, relates to the peculiar plastic scouring forms particularly the sickle-shaped troughs and their varieties. The periglacial zones are connected with cold climates and permafrost system (tjale) which have affected the morphological systems thus modifying the operation of geomorphological processes in and around Yabuk (3,962 m), Green Lake plain area (4,500 m), Poki chu, Tumrachen chu, Langpo chu, Naku chu etc. valleys.

2.3.2 Neotectonics and Landscapes

The Sikkim-Himalayas an uplifted and tilted mountainous terrain which has been divided into several large elongate sub-parallel tributary valleys like the Rangit, Rangpo Chu, Rongni Chu, Rang-Rang Chu, Lachung Chu, Ranikhola, Rora Chu, Takchom Chu, Geilkhola, etc. An important feature of the Tista drainage basin is the remarkable way in which geological structure and the character of the underlying rocks are expressed in the

landforms. Lineation in the topography has been largely controlled by structural and tectonic elements. The Sikkim-Darjeeling Himalayas which sustain the Tista and other drainage basins are classic areas in neotectonics. There is a close relationship between the tectonic patterns and the landscape of the Sikkim Himalayan terrain set in the tectonically active (neotectonics) eastern Himalayas and also Bengal deltaic plains.

The different landscape elements, including suites of glacio-fluvial landforms, drainage and channel patterns have been largely influenced and reformed in recent times. The major morphotectonic lineaments, thrust or folded belts extending from the Bay of Bengal to the eastern Himalayan sector are of critical significance since most of them are involved in the evolution of the present variegated landscape of the Tista and surrounding drainage basins. Different segments of the regional tectonic settings of the Tista basin area in the eastern Himalaya, as a whole, are associated with the corresponding geomorphic units which exhibit the typical landform associations.

The regional tectonic setting of the eastern Himalaya beyond the Bhagirathi-Hooghly channel includes (*a*) Brahmaputra Basin, (*b*) Bengal Basin, (*c*) Eastern Himalaya fold belt, (*d*) Shillong platform and Mikir hills, (*e*) Surma Basin, (*f*) Naga-Lushai Arakan Yoma fold belts, and the others like Central Burma Molasse basin, Trans Himalaya Region, etc. On the other hand, the physiographic lineament is primarily along east-west, while several spurs are aligned in north-south directions. The Tista with its major tributaries and the other rivers like Jaldhaka, Torsa, Mahananda, Manas, etc., have cut up the elevated rugged mountainous terrain into several morpho-units, which are also known as 'geomorphic sites' or 'dynamic ecological sites' being separated from one another by deeply incised valleys with terraces, dissected hills, valley-side slopes and gorges, etc.

The contiguous valley areas of the Tista likewise display the effects of thrusting or over-thrusting, recumbent folding associated with structural disturbance or dynamic metamorphism relating to tectonic activities in

recent times. It is obvious that current landform changes in the slope-transformations, deformed terrace-deposits, dynamic ecological sites and particularly in morphogenetic balance of the Tista basin are believed to be the reflection of the influence of fundamental crustal fractures of recent origin. The Sikkim-Himalayas are under the domain of active deep-seated fundamental crustal fractures. These fracture lines are aligned from Bengal Deltaic Plain towards the Trans-Himalayan zone and Padma-Jamuna-Tista morpho tectonic lineaments along with Main Boundary Fault, etc. This undulating terrain is also typified by the notable discontinuous (broken) lineaments which have brought about remarkable modification in the riverine features like raised and dissected terraces and floodplains along the river valleys. A detailed discussion or implication of all these major morpho-tectonic lineaments in the developments of morpho-regions and their subsequent changes in different aspects is beyond the scope of the present volume.

It is relevant to mention about the Neogene Siwalik and Permo-Carboniferous Gondwanas which are found almost continuous along the foothill zones. These formations are aligned almost in the east-west direction from the western border area of the Central Sikkim Himalayas upto the Siang-Dibang valley in Arunachal Pradesh with a few breaks. Towards the northern parts occur traces of metamorphites of several grades and crystalline rocks. Beyond the Sikkim Himalayas, the mountainous terrain area is characterized by the east west trending Tsangpo and its nearby arcuate and general lineaments along with red-river fault. These are also well expressed in the surface by characteristic drainage and channel patterns, glaciated valley-lakes, ellipsoidal blocks, etc., (Mukhopadhyay 1982, 1998).

The broad north wests south east morpho tectonic lineaments are significant in the study of Sikkim terrain particularly of its drainage and channel patterns - with reference to the Brahmaputra drainage system and the Bengal basin. Those lineaments of geomorphic significance are termed

after the names of important rivers like Tista, Jamuna, Padma, etc. which also include a number of small fractures, boundary fault or a series of thrusts. As an example, the Northern mountainous terrain in the upper parts of the basin, is typified by the large arcuate lineaments with distinct north-south fractures.

The lower reaches of the main Brahmaputra are found to have largely been guided by the underlying structural conditions, e.g., Jamuna lineament, the NW-SE Tista lineament seems not to be involved directly with the total drainage developments except of the upper reaches far beyond the main boundary fault. The basin area is roughly delimited by the Tista in the north and Padma lineaments in the south respectively, while the former lineament is extended from the lower Bengal Deltaic Plain to the higher (Tibet Plateau) Trans-Himalaya through the intervening upper segments.

2.3.3 Constituent Multicyclic Landscape Elements

Constituent elements of the multicyclic landscape of the Tista basin area negotiating the higher eEastern Himalaya and lower Bengal Deltaic Plain in Eastern India are: (*a*) a series of ridge and vales, (*b*) hills of various shapes and origin, (*c*) cirque glaciers, (d) till sheets (*e*) glaciated valleys and lakes including kettles, lenses, dry valleys, (f) truncated planated surfaces, (*g*) wide level surfaces of various shapes, (*h*) small rhomboidal and ellipsoidal blocks of flat plains, (*i*) rugged hill slopes along with marginal ledges, (*j*) landslide slopes, (*k*) deeply incised (meandering) valleys with gorges, (*l*) three to four-tier terraces (glacial and fluvial) with rock benches (*m*) continuous deformed fluvial terraces and floodplains along the rejuvenated valleys, (*n*) antecedent (anteposed) river, (*o*) alluvial cones of multiple generations, (*p*) well marked scarps and spurs (interlocking), (*q*) gullied surfaces, (*r*) valley-side slopes and valley pediments, (*s*) sharp and ridge-like strewn divides with inter-stream uplands, (*t*) extensive braided, meandering channels including ancient channels, and (*u*) several scarps including composite scarps.

The assemblage of these various landscape elements evolved under varied environments has brought about many notable fluvial and glacio fluvial features. The Sikkim landscape complex containing particularly land forms like terraces and floodplains, gorges, alluvial, cones, etc., shows the effects of dynamic geomorphic processes along with interactions between the controlling forces. Many peculiarities landforms and contrasts in the attainment of 'range' of features in different morpho-units have been manifested in the magnitude spectrum of the Sikkim terrain. Actually the Sikkim Himalayas are an ideal play ground where the different geo-complexes like climate-soil-vegetation climax system, water balance, rocks (petro-variance) eustatic, tectonics (epeirovariance), etc. have largely controlled to shape its polymorphic characters. This terrain reflects the effects of recurrent and comparatively rapid uplift set on a truncated planated surfaces in the eastern Himalayan zone and adjacent plain areas. Repeated lowering of the base level has taken place consistently with rejuvenation of the Brahmaputra drainage system.

Of all these types (land forms) much stress is given to the typical riverine features like the terraces and floodplains, and level surfaces at different altitudes which, have been regarded as environmental indicators in fluvial geomorphology (Mukhopadhyay 1978, 1980, 1982). These suites of landforms relating to the study of ecosystem of mountains and plains are significant in the work of establishing both qualitative as well as quantitative interaction between the various components of the geocomplex.

2.3.4 Geomorphic Units

Considering the development of distinct landscapes, soil and drainage features, the terrain has been classified into several geomorphic units from north to south with a varying altitude and climatic conditions. These geomorphic units are (*a*) the Pauhunri (Tista) and Zemu-Talung glaciated areas, (*b*) the periglacial areas in the fringe and of the former, (*c*) the higher northern mountainous terrain, (*d*) the southern rugged hilly tracts, and (*e*) the rejuvenated Tista valley and the Rangit valley (Mukhopadhyay, 1998).

The Sikkim Himalayas are noted for their remarkable ecological diversity and contrasting topographic expressions as well as varied morphogentic conditions. Most of these geomorphic units with their distinct landform assemblages, resulting from a set of endogenous and exogenous factors, have represented well the cause and effect relationships like a process-response model.

These suites of landforms have been observed mainly in the asymmetrical valley-side and hill-side slopes of the trunk stream Tista and its tributaries like Lhonak chu, Zemu chu, Tasang chu, Lachung chu, etc., which indicates unmistakably the dominance of glacial, periglacial and fluvio glacial environment in the respective sectors relating to the glacial retreat and associated shrinkage and desiccation of valleys, and processes of invigorated dissection- down cutting, suffusion and toe-erosion by the Tista. The modifying processes also include solifluction, debris avalanches, slides, slumps, mudflows, debris flows, congelifraction and congeliturbation both in the local summit and base level areas within the northern Sikkim Himalayans terrain.

The hill slopes are characterized by the formation of symmetrical valleys (tributaries), spurs, escarpments (granite) and free-face with a talus slope below thus bringing about variety in this Pleistocene terrace site. The constituting terrace materials relating to stratigraphic successions have been used as meaningful indicators of environments like glacial, periglacial or fluvio glacial particularly of the succession of characteristic episodes since the Pleistocene period. Further upstream, at an altitude 3000 m and more, the different types of valley—asymmetrical, dry valleys or dells, Pleistocene terraces, cut and fill terraces, dryoplanation terraces, (constructional) gelifluction terraces or flats— of various origins have been identified.

The normal topographic forms found so far in the valley areas have been replaced by the peculiar forms with changing processes under higher altitudinal cold environments like periglacial and glacial environments.

For example, fluvial morphogenesis has transformed into cryorival morphogenesis along with associated forms as cryopediments, frost riven scarps, cryoplain, dry valleys, fossil thermokarst basin, cryoplanation terrace and tor-like features, ground patterns of former ice wedge polygons including gelifluction deposits bedded screes and other products of frost creep and slope wash relating to periglacial mass movements. The northwestern Zema and Yakthang-Yabuk areas in the west, and Yumthang area in the east may be described as a typical Periglacial landscape. This zone displays an abundance of features suggestive of pleistocene frost action and also a set of subdued landforms, which were moulded by that frost action and by gelifluction during a succession of cryergic episodes.

Generally, the Yabuk-Green Lake plain area, adjacent to the margins of Zemu-Talung glaciers, has been considered to illustrate the effects of periglacial processes in the northern and north-western part. In the periglacial zone, intensive linear erosion (thermo-erosion) and planation relating to cryogenic processes have brought about many notable features like broad trough-shaped valleys, thermo-erosion gullies, small dry valleys, cryopediments (in granites) or glacis and cryoped in plain, nivation hollows, frost-riven cliffs, frost-riven scarps, cryoplanation terraces and tors, cryoplain, asymmetrical valleys, pingo and other forms of patterned grounds. It is necessary to explain the mechanism and morphological properties of these glacial-periglacial and laciofluvial processes which have distinguished the upper parts from the middle and lower parts.

Thermo-erosion is the combined thermal and mechanical activity of running water relating to the thermal effects of the water which accelerate erosion. Thermo-erosion causes valley widening in periglacial zones. The intensive linear erosion essentially takes place in periglacial zones relating to cryonival morphogenesis, specially in the upper valley sections of the Tista and its tributaries. Developments of thermo-erosion gullies 5 m. and more in depth and broad trough-shaped valleys are found to have associated with the later stage of linear erosion relating to the thawing of ice wedges on steep slopes and subsequent sapping of the valley-sides.

The cryopediments extend from the main valleys into lateral valleys even joining pediment passes over watersheds. As the cryopediments coalesce, a regional planation surface develops called a cryopediplain. Further, planation surfaces in the periglacial zone develop on summits and watershed ridges. The summits and watershed ridges of the periglacial zone often exhibit a distinct stepped topography. The planation process usually begins by the formation of nivation hollows. As they widen and merge, and because of the retreat of rock steps termed 'frost-riven cliffs' and 'frost-riven scarps', cryoplanation terraces develop on the summits; several steps of successive cryoplanation terraces are often to be seen.

As they merge, a cryogenic planation surface termed a 'cryoplain' develops. Periglacial climates, is characterized commonly by very low annual temperatures, fluctuations of temperature above and below freezing, and strong wind action, at certain seasons at least. Areas presently having such a climate are usually denoted as tundra areas. At present, this type of climate is limited to high latitudes and high altitudes. Intensified frost action marks these areas made of gneiss, augen gneiss, pegmatites, etc., and solifluction and patterned ground features are particularly diagnostic. A typical periglacial climate differs substantially from a glacial climate mainly by the aridity and the negative heat balance of the ground surface.

In the elevated regions, the periglacial zone has not been well defined climatically, being delimited so far rather on the basis of occurrence cryogenic phenomena. But most typical periglacial zones with characteristic landforms relating to permafrost with considerable thickness occur in and around Yabuk Green Lake (3,960 m)- plain set in the high north western mountains where the glaciers excepting the snout (Zemu) are insignificant. The development of cryogenic phenomena is connected with the freezing of soil and the phase transformation of water. Ground freezing can be perennial (ground temperature below freezing point for more than two years), seasonal (several months) and short term (from several hours upto days).

The core of the periglacial zone comprises the region of perennial ground freezing with permafrost. Beyond Yakthang -Tomya chu (3,050 m)line, the Yabuk-Green Lake plain surface is conspicuously marked by the development of different heaps of frost shattered rocks, distinct channels of rocks forming fan-like structures at the base of hill slopes, traces of the snout of glacier, soil polygons,, patterned ground features (stone nets, stone stripes, stone rings, earth hummocks or palsen, earth stripes, block fields or felsermeere, etc.), related to solifluction deposits, lakes and others which are intimately connected with periglacial processes like congelifraction, congeliturbation, solifluction along with naval or niveo-aeolian actions.

The occurance of extensive cryogenic planation surfaces is the influential factor for the periglacial environment in the mountain ranges like in Yabuk as a result of the very low temperature. The permafrost or permanently frozen layer of soil is mainly characterized by the process of cryoplanationin in which very low temperature became an active agent. The activity of cryogenic processes prevail within a short period during spring because at that time the temperature rises and the area becomes dry and this process become less active. Whereas in autumn, the temperature decreases rapidly, the active layer freezes and the effects of geomorphological processes become less. Permafrost is a dynamic process adapting itself to the changing conditions of the environment as most of it is linked to present climatic conditions, soil, vegetation, relief, hydrological conditions and the activities of man. The development of landforms in periglacial zones depends mainly upon the dynamism of the permafrost wherein the temperature, thickness and origin of the permafrost are significant. For instance, in low temperature zone the development of landform is slow because of the stable occurence of permafrost. Hence, permafrost thickness plays an important part. The exact permafrost thickness has not yet been recorded in the Tista basin area. However, it has been assumed that thickness is more than 500m.

The origin of permafrost is of considerable geomorphological

significance because it affects the distribution of ground-ice in frozen rocks, and especially in sediments. The dynamics of permafrost, such as its aggradation and degradation, are of unusual significance for the development of landforms in the periglical zone. Increase in the negative thermal soil balance results in a decrease of permafrost temperature. Due to this, permafrost aggradation also begins to result in a decrease of the thickness of the active layer and this in turn affects the dynamics of the geomorphological process. Permafrost usually contains various kinds of ground ice which depends upon the mode of its origin and development. 'Texture ice', involving ice crystals from some millimeters upto a few centimeters in size, forms a typical cryogenic texture in the case of rock freezing. This texture is defined by its forms, dimension and the distribution of ground ice crystals in frozen rock (Mukhopadhyay, 1998).

2.4 Climate

The climate of a locality is the synthesis of day-to-day values of the meteorological parameters like precipitation, temperature, humidity, sunshines, and wind velocity. It is now well established that climate and weather variability play an overriding role in different fields ranging from the development of water resources to the eradication of diseases. It is, therefore, highly essential to make full use of all available meteorological information and services in their planning and at the operational level.

In respect of time, weather is the state of atmosphere at an instant of time while climate may be considered as 'quassi-steady statistical weather ensemble' of earth atmosphere- ocean system for the period of a few (~3) decades. The climate of a locality is the synthesis of the meteorological elements that affect the locality. The main climatic elements are precipitation, temperature, humidity, sunshine, wind velocity and such phenomenon as fog, hailstorm, frost, thunder, gale, soil temperature, potential evapotranspiration, evaporation, cold waves and heat waves. The climate of a place is mainly governed by the following factors: (*a*) latitude, (*b*)

Authors

KC Pradhan (b.1935), former Chief Secretary and Advisor to the Government of Sikkim has been State's most versatile expert on forest resources. A post graduate from the Yale University, USA , he was also a Judge at the prestigious Japan Grand Prix International Orchid Festival at Tokyo in 1991. Currently he is the President of Sikkim Nature Conservation Foundation and also the Chairman, Sikkim Development Foundation. He was awarded the American Rhododendron Society's highest award- ARS Gold Medal for the year 2003, "in recognition of his leadership and tireless dedication to the advocacy, conservation, and protection of the unique rhododendron and the alpine floral legacy in India's Eastern Himalayan State of Sikkim".

Dr Eklabya Sharma, a founder Scientist in-charge of the Regional Centre of the GB Pant Institute of Himalayan Environment and Development in Sikkim (1989-2001) is presently the Programme Manager of Natural Resources Management at the International Centre for the Integrated Mountain Development (ICIMOD), Kathmandu. A well known scientist in the eastern Himalayan region, he was awarded the Young Scientist Award by the Indian National Science Academy and Honorable Mention Paper Award by Soil and Water Conservation Society, USA. He has 95 publications including five books to his credit.

Dr Gopal Pradhan (1962) is the first Ph D in Ecology in Sikkim. He is presently a Senior Environmental Scientist in the Department of Forests, Government of Sikkim.

He has written a number of articles and reports including on the environmental impact assessment on the hydel projects and sustainable tourism in Sikkim.

Dr AB Chettri (b 1970) taught in Sikkim Government College before joining the Sikkim Civil Service in 2003. A promising scholar, he is the author of *Geography of Sikkim*.

Chief Editor

Dr Mahendra P Lama (b 1961) is a Professor of South Asian Economies in the School of International Studies in Jawaharlal Nehru University, New Delhi. He is also Chief Economic Adviser to the Chief Minister of Sikkim with a Cabinet Minister rank. Central to his intellectual pursuits is economic development and cooperation in South Asia. He was India's representative in the Independent Expert Group set up by the South Asian Association for Regional Cooperation (SAARC) in 1997 and also a member of the Prime Ministerial delegation.

He was the prestigious Asia Leadership Fellow in Japan in 2001 and Ford Foundation Fellow in the USA in 1997 and now a Visiting Professor in Hitotsubashi University, Japan (2004-5). He has lectured extensively both in India and abroad. Besides a dozen of books, his major works including that on trade, development, technology, migration, investment and energy have been published in many prestigious refereed journals and translated into a number of languages including Japanese, French, German, Urdu, Hindi and Bengali. A prolific writer, he is also the author of *Sikkim Human Development Report 2001*. He has been in various national and international academic and professional committees. He writes a widely read and debated column "Serophero" in *Himal Khabarpatrika* (a fortnightly news magazine, Kathmandu) and has also been closely associated with Sahitya Akademi and National Book Trust.