Carrying Capacity Study of Teesta Basin in Sikkim

Volume-I

INTRODUCTORY VOLUME

Commissioned by :

Ministry of Environment & Forests, Government of India

Sponsored by :

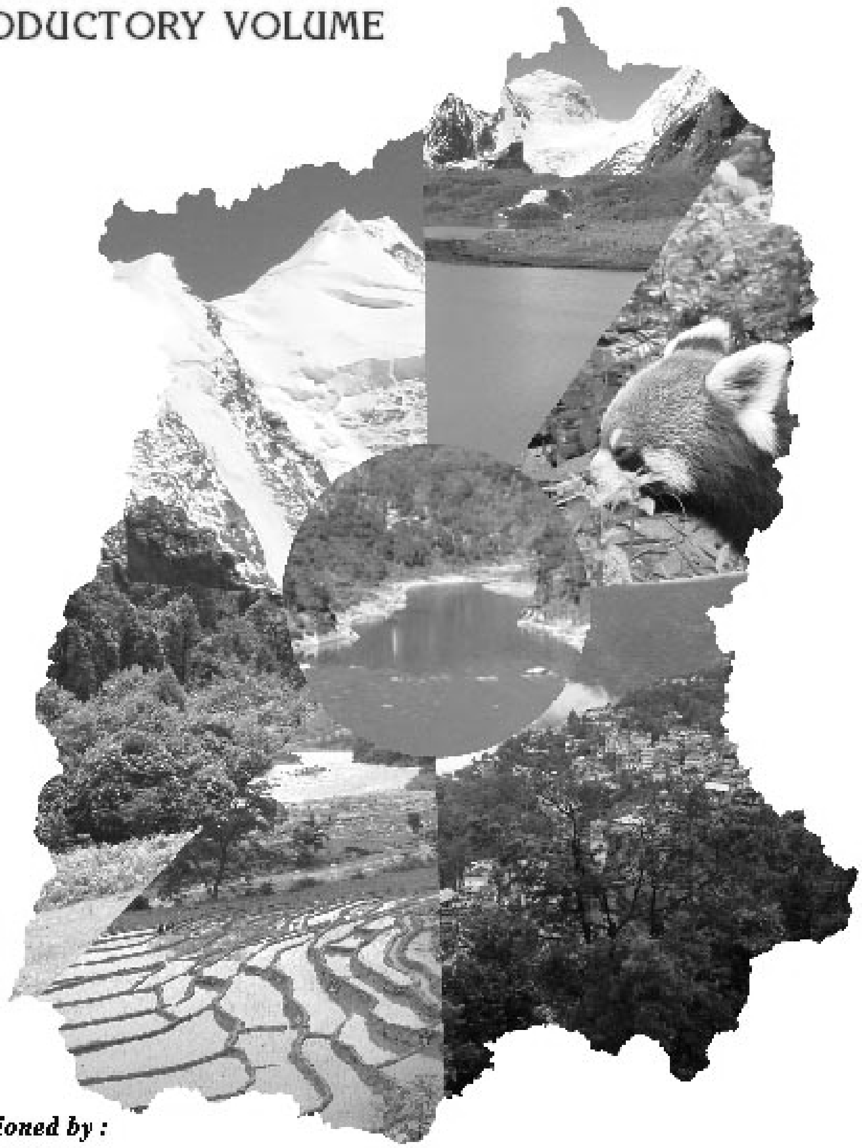
National Hydroelectric Power Corporation Ltd., Faridabad

CENTRE FOR INTER-DISCIPLINARY STUDIES OF
MOUNTAIN & HILL ENVIRONMENT
CISMHE UNIVERSITY OF DELHI, DELHI

Carrying Capacity Study of Teesta Basin in Sikkim

Volume-I

INTRODUCTORY VOLUME



Commissioned by :

Ministry of Environment & Forests, Government of India

Sponsored by :

National Hydroelectric Power Corporation Ltd., Faridabad

CENTRE FOR INTER-DISCIPLINARY STUDIES OF
MOUNTAIN & HILL ENVIRONMENT
UNIVERSITY OF DELHI, DELHI

PARTICIPATING INSTITUTIONS

- **Centre for Inter-disciplinary Studies of Mountain & Hill Environment, University of Delhi, Delhi**
- **Centre for Atmospheric Sciences, Indian Institute of Technology, Delhi**
- **Centre for Himalayan Studies, University of North Bengal, Distt. Darjeeling**
- **Department of Geography and Applied Geography, University of North Bengal, Distt. Darjeeling**
- **Salim Ali Centre for Ornithology and Natural History, Anaikatti, Coimbatore**
- **Water and Power Consultancy Services (India) Ltd., Gurgaon, Haryana**
- **Food Microbiology Laboratory, Department of Botany, Sikkim Government College, Gangtok**

VOLUMES INDEX*

*For Volume-wise Detailed Index – Refer to the end of the report

PREFACE

The 'Carrying Capacity Study of Teesta Basin in Sikkim' was initiated at the instance of Ministry of Environment & Forests, Government of India while issuing Environmental Clearance to Teesta Stage-V H.E. project proposed by National Hydroelectric Power Corporation Ltd., Faridabad. The above mentioned environmental clearance was given in May, 1999 with a stipulation that 'no other project in Sikkim will be considered for environmental clearance till the Carrying Capacity Study is completed' the funds for which would be provided by NHPC Ltd. Therefore, the present study was entrusted to the Centre for Inter-disciplinary Studies of Mountain & Hill Environment (CISMHE) in September, 2001 by Ministry of Environment & Forests, Government of India vide letter No. J.12011/1199-IA.1 for which funds were provided by NHPC Ltd. The study was being coordinated by CISMHE, University of Delhi, Delhi being the Principal Investigator with institutional collaboration with other national level institutes *viz*.,

i) Centre for Atmospheric Sciences, Indian Institute of Technology, Delhi
ii) Centre for Himalayan Studies, University of North Bengal, Distt. Darjeeling
iii) Department of Geography and Applied Geography, University of North Bengal, Distt. Darjeeling
iv) Salim Ali Centre for Ornithology and Natural History, Anaikatti, Coimbatore
v) Water and Power Consultancy Services (India) Ltd., Gurgaon, Haryana
vi) Food Microbiology Laboratory, Department of Botany, Sikkim Government College, Gangtok

The main objective of the study was to assess the 'Carrying Capacity Study of Teesta Basin in Sikkim' in terms of various natural resources like water, land and air encompassing biological, water, air, socio-economic and socio-cultural environments. The study has been completed in three phases over a period of four years. The last phase of the project, Phase-IV would entails conducting workshops, seminars, etc. in the state of Sikkim at different places to appraise the various sections of the people and government officials regarding the technical findings of the report and then to receive inputs from all concerned with the sustainable development of the state of Sikkim. These inputs in the form of suggestions and specific recommendations would then form the appendix to the main report of the study.

This final technical report contains the details of the work done during the study entitled “Carrying Capacity Study of Teesta Basin in Sikkim” covered in three different phases. The findings of the studies undertaken by various participating institutions has been presented in ten volumes covering different aspects of land, water, air, biological and socio-economic and socio-cultural environment in order to understand the importance of these resources.

The Volume-I is an Introductory Volume, which highlights the ‘Carrying Capacity’ concept and methodology adopted for the studies. It provides an account of physiography, terrain, drainage and other characteristics of the study area i.e. Teesta basin in Sikkim. It also provides information on the proposed power development model being adopted by the state. Further, it contains information on various nodal points of water resources. This volume also gives detailed description of the characteristics of Teesta river system and salient features of 17 watersheds delineated in the Teesta basin as most of the information on soil, landuse, etc. has been analysed and presented watershed-wise for future planning. There is a separate chapter on landuse/landcover mapping. In the end a copy of the report of state level workshop on Promotion of Community Health & Development through Medicinal Plants organized by Voluntary Health Association of Sikkim (VHAS) supported by the Centre in January, 2005 as one of the outreach activities of this study has also been annexed.

The Volume-II of the report covers geophysical environment of Teesta basin and deals with various geological and seismotectonic aspects. The phenomenon of frequent landslides in the basin has been highlighted and various mitigation measures also have been suggested in the chapter on landslides. In addition, the problem of floods and mitigation measured to be adopted also has been highlighted in this volume with inputs from WAPCOS. Due to global warming phenomena, glaciers (the vast reserves of water in the form of ice) are melting fast.

Therefore, a separate chapter has been devoted only to assess and evaluate the various issues related to glaciers, glacial lakes and glacial lakes outburst floods (GLOF), and their implications in hazard generation along with appropriate recommendations. The soil resource has been dealt in detail in the Volume-III under the Geophysical Environment. This part of the study was jointly undertaken by the Centre (CISMHE) and Regional Centre, National Bureau of Soil Survey & Landuse Planning (NBSS & LUP), Kolkata. It contains details of the soils of all the 17 watersheds of Teesta basin including the land capability classification and suitability of soils of different regions for various activities like agriculture, horticulture and forestry plantations.

The Volume-IV covers different aspects of water environment in Teesta basin. This volume discusses the hydro-meteorology, hydrology, irrigation, land resource management, agriculture, horticulture and drought prone areas in the state. This volume has been prepared by Water and Power Consultancy Services (WAPCOS) Ltd., Gurgaon.

The Volume-V of the report covers issues related to air environment. It contains report on the air quality status of different areas of Sikkim. It also gives suggestions for improvement in air quality. This volume has been prepared by Centre for Atmospheric Sciences, Indian Institute of Technology, Delhi.

As biodiversity is one of the most important resource of the region, various aspects of this have been covered in three volumes i.e. Volumes VI-VIII. The Volume-VI deals with the plant resources and provides information on forest types, vegetation profile and diversity of different plant resources. Aquatic environment and water quality also has been covered in this volume in a separate chapter. It also deals with the aquatic environment of some of the important lakes of Teesta basin. Similarly fish fauna has been discussed in this volume. The information on protected areas has also been given in this volume. Faunal resources have been dealt in detail in Volume-VII. It provides details of diversity of various animal groups *viz*. mammals, birds, herpetofauna and butterflies in different altitudinal zones of Teesta basin. This volume has been prepared by Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore. Volume-VIII deals with the food resources where emphasis has been laid on ethnic food resources and ethnic food tourism. This volume has been compiled and prepared by Food Microbiology Laboratory, Department of Botany, Sikkim Government College, Gangtok.

Volume-IX and Volume-X deal with the socio-economic and socio-cultural environment of the state. The volume on socio-economic environment deals in details with the problem of livestock in the state. This volume has been compiled by Department of Geography and Applied Geography, University of North Bengal, Siliguri. Volume-X mainly deals with cultural profile and quality of life in the state in addition to the socio-economic conditions in the different districts of the state. This volume has been prepared by Centre for Himalayan Studies, University of North Bengal, Siliguri. A summary of all the volumes along with recommendations that emerged from the study have been given in Executive Summary & Recommendations. It provides an insight into the overall assessment and evaluation of various resources in Teesta basin and discusses about the intrinsic environmental sensitivity of different regions/watersheds of Teesta basin and also with respect to various developmental activities that are being proposed in the basin. The observations made by some of the experts have also been appended with this volume.

Arun Bhaskar

CISMHE, New Delhi March, 2006

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER – 1

INTRODUCTION

1.1 STUDY AREA

Sikkim is a small Himalayan state in north-east India situated between $27^0$00'46" to $28^0$07'48" N latitude and $88^0$00'58" to $88^0$55'25"E longitude with geographical area of 7096 sq km constituting only 0.22% of total geographical area of India. It has a human population of 5,40,493 as per Census, 2001, which constitutes only 0.05% of India's total population. The state is somewhat rectangular in shape with a maximum length from north to south of about 112 km and the maximum width from east to west of 90 km. The state is bounded in the north by the Tibetan plateau, by China (Tibet) on the north-east, by Pangola range of Bhutan on the south-east, by Darjeeling district of West Bengal on the south and Singalila range and Khangchendzonga on the west and north-west (Fig. 1.1). Entire state of Sikkim constitutes upper basin of Teesta river except for a small area of 75.62 sq km in extreme south-east of Jaldhaka river, which originates in East Sikkim and flows through West Bengal parallel to Teesta river to meet Brahmaputra river. In southernmost part of Sikkim, Teesta river flows in southwest direction and defines the inter-state boundary between Sikkim and West Bengal up to Melli Bazar where it is joined by Rangit river which drains West Sikkim district. Rangit river, the largest tributary of Teesta river in Sikkim, from Naya Bazar point flows in southeast direction and marks the inter-state boundary between Sikkim and West Bengal in the southwest.

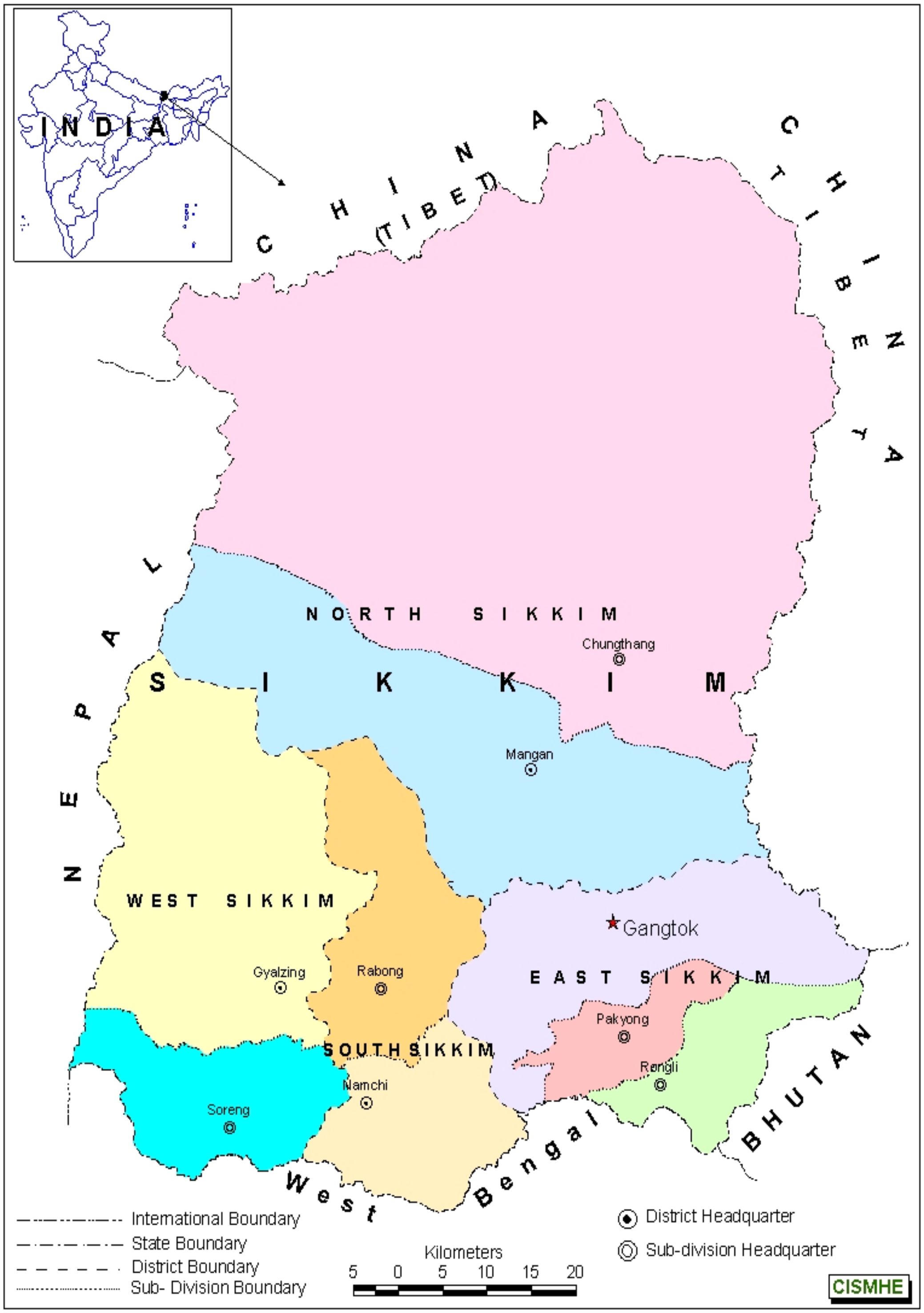


Fig 1.1 Location map of Teesta Basin in Sikkim

The state of Sikkim has been administratively divided into four districts *viz*. North Sikkim, South Sikkim, East Sikkim and West Sikkim using water divides of major and minor tributaries of Teesta river as criteria. North Sikkim is the largest district with an area of 4,226 sq km constituting about 60% of the entire state. The West, East and South districts constitute about 16%, 13% and 11% of the geographical area of the state, respectively. The state capital is located at Gangtok in East Sikkim. Each district has been further divided into two sub-divisions each except in East Sikkim, which has been divided into three sub-divisions. All the districts together have 407 revenue blocks and 42 forest blocks. The administrative set up of the state is outlined in Table 1.1. East Sikkim is the most populated district having 45.29% of state's total population and North Sikkim is the least populated with 7.59% share of the total human population.

Table 1.1 Administrative set up of Sikkim

Particulars	District			
	North Sikkim	**South Sikkim**	**East Sikkim**	**West Sikkim**
Area (sq km)	4,226	750	954	1166
Sub-division	Mangan*	Ravang	Gangtok*	Gyalzing*
	Chungthang	Namchi*	Pakyong	Soreng
			Rongli	

*District headquarters

Human population of Sikkim is comprised mainly of Nepali, Bhutia and Lepchas. Main languages of the state are Nepali, Bhutia and

Lepcha. Majority of the population speaks Nepali, which is the main medium of instruction in educational institutions along with English. The inhabitants of the state are predominantly Buddhists. Majority of residents depend on agriculture and related activities for their livelihood. Maize, large cardamom, rice and wheat are principal crops grown in the state.

1.2 PHYSICAL FEATURES

Sikkim state being a part of inner mountain ranges of Himalaya, is entirely hilly, having no plain area with altitude varying from 213 m in the south to above 8,000 m in the north-west and north. The human habitable area is limited only up to the altitude of 2,100 m constituting only 20% of the total area of the state. North Sikkim, which is deeply cut into escarpments is the least populated with a population density of 9.7 persons/ sq km only. The habitation at higher altitudes exists mainly in Lachen and Lachung valleys comprising the upper catchment of Teesta river. The population, however, is concentrated in lower altitude habitations, *viz*. Mangan, Singhik, Chungthang, etc. North Sikkim is endowed with a number of glaciers that descend from the eastern slopes of Khangchendzonga and western slopes of Pauhunri. Zemu glacier located in North Sikkim is one of the largest glaciers in India with a total length of about 25 km. This high altitude district forms the upper Teesta basin and is endowed with number of glacial lakes of various sizes and shapes. The prominent among them are Chho Lhamo, Gurugongmar Chho, Lhonak Chho, Green lake and Khangchung Chho.

Other important lakes in the state are Chhangu and Kupup lakes in East Sikkim and Khecheopalri in West Sikkim. More than 43% of Teesta basin in Sikkim is characterised by very steep slopes and escarpments i.e. more than 43% of its geographical area lies in more than 50% slope category. This district can safely be called as the hydrological estate of Sikkim state as it holds a pivotal position in controlling the water regime in the entire Teesta basin.

The landforms and drainage of Teesta river are characterised mainly by the four tiered terraces, canyons or gorge-valleys at different altitudes, asymmetric valleys, polyprofilic U-shaped valleys and steps or troughs, lakes, alluvial cones, truncated ridge-spurs, terracettes (soil landscape systems), rectangular-barbed-parallel-trellis-radial to sub-dendritic drainage patterns, straight to meandering and braided channels. All these physiographic features are indicative of active processes of weathering, denudation and deposition making the area physically very sensitive.

1.3 GEOLOGICAL SETTING

The regional geological set-up of the Sikkim Himalaya is best displayed in the form of Teesta gorge, flowing in general from north to south. The Central Crystallines represented by a sequence of high-grade meta-sedimentaries (calc-granulities, schist, quartzite), gneisses/ migmatites and a number of granitic intrusions are exposed in the Axial Zone of North Sikkim. The Central Crystalline rocks are separated from the gneisses and schists (Darjeeling gneiss and

Daling Group) in the south by a prominent dislocation zone, namely the Main Central Thrust, which is an important tectonic feature or activity all along the Himalaya. The foothills in southern part of Teesta basin in Sikkim is characterised by low grade pelite-psammite assemblage (Dalings) followed by alternate sequence of the sandstone-shale-coal assemblage (Gondwana) occurring with prominent structural dislocations in between. Further south, the Gondwana rocks are separated tectonically from the Shiwaliks by the Main Boundary Fault. Though there are no recorded events of macro- and/or micro-seismicity in North Sikkim, which makes the area is highly vulnerable to earthquakes and natural hazards. As per the revised Seismic Zoning Map of India, the state of Sikkim lies in the seismic zone classified as Zone-IV.

1.4 RIVER TEESTA

The river Teesta is one of the main Himalayan rivers and originates from the glaciers of Sikkim in North at an elevation of about 5,280 m. The river rises in mountainous terrain in extreme north as Chhombo Chhu which flows eastward and then southward to be joined by Zemu Chhu, upstream of Lachen village. The river takes a gentle turn in southeast direction and meets Lachung Chhu at Chungthang where it takes the form of a mighty Himalayan river (Fig. 1.2). Teesta, therefore, is the main river of the state with its several tributaries *viz*. Zemu, Lachung, Rangyong, Dikchu, Rongli, Rangpo and Rangit and constitutes an extremely important resource of the state.

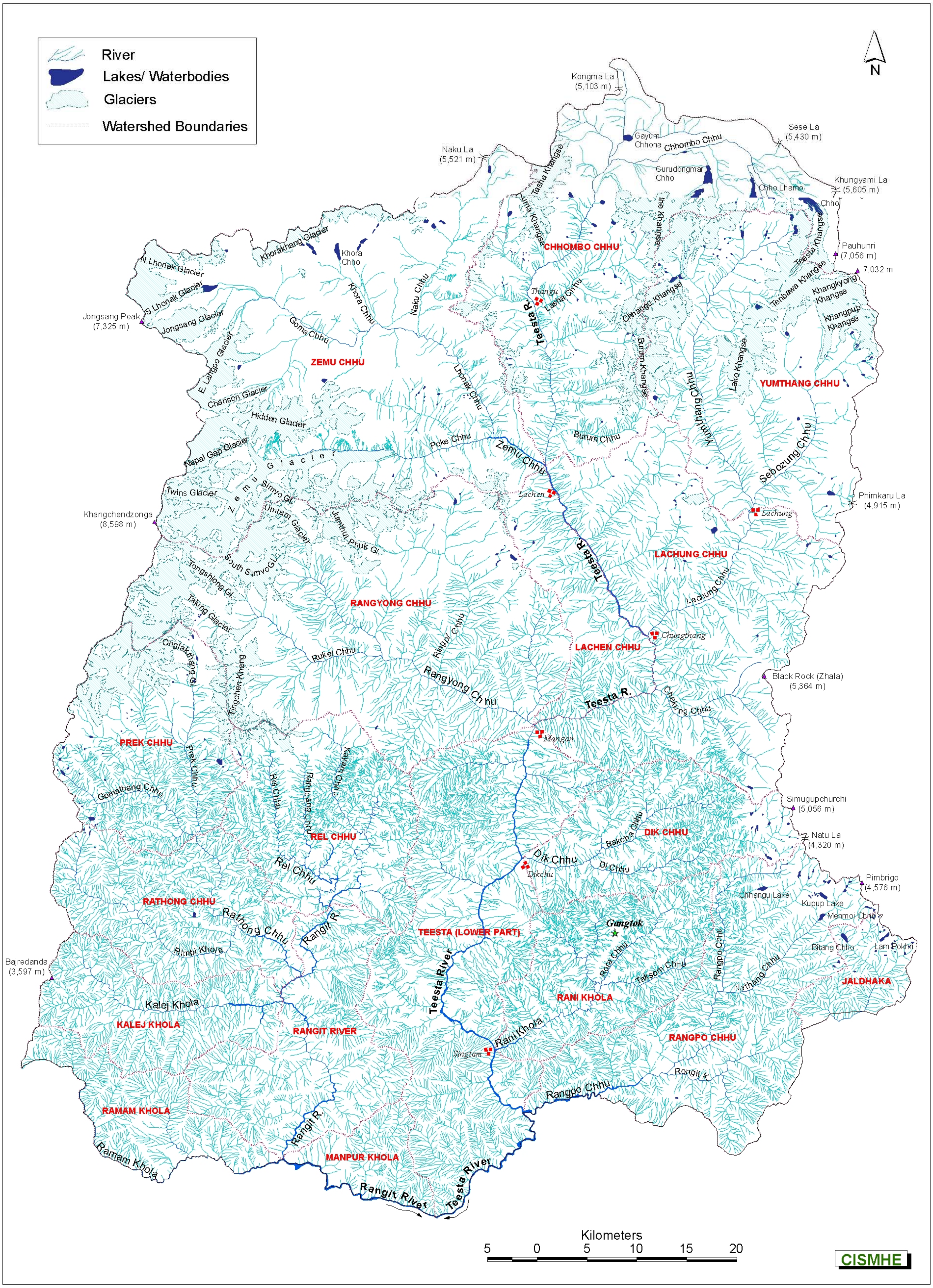


Fig.1.2 Drainage map of Teesta river basin in Sikkim

After the confluence of Lachen Chhu and Lachung Chhu at Chungthang, the river gradually widens and takes a strong westward turn upstream of Tong and after flowing down to Singhik, the river drops from 1,550 m to 750 m. At Singhik, the river receives one of its major tributaries, Rangyong Chhu on its right bank, which originates from the Talung glacier, a part of the Khangchendzonga mountain range. From Singhik, the river flows southwards to Dikchu with a 200 m drop through a very deep valley for about 30 km. From Dikchu onwards, the river takes many sharp and wide curves and flows down to Singtam with a further drop of about 200m. Rangpo Chhu, which drains the Chhangu lake area in East Sikkim joins Teesta river on its left bank at Rangpo. Downstream of Rangpo, Teesta river widens and is joined by Rangit river at Melli Bazar on Sikkim-West Bengal border. From Melli Bazar downstream, the river leaves the hilly terrain and enters the plains of West Bengal at Sevoke near Siliguri. Teesta river ultimately drains into Brahmaputra at Teestamukh Ghat (Kamarjani-Bahadurabad in Rangpu district of Bangladesh) and traverses a distance of about 400 km from its origin.

Teesta and most of its tributaries are flashy mountain rivers and carry boulders and considerable quantity of sediment. The flow is turbulent and characterised by high velocities. Throughout its course in Sikkim, Teesta and its tributaries flow in very narrow and deep valleys having precipitous hill slopes, except where the tributaries join the main stream. The hill slopes are mostly friable and landslips are very common throughout the basin.

1.5 HYDRO-METEOROLOGY

Teesta basin is characterised by frequent occurrence of extreme (catastrophic) meteorological events during monsoon season. These events lead to slope transformation accompanied with gravitation, slope wash and linear erosion under fluvo-glacial environment in North Sikkim and are mainly responsible for large quantities of silt and aggradation material which is deposited in river channels. The high rainfall (about 2,300 mm) over the steeper slopes has created a suitable environment for initiation of run-off and subsequent soil erosion, slope failures, slides or sinking of land masses in Teesta basin. Large slope areas are (glacial) morainic in nature.

1.5.1 Climate and Rainfall

Variation in altitudinal profile of the state from 213m to 8,598m in less than 100 km is responsible for abrupt changes in climatic conditions in the basin and the state. Relief features, such as high mountains act as a barrier for the movement of monsoon winds resulting in a significant variation in rainfall and temperature profiles across the Teesta basin in Sikkim.

March, April and May are the transition months between the winter, summer and monsoon. The surface temperatures start rising in late April which are accompanied by thunderstorms and hails. The rainfall in Sikkim, decreases with elevation after a certain limit. Rainfall at Chungthang (1,600 m) is 2,650 mm and at Lachen (2,730 m) being situated at a distance of only about 20 km north of Chungthang is 1,680 mm, whereas Thangu (3,800 m), located about 20 km further north receives only 840 mm of rain annually. As a result, across the altitudinal gradient of Teesta basin the southern and middle valleys are hot humid and wet, while northern parts are comparatively drier and cold.

The climate of Teesta basin in Sikkim can be categorised into four distinct seasons *viz*. i) Winter season from mid-November to mid April, ii) Spring (summer equivalent) season from mid-April to mid-June, iii) Monsoon season from mid-June to mid-September, and iv) Autumn season from mid-September to mid-November.

1.6 DEVELOPMENT SCENARIO

Sikkim is a thinly populated state with its unique environment and ecology. The population is concentrated around the capital Gangtok only and the rest of the area is occupied by forests with small villages and townships. The economy is largely agriculture and forest based with very little technologically advanced industrial base. The general economic conditions of the inhabitants of the state are average and below average. Due to the hilly terrain, the agricultural production is not sufficient even for sustaining local consumption needs of the human population. Energy needs of the region are chiefly met by petroleum products and wood based products.

In view of physical constraints to development of industries and allied economic activities the state for its economic welfare concentrates on the harnessing and exploitation of natural resources. One such important resource of the state is a massive network of rivers in the basin which provides tremendous opportunities and potential for the economic development of the state. For many years various Central and State Government agencies have proposed a model of hydropower development for Teesta basin which aims at harnessing the hydropower potential of Teesta river. Accordingly, a cascade of six power projects across the basin were proposed from North to South. Out of six proposed projects, Teesta Stage-V H.E. project, under construction by NHPC is an on-going project. However, after the Hon'ble Prime Minister's 50,000 MW initiative in 2003, number of schemes have been proposed on Teesta and its tributaries. The present study ascertains an environmentally sound development in the state.

CHAPTER - 2

CONCEPT AND METHODOLOGY

2.1 CARRYING CAPACITY

Carrying capacity of any ecological system can be defined as its ability to provide optimum support for various natural processes and allow sustainable activities undertaken by its inhabitants. It also provides for assimilation and absorption of bye-products of these activities without harming the production capability of the system. Carrying capacity of different ecosystem can be modified but is not elastic beyond a point, though the limits at a particular period of time or place can be enhanced or decreased depending on the quantum of activities undertaken. Owing to its integrated approach carrying capacity has emerged as a new and dependable tool in planning and development process which is sustainable.

In the following pages we have attempted to provide various dimensions of the carrying capacity as a concept and various methodologies for estimating the same. Though modeling is an authentic tool in making past assessments of developmental process and future projections, ecosystems tend not to fit in deterministic framework and predictive models simply because too many factors/variables in an ecosystem works singly and/or in concert. This is particularly true of natural ecosystems where processes and patterns are most often controlled by a plethora of interactions and feedback mechanisms. In the current exercise we have, therefore, tried to assess and estimate carrying capacity based on natural processes of production, consumption and assimilation. These functions have been expressed in terms of environmental sensitivity and fragility of physical, biological, socio-economic and cultural attributes of a region. Thus, more consumption than production and more waste than assimilation in a system would make the system more fragile and, in turn, it would have less carrying capacity. In contrast a system which is more productive, consumes less resources and generates less waste makes a system ecologically less fragile and has more carrying capacity.

For natural ecosystems carrying capacity can be described in terms of the following :

a) Allowance of interactions among biotic and abiotic components and absorption of bye-products of these interactions, and

b) Any changes occurring in the ecosystem must be within its resilience and without causing any impairment to the structure and functions of the ecosystem.

Based on above definition all the natural ecosystem processes, patterns and structure must be maintained by the ecosystem. Under such circumstances a natural ecosystem absorbs and assimilates any raw materials and bye-products which are formed by ecosystem processes such as weathering, decomposition, bio-geochemical cycling, regeneration, food webs and food chains, etc. It also allows perpetuation of all the life processes in the ecosystem without favoring or bias to an individual or a group of individuals.

For a managed ecosystems, particularly those inhabited by humans, carrying capacity can be defined in terms of maximum rate of resource utilisation, consumption and generation of bye-product of this activity (waste) which is discharged into the system, without causing any imbalance and negative impact on any one of the life supporting environmental resources. The survival of human societies, their economic and physical well-being depend on availability of different environmental resources. Most of the human activities are, therefore, linked to the unhindered supply of natural goods and services. However, it needs to be understood that these goods and services from natural environment cannot flow in unlimited quantities for unlimited period of time and for unlimited number of human individuals. One or many of these vital life supporting natural products could be in short supply in time and space resulting from over-exploitation of natural depletion. It is, therefore, important to emphasize that the carrying capacity of a system may be ultimately governed by a resource which is in the least supply. In other words, the rate of development would be determined by the resource which is least available. Depending on the time or place, it could be air, water, land, biomass, etc. which would determine the carrying capacity of a region/system. For a sustainable society, it is, therefore, important that human activities must be carried out within the carrying capacity of its environmental resources. Though we may be able to increase the carrying capacity of a system through technology innovations, management practices, conservation measures but in the final analysis it can not be elastic beyond a limit.

Carrying capacity as a concept, therefore, envisages betterment in the living standards of individuals through development processes which is based on sound and sustainable use of environmental resources. This paradigm of development takes into account the concerns, aspirations and expectations of human populations living within ecological resilience of a system. Like a natural ecosystem it must balance production and waste, demand and supply, availability of amenities and their use and must aim at becoming a homeostatic system. Such a system would be sustainable and just, keeping in view the intergenerational equity by ensuring resource availability for future generations.

2.2 DEVELOPMENTAL PLANNING AND CARRYING CAPACITY

The aim of this exercise is to achieve the goal of development which is simple to understand, easy to execute, locally relevant and economically viable. To determine the limits of development we must estimate the carrying capacity of a region/system and only then plan a developmental process which is sustainable. The concept of carrying capacity does not undermine a system's ability to allow production of goods and services from the existing quantity and/or quality of environmental resource base without compromising on the improved quality of life. On the other hand, it ensures that there is no impairment of the environmental quality of the system. In addition to this, it must also provide for the possibility of regeneration, rejuvenation, reinforcement and alleviation through additions (imports) and removals of resources, services, management and technology interventions, etc. Though carrying capacity envisages a framework for planning and development within the sustainable resource consumption pattern, it can not completely wash away the loss of existing resource base or its quality. It is, therefore, necessary to understand that a likely scenario would develop in which necessary trade-offs between consumption patterns and conservation levels are provided for.

In some of the past studies the operational framework for the internalization of the concept of carrying capacity in decision-making related to developmental planning involved :

- Estimation of supportive capacity
- Estimation of assimilative capacity
- Allocation of resources to various socio-economic activities for maximization of the quality of life.

In the present context, however, we have attempted to determine carrying capacity in terms of the following :

- Inventorisation and analysis of the existing resource base and its production, consumption and conservation levels
- Determination of regional ecological fragility/sensitivity based on geo-physical, biological, socio-economic and cultural attributes
- Analysis of the existing and projected developmental profile of Teesta basin in view of its geo-biological setting, ecological sensitivity and socio-economic aspirations

- Estimation of existing quality of life (QOL) of human population in the basin as also their perceived and preferred QOL scenarios
- Preparation of comprehensive evaluation reports for major proposed developmental projects within the carrying capacity framework.

The ecological fragility/sensitivity of the basin will be evaluated through analysis of data on the following parameters :

- Geological and physical features including seismicity and seismic history
- Natural hazards phenomena and land instability including landslides/landslips
- Drainage, hydrology, hydrometeorology, sedimentation in river systems
- Landuse and landcover through remote sensing and GIS
- Demographic evaluation of extant, endemic, endangered, keystone species
- Evaluation of past, continuing, proposed development activities and human interventions in the basin
- Evaluate people's aspirations for better quality of life and integrate these in sustainable development plan.

The attributes of various environmental resources and human activities have been presented in the form of a model used in the present study for estimation of carrying capacity. A schematic presentation of the model is depicted in Figure 2.1.

2.3 EXISTING ENVIRONMENTAL RESOURCES BASE

A detailed account of environmental resource base in terms of air, water, land including biotic resources, socio-economic and quality of life is provided for determining the quality and quantity of available resources for use in the process of planning and development. This body of data does not only aim at inventorisation of resources but also gives detailed analysis of the prevailing environmental resource base and environmental quality of the basin. This data would ultimately help us identify limiting resources as also the environmentally critical areas which can be delimited as hot spots for conservation or remediation. The evaluation of resources would also lead to understanding the impacts of various developmental activities on these resources on one hand and the planning process on the other. In the final analysis evaluation of the entire environment resource base *vis-a-vis* various developmental activities would provide a scientific basis for developing management plans and alternate development plans for critical environmental resources and areas.

2.3.1 Air Environment

Though air pollution is not so far an area of critical concern of critical importance in the Teesta basin in Sikkim, yet it was considered

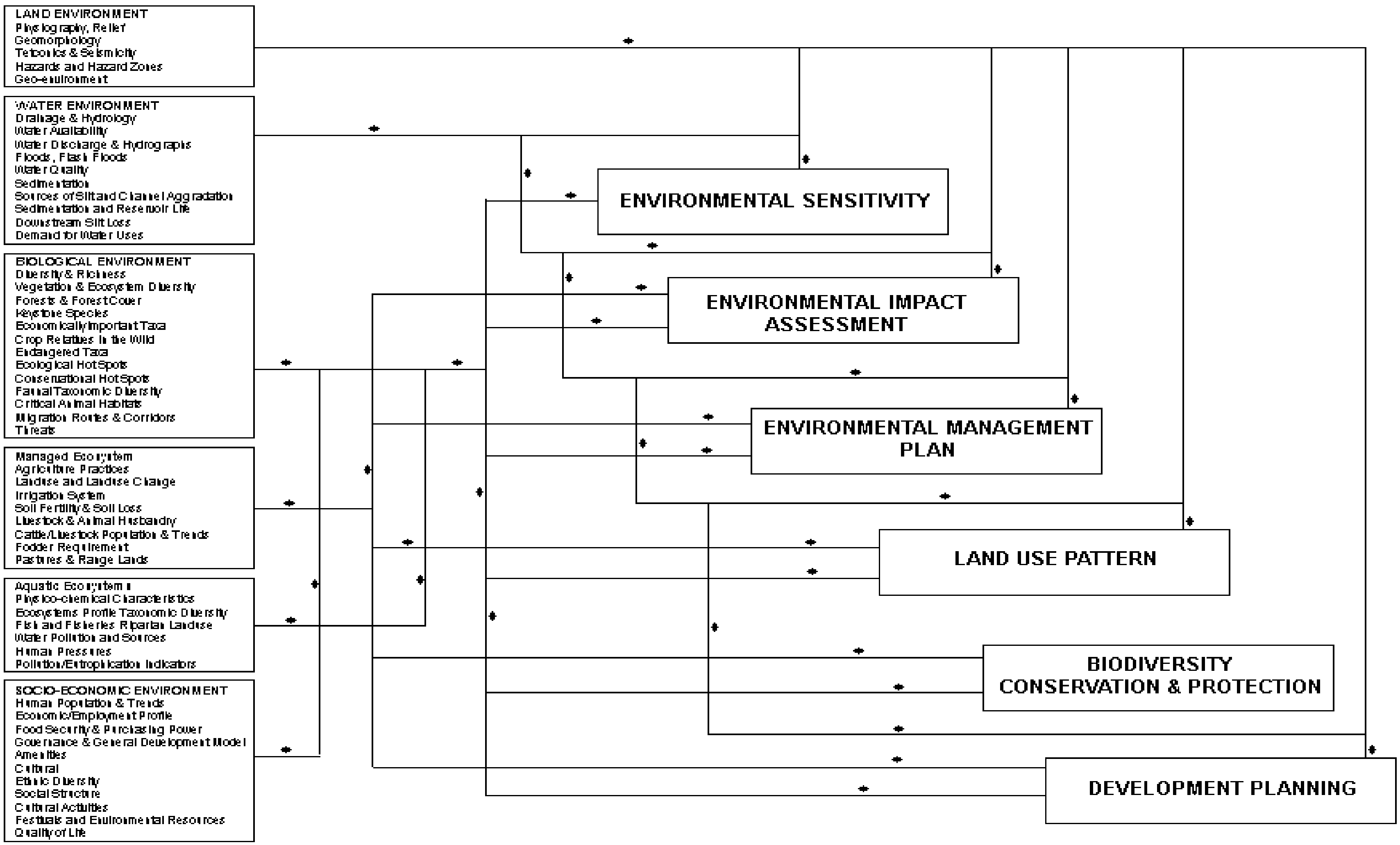


Fig.2.1 Schematic presentation of the model used for estimating Carrying Capacity

important to evaluate the resource for future development scenarios. The air environment has been assessed for the following :

- Ambient air quality
- Pollution sources
- Air environment sensitivity analysis

In order to collect data for air environment the following standard methodologies were followed :

- Delineation of air sheds based on topography, identification of micro-climatic zones and wind fields data
- Inventorisation of point, area and line sources of pollution and estimation of pollution loads
- Temporal and spatial variations in air pollutant concentration for existing sources using multiple source-receptor model to establish sources-receptor relationships
- Estimation of air environment sensitivity in critical micro-climatic zones for various pollutants *vis*-a-*vis* air quality standards for sensitive receptors
- Quantification of upper limits of pollution load in critical pockets

2.3.2 Water Environment

Water is the key resource of Sikkim and majority of present and future developmental activities revolve around this resource. This may not be a critical resource from environmental point of view at present, but it is surely a critical economic resource for the state. Any resource utilisation, consumption and conservation must take into account both the ecological as well as economic criticality of this resource. The present study has focused on evaluation of water environment in the basin in terms of the following :

- The drainage characteristics of the basin which include surface water bodies like rivers and lakes, underground drainage of various types and origins
- Nodal points of water resources
- Precipitation of rainfall and drainage during dry and/or non-dry periods
- Seasonal flows of water bodies (lakes including glacial lakes, rivers, ponds, etc.) and estimation of flood levels
- Water availability at various points and estimation of 75% and 90% dependable discharge
- Estimation of sediment load at various points in the basin and its qualitative analysis and seasonal flow of silt
- Water availability and demand for various sectors
- Inventorisation of point and non-point sources of pollution
- Quantification of upper limits of pollution load in various stretches

2.3.3 Land Environment

Keeping in view the mountainous terrain of the basin it is pertinent to consider land environment as a critical resource for developmental activity. The criticality of land for developmental purposes has to be understood in terms of its fragility, capability and availability. In order to classify the land as ecologically fragile, production-wise capable and resource-wise available, it is important to understand the physical nature in terms of basic landforms, physiography, rock types, tectonic processes, hazardous phenomena as also the soil types. To ascertain the existing levels of land resource exploitation a landuse/land cover map is a pre-requisite for estimating the existing scenario and projecting the future scenario of development. A detailed account on various physical features, processes and activities of the basin's land environment have been evaluated for following attributes for estimating ecological sensitivity/fragility of land resource. It included the following considerations :

- Preparation of a base map delineating major watersheds of the Teesta basin
- Watershedwise slope, aspect, elevation profile and preparation of digital elevation models at 1:50,000 and/or 1:25,000 scale
- Mapping of erosion prone areas, old and active landslides using merged LISS-III and PAN data at 1:50,000 scale
- Preparation of watershedwise detailed soil maps
- Mapping of important zones of crustal weakness in terms of structural discontinuities, thrust, shear, ductile zones
- Mapping of river terraces, moraine deposits including glacial moraines
- Regional stratigraphic - tectono-stratigraphic succession along south-north Sikkim Himalaya for estimation of possibility of tectonic diverticulation

- Seismo-tectonic map of the basin including micro-seismic activities and seismic history
- Physical environmental/ecological sensitivity analysis.

2.3.4 Biological Environment

Sikkim is one of the most important areas of biological importance and has been classified as a global hot spot for biodiversity conservation. The importance of assessing the status and nature of biological diversity including ecosystem diversity of Teesta basin, therefore, can not be over- emphasized. A great variation in the agro-climatic conditions of the basin have given rise to a myriad ecosystems from hot humid tropics and sub-tropics to frigid alpine areas in the state of Sikkim. It is, therefore, important to understand that biological resource holds an important place in the planning and developmental process of Sikkim. In order to achieve a balancing act of conserving the biological diversity and ensuring economic gains from conservation and also utilisation of biological resource, it is essential to assess the existing biological environment base of the basin. To achieve this objective following aspects of biological environment have been evaluated in the study :

- Inventorisation of floral and faunal species diversity in terrestrial, aquatic and aerial ecosystems
- Identification and mapping of endangered rare taxa of conservational and economic significance

- Identification of hot spots for conservation and sustainable exploitation
- Landuse and vegetation mapping including forest cover
- Biological sensitivity analysis of ecosystems/areas where developmental projects are proposed
- Identification of potential areas for eco-tourism
- Identification of potential biological resources for economic welfare of local population and industrial use

2.3.5 Socio-economic Environment

The human population density, demographic profile, cultural practices and the associated activities play the most crucial role in shaping the nature of environmental resources of land, air and water of a region. In highlands particularly, there are even more profound results on these resources arising out of human activity. The Teesta basin in Sikkim exhibits varied demographic profiles and patterns in various districts and along the altitudinal gradients. The state is also rich in cultural and ethnic diversity besides being rich in water and biological resources. For any planning and development process to be successful and meaningful it is essential to understand the existing socio-economic resource base and levels of its exploitation by the human population. Linked to it is the quality and quantum of services and amenities provided by the state for providing better quality of life to the human population. Since human ecosystems are heavily loaded towards producing higher quantities of waste as a result of various activities it is important to assess the consumption and waste production levels and suggest measures to reduce pollution loads in land, air and water resources. To evaluate the socio-economic environment in this study following parameters have been considered relevant to the carrying capacity study.

- Assessment of human population density and population growth
- Economic profile of human population living in various districts and sector-wise employment and employment potential
- Man land ratio across the population profile
- Evaluation of agricultural practices, food production *vis*-a-*vis* land capability and agricultural productivity
- Distribution pattern of input resources in agriculture *vis*-a-*vis* socio-economic profile of the population
- Agricultural productivity and carrying capacity
- Evaluation of amenities and services provided by the state in terms of educational, health, communication and other facilities
- Assessment of quality of life in terms of existing scenario, perceived scenario and preferred scenario

CHAPTER - 3

PROPOSED POWER DEVELOPMENT PROFILE OF TEESTA BASIN

3.1 POWER DEVELOPMENT SCENARIO

The power situation of Sikkim before its merger with India in 1975 was in its infancy because of low demand. The power requirement of Gangtok and a few townships located on the national highway was met from the small 2.1 MW Jali Power House commissioned in 1964. Also, a small Diesel Powerhouse was used as a standby to meet the requirement during emergencies. Similarly, Roathak (South) and Rimbi (West) micro hydels with an installed capacity of 200 KW each were under operation to feed District Headquarters and major townships in the South and West districts, while the North district had to manage with a 50 KW micro hydel unit known as Manul micro hydel, which has since become inoperative. Till the end of 1975, there were only 8 declared towns that used electricity in Sikkim, while rest of the areas had no power supply.

Till the end of 1979, the state had a total power generation capacity of only 3 MW to meet the increasing demand of the state and hence drastic load shedding had to be resorted to. Thereafter, the state undertook the extension of electrification to small townships and villages at a faster pace. Today, the state has an installed capacity of 39 MW as given in Table 3.1.

Table 3.1 Installed capacity in power projects (in MW)

Sl. No.	Name of Scheme	Capacity	
		Installed	firm
1.	Rongni Chhu (Stage-I) Jali Power House	2.10	1.20
2.	Lower Lagyap Hydel project	12.00	5.50
3.	Rongni Chhu (Stage-II)	2.50	1.20
4.	Rimbi (Stage-I)	0.60	0.30
5.	Rimbi (Stage-II)	2.50	1.20
6.	Lachung Micro-hydel scheme	0.20	0.10
7.	Lachen Microhydel scheme	0.10	0.05
8.	Lachung Micro-hydel scheme	0.20	0.10
9.	Mayong Chhu H.E. project	4.00	2.00
10.	Upper Rongni Chhu	8.00	4.00
11.	Kalej Khola H.E. project	2.00	1.00
12.	Diesel Power House, Gangtok	4.00	Stand by
13.	Diesel Power House, LLHP	1.00	Stand by
	Total	**39.20**	**22.00**

(Source: Department of Power, Government of Sikkim, Gangtok)

Besides, the state's share in Chhukha Hydel Project, Bhutan (5 MW) and Farakka Super Thermal Power Station (7.20 MW), Raman Hydel Project (10 MW) and Rangit Hydel Project (7.20 MW) are drawn through the West Bengal transmission system. However, the experience with these drawals has not been satisfactory as they are marred by frequent interruptions due to tripping, etc. Even otherwise, the existing transmission system of West Bengal looks weak and dependence on such a network for drawal of the state's share of Central Sector power would always be subject to disruption.

3.2 POWER REQUIREMENT

The estimated peak shortfall in Sikkim has increased almost three-fold from 5.7 MW in 1988-89 to about 15 MW at present. The average annual growth rate of this shortfall (12.32 %) has been almost double that of the average growth rate in installed capacity up to 1998 as indicated in Table 3.2.

Table 3.2 Power requirements of Sikkim state

Year	Installed Capacity (MW)	Growth Rate (%)	Peak Shortfall (MW)	Growth Rate (%)
1988-89	21.50		5.70	
1989-90	21.60	0.47	8.60	50.88
1990-91	21.60	0.00	11.60	34.88
1991-92	21.80	0.93	11.35	-2.16
1992-93	31.80	18.35	9.35	-17.62
1993-94	33.80	23.26	8.35	-10.70
1994-95	35.80	6.29	9.35	11.98
1995-96	35.80	5.92	10.35	10.70
1996-97	38.10	0.00	12.35	19.32
1997-98		6.42	14.03	13.60
Annual Growth Rate		6.85		12.32

(Source: Annual Report 1996-97 & 1997-98, Power Department, Gangtok, 1999).

The nationwide problem of massive transmission and distribution losses also plagues Sikkim state. To minimize such losses upgradation of the existing system of transmission voltage to a suitable grade after load flow is essential. Introduction of 132 KV transmission lines and extension of Eastern Regional grid up to Melli and Gangtok, and upgradation of sub-stations and distribution lines including energy audition, etc. at all levels of generation, transmission and distribution up to the consumers' premises are other primary requirements.

In view of the anticipated development in the industrial sector and also growing urban, domestic and rural needs, the present not so reliable and inadequate power supply has been a major reason for the state's power economic development. It has also affected private investments in the state. In fact, even without further industrial expansion, the peakload demand of the state by 2002 is expected to reach 60 MW. The state has to be geared to generate this power for its economic welfare.

3.3 HYDRO POWER POTENTIAL IN TEESTA BASIN

The topography and resource availability in the Teesta basin makes development of thermal or petroleum based power development very expensive and environmentally unsustainable. The increase in the power demands can, therefore, be met quite profitably by the development of hydro-power. The surplus power will enable the state to earn a substantial amount of revenue which can be utilised for the much needed economic upliftment of its inhabitants.

The river Teesta has great potential for development of power, as the river descends from an elevation of about 5200 m to about 300 m over a distance of about 175 km. According to the preliminary reconnaissance survey by the team of experts of erstwhile Central Water & Power Commission in 1974, the river could be harnessed under a cascade development for hydro-power generation. The hydro-electric potential of the Teesta and its tributaries in Sikkim was estimated at about 3735 MW (Table 3.3) (Fig. 3.1). The cascade development consists of power generation in six stages along Teesta river. In addition Sikkim Power Development Corporation had identified more schemes to be developed with the help of private agencies. Recently under the Hon'ble Prime Minister's 50,000 MW, ten schemes were proposed for pre-feasibility studies. All these schemes have been described in brief below.

3.3.1 Schemes indentified by CWC

3.3.1.1 *Teesta Project Stage-I*

Under this stage of development, it is proposed to divert the waters of Lachen Chhu (Teesta), Lhonak Chhu and Poke Chhu by constructing diversion structures and inter-connecting tunnels. The combined water to be dropped at Lachen Chhu to generate power. The diversion weirs across Poke Chhu, Lhonak Chhu and Lachen Chhu would be located at an elevation of nearly 3300 m. At powerhouse site, the drop of about 730 m would be available. Estimated dependable discharge would be of the order of 17 cumec which may generate 96 MW of firm power with an installed capacity of 390 MW.

3.3.1.2 *Teesta Project Stage-II*

Under stage-II, it is proposed that the tail race waters of Lachen Chhu would be picked up near Chhatten village and diverted through a

Fig. 3.1 Proposed hydro-power development model in Teesta river basin in Sikkim

tunnel. A second weir across the Lachung Chhu at Lachung would divert the waters through another tunnel. The combined waters would be utilised to generate power in a powerhouse located upstream of Chungthang. The gross head available at the powerhouse would be about 1100 m with a power draft of about 26 cumec. This is expected to generate 224 MW of firm power with an installed capacity of 330 MW. In absence of a possible site for constructing a balancing reservoir, Stage I & II schemes may have to be operated as run-of-the-river schemes for base load generation.

3.3.1.3 *Teesta Project Stage-III*

Under this stage of development, which is the most ambitious and economic one, the waters of Teesta would be diverted through a 12.93 km long tunnel by constructing a dam downstream of Chungthang. The waters will be dropped through a height of about 800 m at the proposed power house located at an elevation of about 780 m in the left bank hill of Rangyong Chhu (Talung Chhu), about 700 m upstream of its confluence with Teesta. The proposed surge shaft, powerhouse and penstock will be underground. As this powerhouse will be utilised as the peaking station for the North Eastern grid, the installed capacity of the project has been proposed at 1200 MW.

3.3.1.4 *Teesta Project Stage-IV*

In this scheme, the tail race waters from powerhouse of Teesta project Stage-III will be picked up by a diversion structure downstream of confluence of Rangyong Chhu and Teesta and diverted through a tunnel leading near Dik Chhu where a firm power of 85 MW is proposed to be generated with an installed capacity of 495 MW. This will involve construction of a 11.3 km long tunnel. The dependable discharge would be of the order of 56 cumec with available gross head of 194.5 m.

3.3.1.5 *Teesta Project Stage-V*

This project is already under execution by NHPC. Under this stage of Teesta basin development, the waters of Teesta are being diverted through a tunnel of about 15 km length by constructing a dam at Dikchu immediately below the confluence of Dik Chhu with Teesta. The dependable discharge available throughout the year has been assessed at 42 cumec and the gross head available is 198 m. The power house is located near Singtam about 4 km upstream of the confluence of Rongni Chhu (Rani Khola) and Teesta and is expected to generate 72.4 MW of firm power with an installed capacity of 510 MW.

3.3.1.6 *Teesta Project Stage-VI*

In the river stretch downstream of Singtam, it is proposed to utilise the drop of about 70 m of water between Singtam and Rangpo by diverting the Teesta river through a suitable 4.3 km long water conductor system. The powerhouse would generate about 55.5 MW of firm power and an installed capacity of 440 MW.

Thus, this proposed model envisages to generate a large quantity of hydro-power to the tune of about 3735 MW (see Table 3.3) in the state. This development scheme is expected to be a boon for socio-economic development of this small state. Various stages of Teesta Basin hydro-electric power development are indicated in Fig.3.1.

Table 3.3 Estimated Hydro-power Potential in Sikkim State

S.No.	Name of Project	Installed Capacity (MW)
A.		
1.	Teesta Hydel Project Stage-I	320
2.	Teesta Hydel Project Stage-II	330 ?
3.	Teesta Hydel Project Stage-III	1200
4.	Teesta Hydel Project Stage-IV	495 ?
5.	Teesta Hydel Project Stage-V**	510
6.	Teesta Hydel Project Stage-VI	440
Total A		**3295 ?**
B*.		
7.	Rolep H.E. Project**	32
8.	Ralang H.E. Project	40
9.	Chakung Chhu H.E. Project	50
10.	Chuzachen H.E. Project	99
11.	Sada Mangder H.E. Project	71
12.	Bhasmey H.E. Project	32
13.	Rangit Stage-II H.E. Project	60
14.	Rangit Stage-IV H.E. Project	90
15.	Jorethang Loop HEP	96
Total B		**570**
C. Pre-feasibility Studies		
1.	Jedang H.E. Scheme†	185
2.	Talem H.E. Scheme†	75
3.	Rongni H.E. Project	95

4.	Ringpi H.E. Scheme	160
5.	Dik Chhu H.E. Power Project	90
6.	Lachen H.E. Scheme	210
7.	Lingza H.E. Scheme	160
8.	Rangyong H.E. Scheme	90
9.	Talem H.E. Project	75
10.	Rukel H.E. Scheme	90
11.	Panan H.E. Scheme	200
Total C		**1430**
Total A + B + C		**5295**

A = Schemes identified by Central Water Commission

B = Schemes being promoted by private agencies

C = Schemes identified under Hon'ble Prime Minister's 50,000 MW initiative

* The list is incomplete

** Under construction

† These schemes are modified version of original Teesta Stage-I and Stage-II schemes

3.3.2 Schemes Proposed by SPDC

3.3.2.1 *Rolep Stage-I H.E. project*

The proposed Rolep H.E. Project of 32 MW capacity on Rangpo Chhu is located near Rolep village, Tehsil Rongli, East District in Sikkim. The proposed dam site (1284 m) is located about 3-4 km upstream of Rolep village situated on the left bank of Rangpo Chhu, downstream of the confluence of Rangpo Chhu and Nathang Chhu. The power house (940 m) would be located in an underground cavern about 5.4 km downstream of the proposed dam site on the left bank of Rangpo chhu. A head race tunnel of 5 km length is proposed.

3.3.2.2 *Ralang Stage-I H.E. project*

The proposed Ralang H.E. project of 40 MW capacity is located near Polaut village, tehsil Ralong, Sub-division Rabong, South Sikkim district. The proposed dam site is located at the foot of Polaut about 500m downstream of the confluence of Rel Chhu with Rangit river. The water of Rangit river would be diverted through 5.0 km long head race tunnel and conveyed to an underground powerhouse. The powerhouse is proposed to be in an underground cavern about 5 km downstream of the proposed dam site on the left bank of Rangit river. The project envisages generation of 40 MW of electricity.

3.3.2.3 *Chakung Chhu Stage-I H.E. project*

The proposed Chakung Chhu H.E. Project of 50 MW capacity on Chakung Chhu river is located near Tong village, tehsil Chungthang, North Sikkim district. The proposed dam site (1,950 m) is located about 3-4 km upstream of Tong village and the powerhouse (1,320 m) would be located about 3 km downstream of the proposed dam site near Tong village. A head race tunnel of 3 km length is proposed.

3.3.2.4 *Chuzachen H.E. project*

Chuzachen H.E. project is located downstream of the under construction Rolep H.E. project. It envisages construction of two dams, dam-I on Rangpo Chhu intakes through Rangpo and dam-II on Rongli with head race tunnels of 2.6 km and 2.3 km long, respectively. The powerhouse is proposed on the left bank of Rangpo Chhu with an installed capacity of 99 MW.

3.3.3 Under 50,000 MW initiative

3.3.3.1 *Jedang H.E. Scheme*

Jedang H.E. scheme is one of the various projects proposed in the higher reaches of Teesta river basin in Sikkim. It is a modified version of earlier Teesta Stage-I. The proposed project envisages construction of a dam upstream of confluence of Lhonak Chhu with Zemu Chhu in North Sikkim. The project involves construction of diversion structure and diversion of water through a head race tunnel of about 9 km length. The powerhouse is proposed near the confluence of Lhonak Chhu with Zemu Chhu on its left bank. The proposed project envisages power generation of 185 MW.

3.3.3.2 *Teesta Stage-I H.E. Scheme*

Teesta Stage-I H.E. scheme envisages construction of two dams, i.e. dam-I to be located downstream of confluence of Lhonak Chhu with Zemu Chhu and dam-II downstream of the confluence of Chento Chhu with Teesta river in North Sikkim. The project involves construction of 40 m high dam-I and diversion of water to the dam-II reservoir through a 3.5 km long link tunnel. The water from the 45 m high dam-II is proposed to be diverted through a 3.5 km long head race tunnel. An underground powerhouse is proposed immediately upstream of Zema on the right bank of Teesta river. The proposed project envisages power generation of 300 MW.

3.3.3.3 *Rongni H.E. Project*

Rongni H.E. Project is located 700 m downstream of the confluence of Rongni Chhu (Rani Khola) and Andheri Khola near Namli township in East Sikkim. The project involves the construction of a diversion structure on Rongni Chhu and 10 km long head race tunnel with power house to be located on the right bank of Rangpo Chhu near Bhasme village. The proposed project envisages power generation of 95 MW. This scheme has now been revised as Rongni H.E. Project with dam site located near village Namli with very little submergence with envisaged power generation of 96 MW.

3.3.3.4 *Ringpi H.E. Scheme*

Ringpi H.E. scheme is located downstream of the confluence of Jumthul Chhu and Kishong Chhu in North Sikkim. This is one of the high altitude hydro-electric schemes proposed on Rangyong Chhu or its tributaries. The project involves construction of a diversion dam immediately downstream of the confluence of the two streams, Jumthul and Kishong and a 7.0 km long head race tunne. The dam site is to be located near the Talung village in Sakyong Pentong Revenue Block at the confluence of Jumthul Chhu and Kishong Chhu. The power house is located on the right bank of Ringpi Chhu about 2 km upstream of Shabrung village. The proposed project envisages power generation of 160 MW.

3.3.3.5 *Dik Chhu H.E. Scheme*

Dik Chhu H.E. scheme is located 100 m downstream of the confluence of Dik Chhu/ Rate Chhu and Bakcha Chhu near Phodong township in North Sikkim. The project involves the construction of a diversion structure on Dik Chhu and 7.5 km long head race tunel with power house proposed on the left bank of Teesta river at the confluence of Dik Chhu with Teesta river near Dikchu town. The proposed project envisages power generation of 90 MW.

3.3.3.6 *Lachen H.E. Scheme*

Lachen H.E. scheme envisages construction of a dam downstream of confluence of Zemu Chhu with Teesta river in North Sikkim. The project involves construction of diversion structure and diversion of water through a head race tunnel of about 4.5 km length. The power house is proposed near village Bonsoi upstream of Teesta Stage-II project site. The proposed project envisages power generation of 210 MW.

3.3.3.7 *Lingza H.E. Scheme*

Lingza H.E. scheme is located on Ringpi Chhu in North Sikkim. The proposed project is located on Ringpi Chhu. The project involves construction of a diversion structure immediately downstream of the power house of proposed Ringpi H.E. scheme with a 4.0 km long head race tunnel for carrying waters to a power house to be located on the left bank of main channel Rangyong or Talung Chhu about 2 km upstream of Lingza village. The proposed project envisages power generation of 160 MW.

3.3.3.8 *Rangyong H.E. Scheme*

Rangyong H.E. scheme envisages construction of two dams, i.e. upper dam to be located immediately downstream of confluence of Umram Chhu and Passaram Chhu in North Sikkim and lower dam on Rangyong Chhu upstream of the confluence of Umram Chhu with Rangyong Chhu. The project involves construction of 55 m high upper dam and diversion of water to the lower dam reservoir through a 2 km long link tunnel. The water from the 55 m high lower dam is proposed to be diverted through a 7.5 km long head race tunnel. An underground power house is proposed immediately upstream of the reservoir of Panan H.E. scheme. The proposed project envisages power generation of 90 MW.

3.3.3.9 *Talem H.E. Project*

Talem H.E. project envisages construction of a rockfill dam downstream of confluence of Kalep Chhu with Teesta river in North Sikkim. The project involves construction of a 50 m high dam on Teesta river and diversion of water through a head race tunnel of about 4.5 km length. An underground power house is proposed near village Talem upstream of the proposed Teesta Stage-I project site on the right bank of Teesta river. The proposed project envisages power generation of 75 MW.

3.3.3.10 *Rukel H.E. Scheme*

Rukel H.E. scheme is located downstream of confluence of Rukel Chhu and Rangyong Chhu in North Sikkim. This is the uppermost hydro-electric scheme proposed on Rangyong Chhu. The project involves construction of a diversion dam immediately downstream of the confluence of the two streams and a 4.0 km long head race tunnel. The proposed project envisages power generation of 90 MW.

3.3.3.11 *Panan H.E. Scheme*

Panan H.E. scheme is located about 1.75 km downstream of the confluence of Rangyong Chhu (Talung Chhu) and Ringpi Chhu near Lingah village in North Sikkim. The project involves the construction of a diversion structure on Rangyong Chhu and a 9.0 km long head race tunnel with underground power house proposed on the right bank of Teesta river at the confluence of Talung Chhu with Teesta river near Panan town. The proposed project envisages power generation of 200 MW.

CHAPTER - 4

TEESTA RIVER SYSTEM - THE STUDY AREA

4.1 INTRODUCTION

Teesta river originates as Chhombo Chhu from a glacial lake Khangchung Chho at an elevation of 5,280 m in the northeastern corner of the state. The glacial lake lies at the snout of the Teesta Khangse glacier descending from Pauhunri peak (7,056 m) in north western direction. Teesta Khangse glacier and Chho Lhamo are also considered as the source of Teesta river by many authors. Along its traverse from its origin to the plains, the river receives drainage from a number of tributaries on either side of its course. The tributaries on the eastern flank are shorter in course but larger in number whereas the tributaries on the western flank are much longer with larger drainage areas, consequently contributing much more amount of discharge to the main Teesta river. Furthermore, right-bank tributaries drain heavily glaciated areas with large snow-fields. The left bank tributaries, on the other hand, originate from semi-permanent and much smaller snow-fields as compared to right bank tributaries. The major tributaries of Teesta river are listed in Table 4.1. For better understanding of Teesta river system, it has been divided into a number of river sub-systems which are described in the succeeding paragraphs. These sub-systems are: i) Chhombo Chhu/ Teesta river upstream of Zemu Chhu-Teesta confluence, ii) Zemu Chhu, iii) Teesta river between Lachen and Chungthang, iv) Lachung Chhu, v) Chungthang-Mangan and Chakung Chhu sub-system, vi) Rangyong (Talung) Chhu, vii) Dik Chhu, viii) Teesta river between Mangan and Singtam, ix) Rani Khola, x) Teesta river between Teesta-Rani Khola confluence and Teesta-Rangpo Chhu confluence, xi) Rangpo Chhu, xii) Rangit River, and xiii) Jaldhaka River. A brief description of each of these sub-systems is given in the following paragraphs.

Table 4.1 Major tributaries of Teesta river

S.No.	**Tributaries**	
	Left-bank tributaries	**Right-bank tributaries**
1.	Lachung Chhu	Zemu Chhu
2.	Chakung Chhu	Rangyong Chhu
3.	Dik Chhu	Rangit River
4.	Rani Khola	
5.	Rangpo Chhu	

4.2 CHHOMBO CHHU/TEESTA RIVER UPSTREAM OF ZEMU CHHU-TEESTA CONFLUENCE

This sub-system comprises the source of the main Teesta river system (Fig. 4.1). Originating from Khangchung Chho (5,280 m) the Teesta river flows as Chhombo Chhu towards the northwest. After flowing for about 5.7 km, the river receives drainage from Chho Lhamo, a glacial lake (4820 m), and then it flows predominantly in western direction. Along its course, water from Gurudongmar lake (5100 m) drains into Chhombo Chhu through a small stream. On its westward journey from this point, the river receives water from a number of small

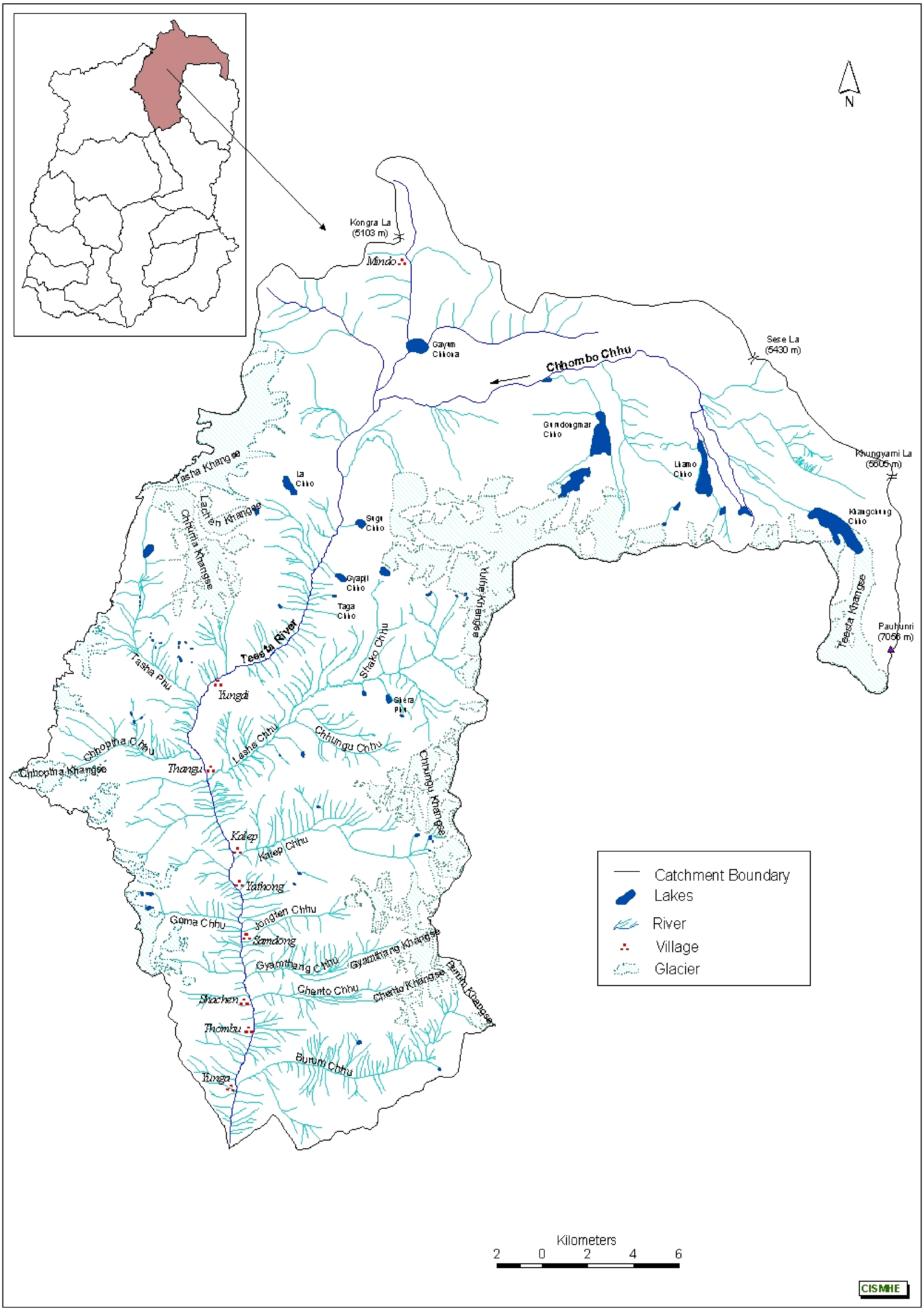


Fig.4.1 Drainage map of Chhombo Chhu watershed of Teesta river basin in Sikkim

streams joining it on either side. The river changes its course towards southwest near Oakra, where it receives drainage from a stream flowing from Gayum Chhona lake on its right bank. Thereafter, south of Oakra, Chhombo Chhu flows as Teesta river. About 6.4 km downstream of Oakra, a stream draining Sugu Chho joins Teesta river at its left bank at 4,620 m. A little further downstream of this confluence, a stream draining Gyapji Chho lake joins the river on its left bank at 4,540 m and another stream coming out from Lachen Khangse glacier (5,100 m) joins the river at 4,550 m on its right bank. From this point the river flows towards southeast through an arcuate valley for about 7.3 km where a stream with its head waters at Chhuma Khangse glacier (4,800 m) confluences on its right bank at 4,220 m. Along this arcuate valley several small streams join the river on either bank. After about another 2 km from this confluence Tasha Phu with its head water at Tasha Khangse (4,840 m) joins the river on its right bank at 4,090 m near Yongdi. At about 3 km downstream of Yongdi, Chhoptha Chhu which has its headwaters at Chhobu Khangse (>5000 m) flowing towards east joins Teesta river at 4,100 m downstream (~0.9 km) of Chhoptha. A little distance downstream, Lasha Chhu joins Teesta river at 3,835 m near Thangu. Originating from Yulhe Khangse at >5000 m, Lasha Chhu flows towards southeast for 17.8 km. In its initial course it is known as Shako Chhu which after joining the tributary Chhungu Chhu (5 km long) flows as Lasha Chhu for a distance of 4.5 km. About 3.6 km downstream of its confluence, Kalep Chhu joins the Teesta river on the left bank at 3,648 m. Kalep Chhu is a short course glacier-fed stream (10.6 km). After flowing about 3.0 km from Kalep Chhu confluence, Teesta is joined by Goma Chhu at 3,500 m. Further downstream at 3.0 km and 3.8 km two snowfed rivers, Goma Chhu and Jongten Chhu join Teesta river at 3,500 m and 3,455 m, respectively. Gyamthang Chhu, originating from Gyamthang Khangse glacier above 4,600 m traverses a distance of about 16 km to join Teesta river on its left bank at 3,310 m near Chhochen. Two streams, Chento Chhu and Burum Chhu drain Chento Khangse and Burum Khangse glaciers, respectively and merge with Teesta river on its left bank at Shacham and Yunga villages. Thereafter, Teesta river flows for a distance of about 2.5 km and is joined by Zemu Chhu on the right bank at 2,675 m near Zema.

4.3 LACHUNG CHHU

Lachung Chhu sub-system, is one of the main drainage system contributing to the discharge of Teesta in upper reaches. Lachung Chhu in its initial stretch is known as Yumthang Chhu formed by the confluence of Sebu Chhu and Dongkya Chhu (Figs 4.2 & 4.4). Dongkya Chhu originates in the glaciated terrain near Dongkya La at an elevation above 5,000 m in the northeastern part of Sikkim. From its headwater, Dongkya Chhu flows for about 7 km towards southeast up to Zadong where a southward flowing stream (3.8 km long) draining Sanglaphui lake, joins it on the right bank at 4,880 m. From this confluence downstream, Dongkya Chhu is met by its tributary Jakhthang Chhu on its left bank at 4,780 m. Further downstream Tenbawa Chhu flowing westward from Korpo La and draining Tenbawa glacier (> 5,000 m) joins the river at 4,685 m near Yumesamdong. About 1.3 km downstream of

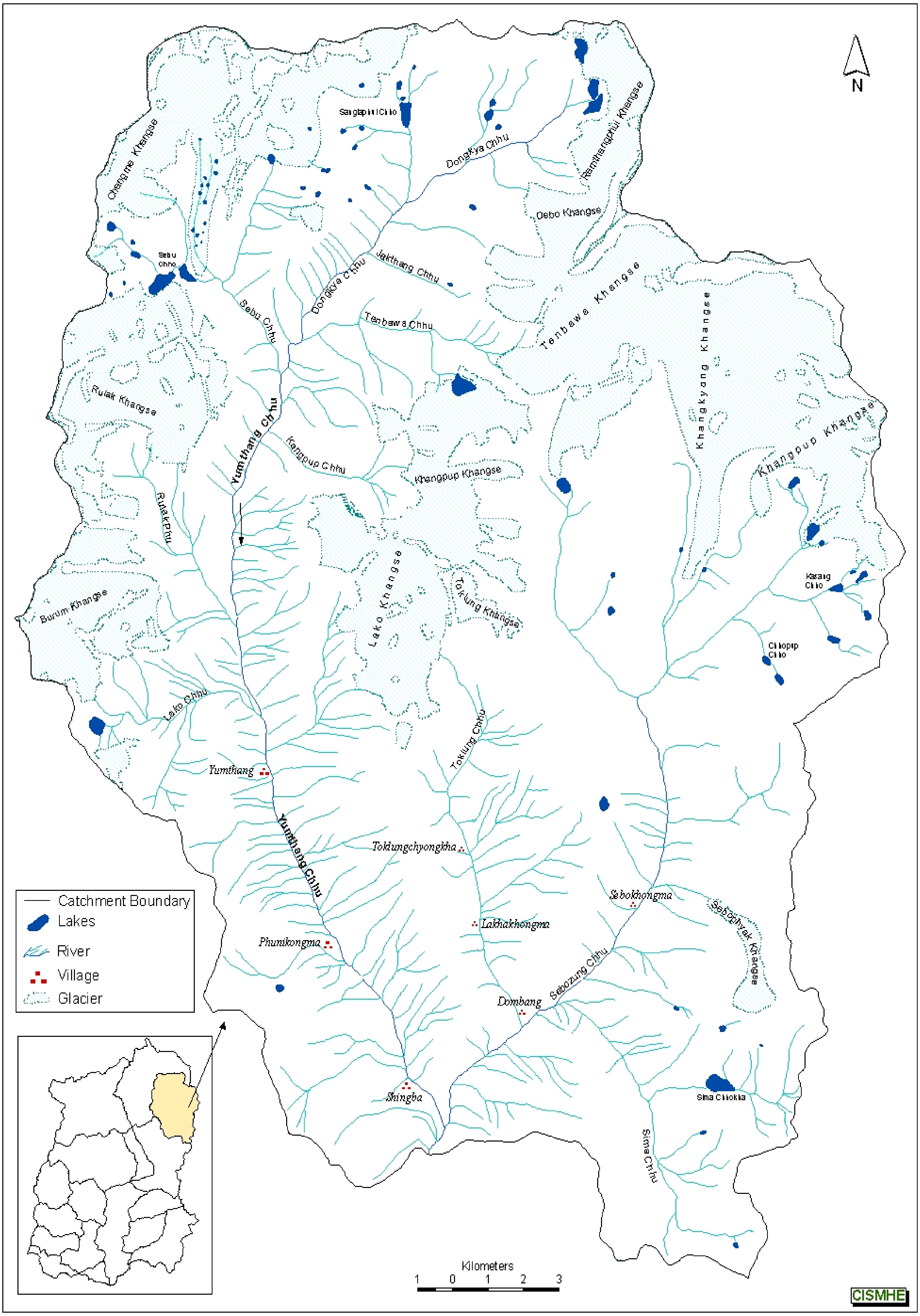


Fig.4.2 Drainage map of Yumthang Chhu watershed of Teesta river basin in Sikkim

this confluence, Sebu Chhu joins Dongkya Chhu at 4,485 m. Sebu Chhu is a major right bank tributary of Dongkya Chhu which flows for 7.3 km from its headwater near Sebu La in Changme Khang and Changme Khangpu glaciers draining a number of glacial lakes before joining the main river channel. Yumthang Chhu flows for a distance of about 18-19 km in southward direction before it is joined by Sebozung Chhu at Chhuba (2,800 m). After this confluence, the river flows as Lachung Chhu in south-west direction in general. Along its course Yumthang Chhu receives drainage from Khangpup Chhu on its eastern flank and Rulak Chhu, and Lako Chhu draining the right bank slopes of Yumthang valley.

Sebozung Chhu is a major left bank tributary of Yumthang Chhu with a total course of about 23 km from its headwater above 5,000 m. It received water from Khangpup Khangse, Khangkyong Khangse and Ghorathang glaciers and a number of glacial lakes like Kasang Chho, Chhopup Chho, etc. Sebozung Chhu originates at about 4,055 m and flows southward receiving drainage from Sebophyak Khangse through small streams on its left bank and then is joined by Toklang Chhu at Dombang on its right bank. Toklung Chhu originates from Toklung Khangse at about 4,600 m. Sima Chhu is another left bank tributary, which joins Sebozung Chhu before Dombang at 3,100 m. Sima Chhu has its origin in a glacial lake named Sima Chhoka.

Shargophui Chhu with its headwater above 5,000 m flows eastward and joins Lachung Chhu on its left bank at 2,560 m. Tibik

Chhu and Nimuphui Chhu are the other main streams that join the river on its right bank at Lema (2,320 m) and Khedum (1,980 m) villages, respectively. The tributaries on the right bank have a very short course between Lachung and Chungthang and the only significant contribution comes from an unnamed stream rising from a glacial lake (Chhumzomni Chhokha) which joins Lachung Chhu near Gompa village.

4.4 ZEMU CHHU

Zemu glacier, N. Lhonak and S. Lhonak twin glaciers, Hidden glacier and Green lake are the characteristic features of this sub-system, contributing large amount of discharge to Teesta river (Fig. 4.3).

Lhonak Chhu is main drainage of this complex with North and South Lhonak glaciers being the source of this drainage system. These two glaciers on the eastern faces of Lhonak and Jongsang peaks form the origin of Lhonak Chhu as Goma Chhu and is marked by a number of glacial lakes that drain into Goma Chhu. Goma Chhu flows in W-E direction and is joined on its right bank by Phutung Chhu which drains Langpo and Chanson glaciers. Goma Chhu is then joined by Khora Chhu on its left bank which drains Khora Chhobuk (glacial lakes) and Khora Khang glacier. Further downstream, it receives drainange from Naku Chhu to form Langpo Chhu. Naku Chhu rises at Naku La and drains a number of glacial lakes, with Thang Chho being the major glacial lake. It flows in southward direction to merge with Goma Chho near Puckchhang. Langpo Chhu, thereafter, takes a

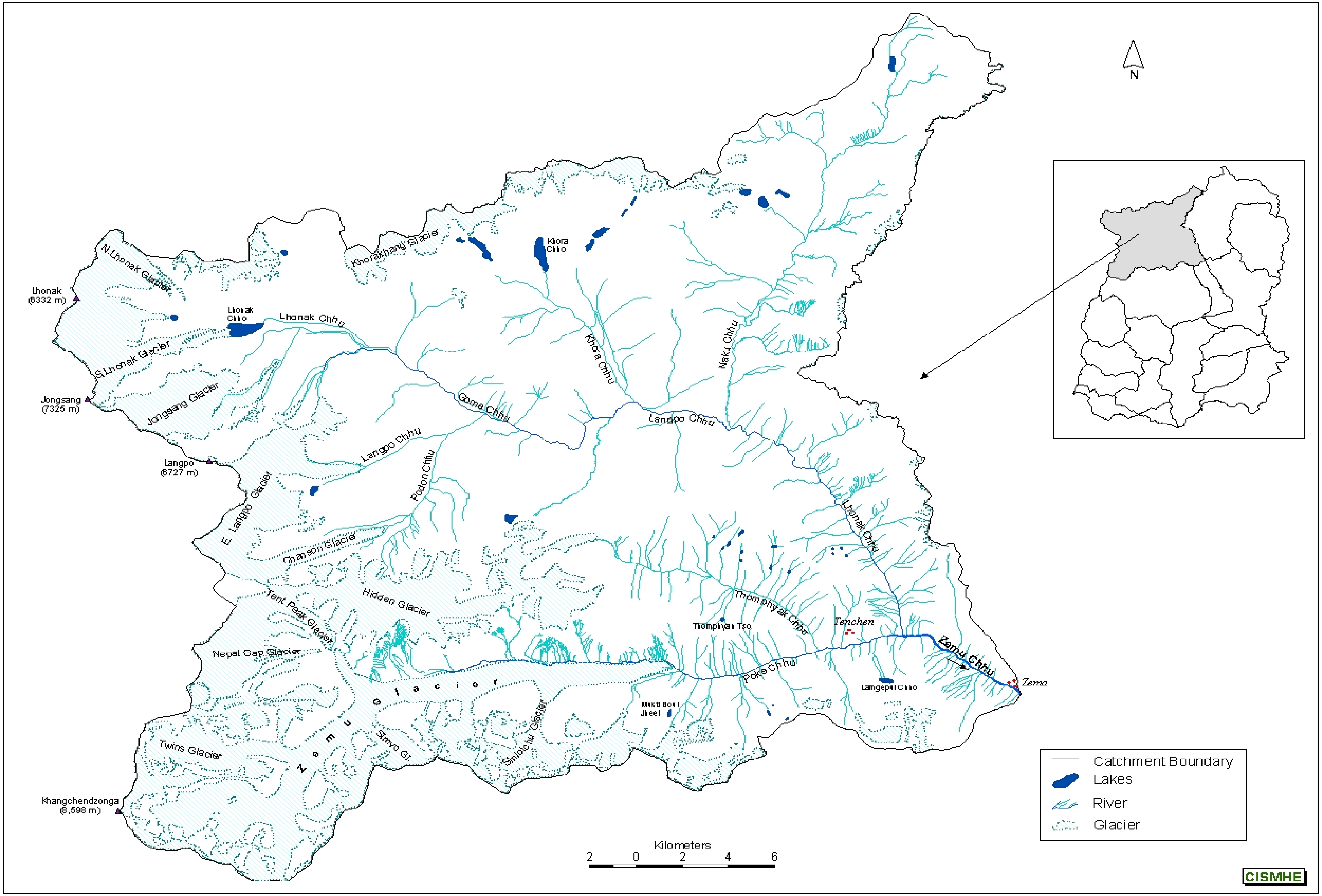


Fig.4.3 Drainage map of Zemu Chhu watershed of Teesta river basin in Sikkim

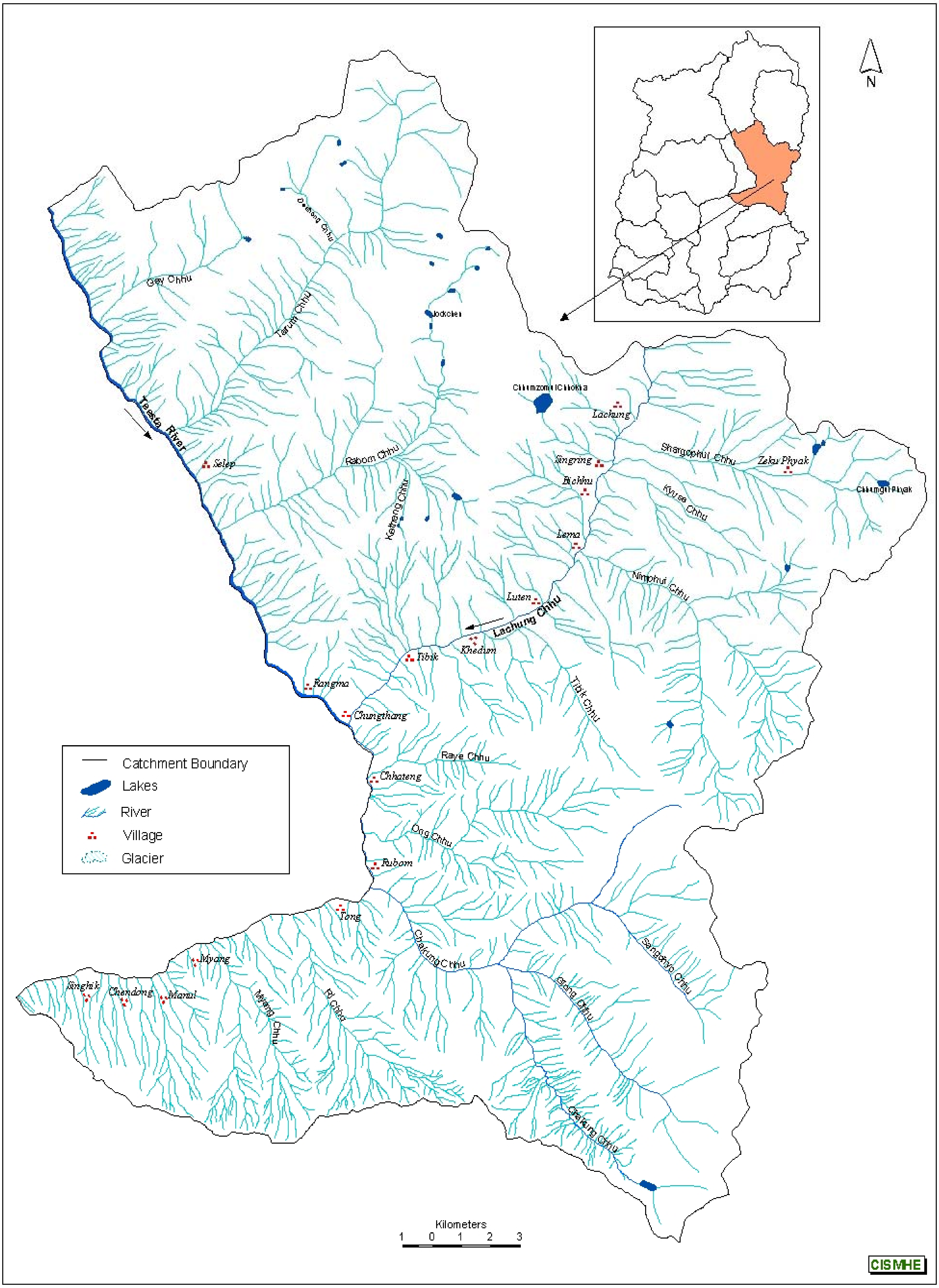


Fig. 4.4 Drainage map of Lachung Chhu watershed of Teesta river basin in Sikkim

southward turn and flows as Lhonak Chhu to join Zemu Chhu near Jakthang on its left bank.

Zemu Chhu originates as Poke Chhu from Zemu glacier, which is the largest glacier in Teesta basin about 25 km in length (see Fig. 4.3). Zemu glacier lies on the eastern face of Khanchendzonga peak (8,598m) and is joined by Simvo glacier on its right and Nepal Gap and Tent Peak glaciers on its left. It is joined by Hidden glacier on its left. Poke Chhu flows in W-E direction and receives drainage on its left bank from Thomphyak Chhu. Thereafter, it flows as Zemu Chhu to drain into Teesta river near Zema village.

4.5 TEESTA RIVER BETWEEN LACHEN AND CHUNGTHANG

In this stretch the river flows 22 km towards southeast from Teesta-Zemu Chhu confluence (2,675 m) to Teesta-Lachung Chhu confluence (1,560 m) at Chungthang (Fig.4.5). Several streams mostly flowing through arcuate valleys join Teesta river on either side. The left bank tributaries have a longer course than those joining on the right bank. Among the left bank tributaries, Gey Chhu joins near Chhaten, Tarum Chhu joins downstream of Jorphul at 2,200 m and Rabom Chhu joins near Rapung at 2,135 m. Chyaga Chhu, Nathang Chhu, Yukti Chhu, Yel Chhu, Phim Chhu and Rolazong Chhu are the major right bank tributaries of this sub-system.

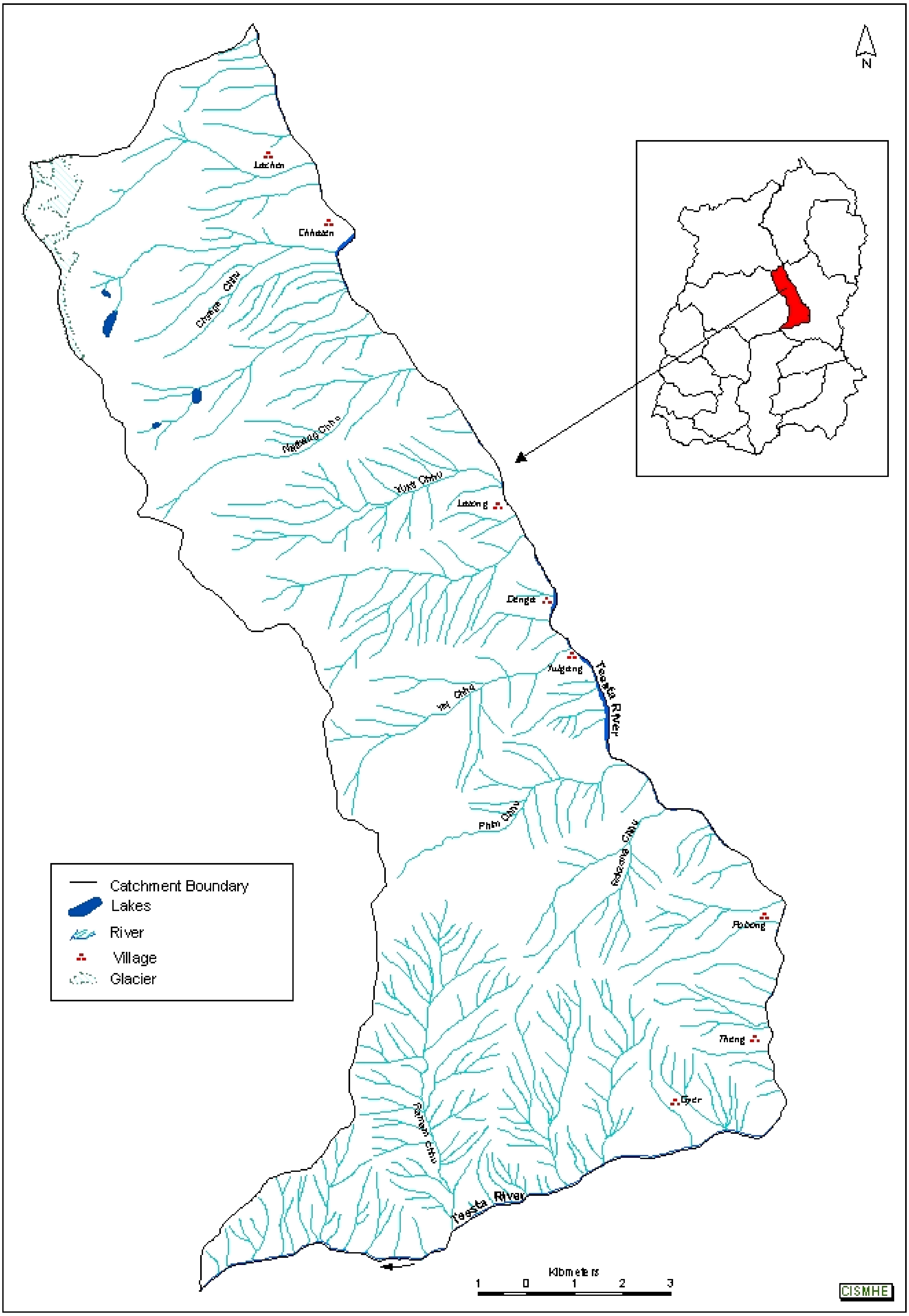


Fig.4.5 Drainage map of Lachen Chhu watershed of Teesta river basin in Sikkim

4.6 CHUNGTHANG-MANGAN-CHAKUNG CHHU SUB-SYSTEM

In this stretch Teesta river flows from north to south and then east to west forming an oblong basin with steep slopes facing east and west (see Fig. 4.4). The predominant tributaries in this stretch are on the left bank. Raye Chhu and Ong Chhu are two main tributaries before Rubom village, flowing east to west joining Teesta river at Chhaten and Theng, respectively. Chakung Chhu is the main left bank tributary draining the wedge-shaped basin.

Chakung Chhu has its headwaters in Tosa Chho (4,120 m) where from it flows down up to 2,480 m in an arcuate valley towards northwest and receives water from Glong Chhu on its right bank. From this point onward, Chakung Chhu flows east ward and is joined by Sangchyo Chhu on its right bank at 2,400 m. Chakung Chhu, thereafter flows for 4.6 km through an arcuate valley up to 1,570 m where a stream coming from Makangchu ridge (3,720 m) drains into it on the right bank. Then Chakung Chhu, after flowing northwest, drains into Teesta on its left bank at 1,350 m near Tong.

In the stretch between Tong and Mangan, Teesta river flows for a distance of about 14 km traversing a deep valley with triangular faces steeply sloping southwest and northeast. Several small streams with steep gradients passing through waterfalls and landslide scars join the river in this stretch mainly on the left bank. Teesta river flows in EW direction and receives water from Ri Chhu and Myang Chhu (from Anden peak : 3,698 m), which join it on the left bank. Ramam Chhu coming from Rockzongchu peak (4,097 m) is the main right bank tributary of Teesta.

4.7 TALUNG CHHU (RANGYONG CHHU)

Talung Chhu also known as Rangyong Chhu in different stretches is 36.9 km long and originates from Tongshiong glacier at about 4,800 m in the western part of Sikkim (Fig. 4.6). In its initial stretch the stream is known as Rukel Chhu. After flowing for about 10 km from its headwaters Rukel Chhu receives water from a stream (6.3 km long) which drains a glacier present above 4,600 m coming from the Narsingh peak (5,825 m). From this confluence Rukel Chhu flows downstream for 7.5 km where Umram Chhu confluences with it at 1,420 m near Lom. Umram Chhu has its headwaters at South Simvo glacier (> 5,000 m) and Umram Khang glacier (> 4,800 m). After flowing 13.2 km from its headwaters, Umram Chhu receives water on its left bank from Passaram Chhu at 1,795 m near Passam Phyku. Passaram Chhu originates from Jumthul Phuk glacier (> 5,200 m) and flows for 7.7 km. From this confluence Umram Chhu flows 2.2 km and joins Rukel Chhu near Lom. From Lom Rukel Chhu flows for 3.4 km and receives water from Ravingrum Chhu. This stream originates from Ringpi Lama Ridge (> 4,200 m) and flows southward for 8.9 km through a 171 m fall and confluences with Rukel Chhu at 1350 m on its left bank. After flowing 1.6 km from this point, Rukel Chhu receives water at 1320 m from its right bank tributary Pokhram Chhu (6.2 km long), which has its headwater at

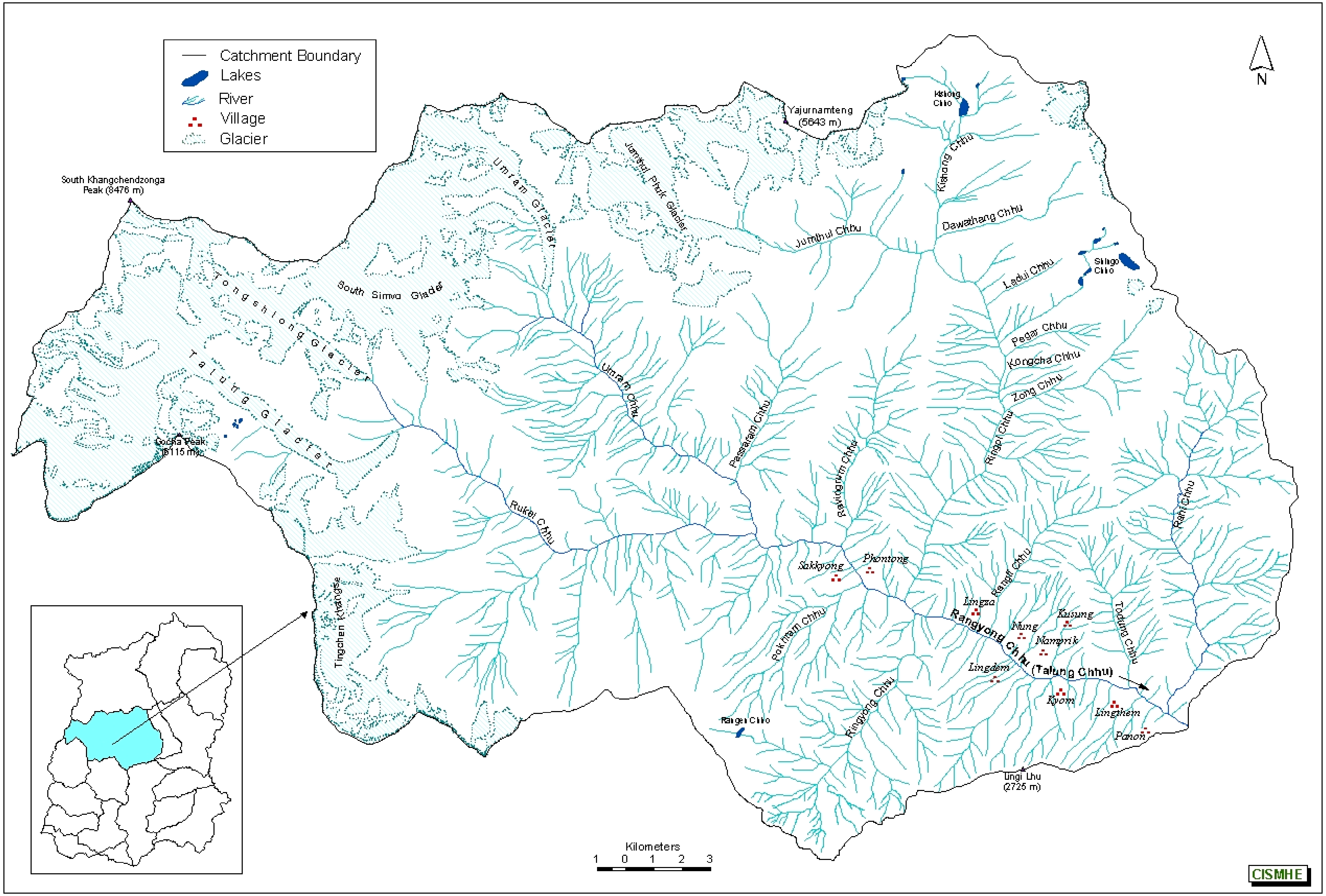


Fig. 4.6 Drainage map of Rangyong Chhu watershed of Teesta river basin in Sikkim

Paki Lhu peak (4,934 m). From this confluence it flows 2.7 km downstream where Ringpi Chhu confluences it at 1,150 m on its left bank. Ringpi Chhu originates as Jumthul Chhu from Jumthul Phuk glacier (> 4,200 m) and travels for 7.3 km up to Talung where Kishong Chhu flowing 7.4 km from a lake joins it at 2950 m. While flowing further downstream for 7.6 km through the Talong Gompha region up to 2,000 m, Jumthul Chhu receives water on its left bank from Ludui Chhu, Pegor Chhu, Kangcha Chhu and Zong Chhu. From here this stream flows 8 km as Ringpi Chhu. About 0.5 km downstream of Ringpi Chhu confluence Ringyong Chhu (10.5 km long) with its headwaters at Urednra ridge (> 3,400 m) joins Rukel Chhu, which flows downstream as Rangyong Chhu. After flowing 2.9 km, Rangyong Chhu receives water from Rangli Chhu on its left bank at 1005 m near Laven. Rangli Chhu originates above 3,800 m and flows 7.5 km towards southwest and passing through a fall of 80 m confluences with Rangyong Chhu. From this point the river flows 5.9 km up to 850 m where Tadung Chhu (6.6 km) joins it. From here the river flows as Talung Chhu. After flowing for 1.8 km, it receives water from Rahi Chhu on its left bank at 780 m. Rahi Chhu has its headwater in Thepala ridge (5,064 m) and flows southward for 16 km. From this confluence Talung Chhu flows 0.9 km and joins the Teesta river on its right bank at 750 m near Sangklang Forest Guest House.

Teesta river flows southward for 15 km from Mangan (750 m) to Dikchu (538 m). Several eastward and westward flowing streams joins the river, respectively on its right and left banks, in this stretch.

Mani Chhu and Mormu Chhu are some of the streams draining into Teesta river on its either bank in this stretch.

4.8 RANGIT RIVER SUB-SYSTEM

Rangit basin is a rectangular shaped basin in which majority of its tributaries flow in canoe shaped basin. The drainage pattern in Rangit basin is mostly dendritic, however, towards the mouth of the major tributaries, rectangular drainage pattern is well observed, which indicates structural control on the drainage network.

Rangit river originates as Rangit Chhu from 4,080 m ridge dividing watersheds of Rangit river and Talung Chhu (Figs 4.8 and 4.12). Kayam Chhu, a major tributary of Rangit Chhu, has its head water in Narsingh glacier at 5,825 m. Rangit river meanders for a distance of 8.4 km up to the confluence of Barme Chhu on the left bank. Then after flowing a distance of 3.8 km, the river is joined by Rel Chhu on its right bank. Rel Chhu has its headwaters in Narsingh glacier. It flows for 4 km up to 3,880 m where Leduwa Chhu, flowing 4.8 km from 4,900 m (also fed by Narsingh glacier), joins it on the right bank. Rel Chhu travels in southward direction and receives water from a number of streams joining it on either side before it confluences with Rangdong Chhu. After this confluence Rel Chhu receives water from Nar Khola on its left bank at 1,300 m. From here downstream, Rel Chhu exhibits distinct rectangular drainage pattern and joins Rangit Chhu on its right bank. Rangit Chhu hereafter is known as Rangit river and receives water from a number of streams

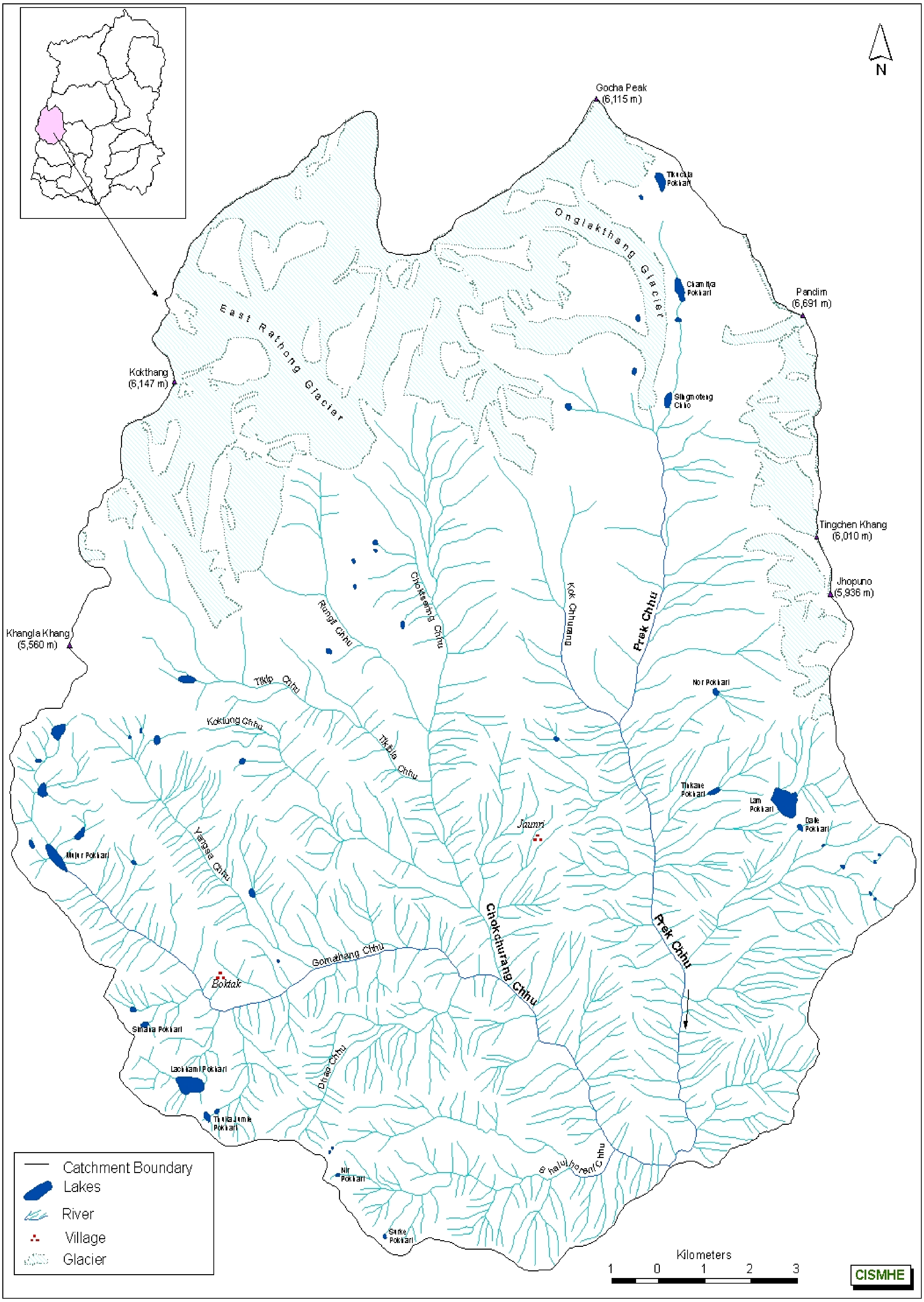


Fig. 4.7 Drainage map of Prek Chhu watershed of Teesta river basin in Sikkim

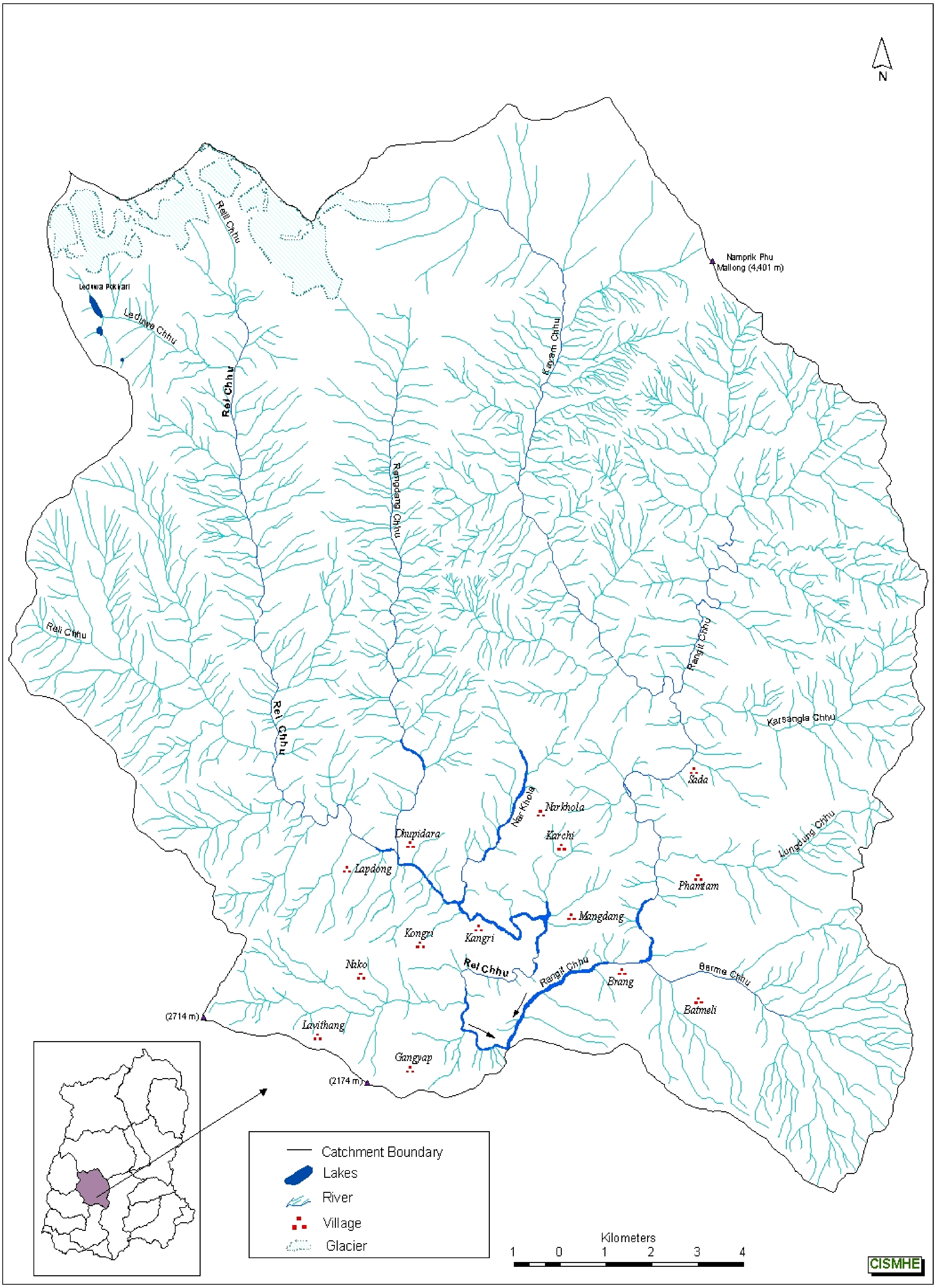


Fig. 4.8 Drainage map of Rel Chhu watershed of Teesta river basin in Sikkim

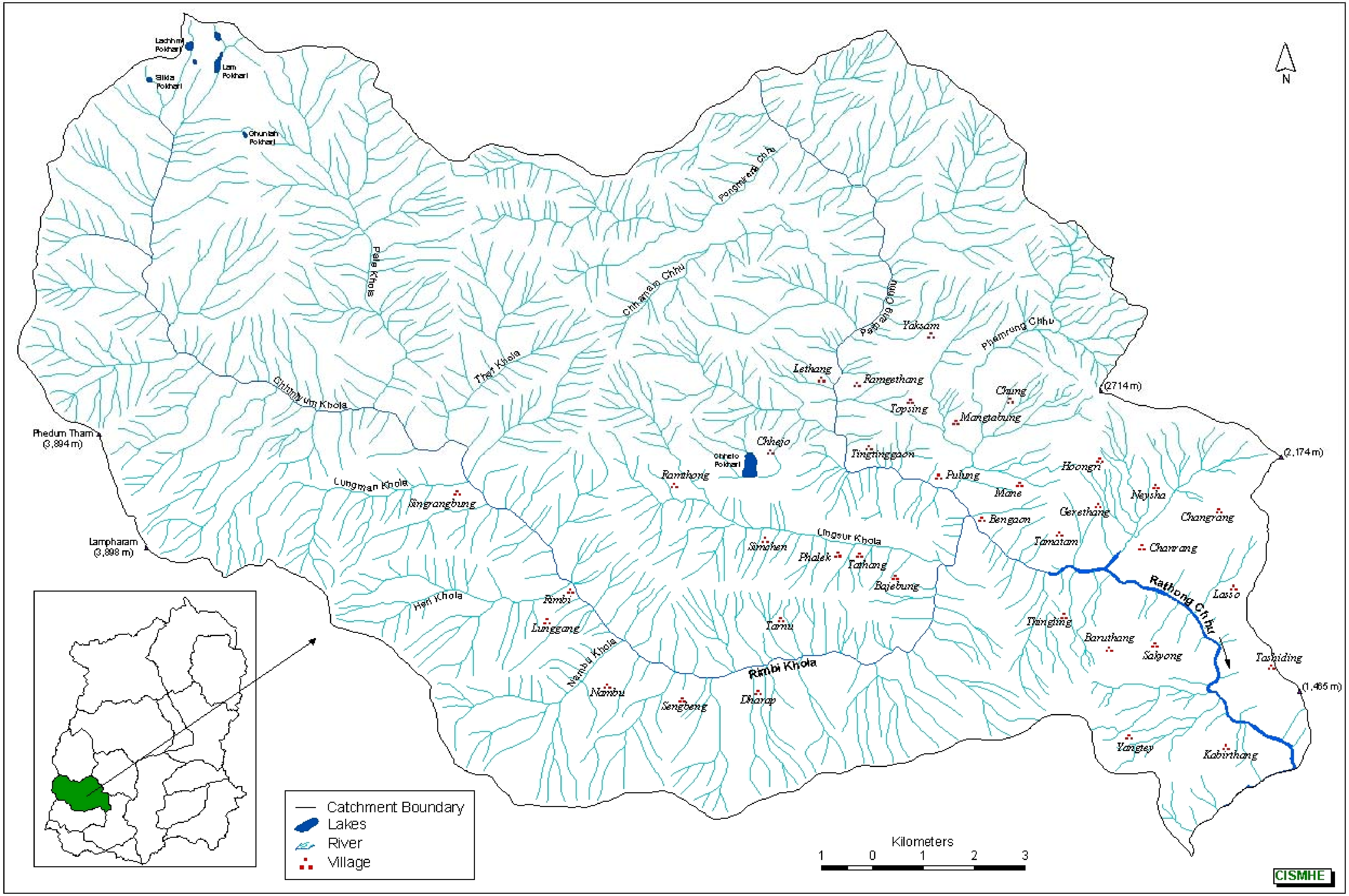


Fig. 4.9 Drainage map of Rathong Chhu watershed of Teesta river basin in Sikkim

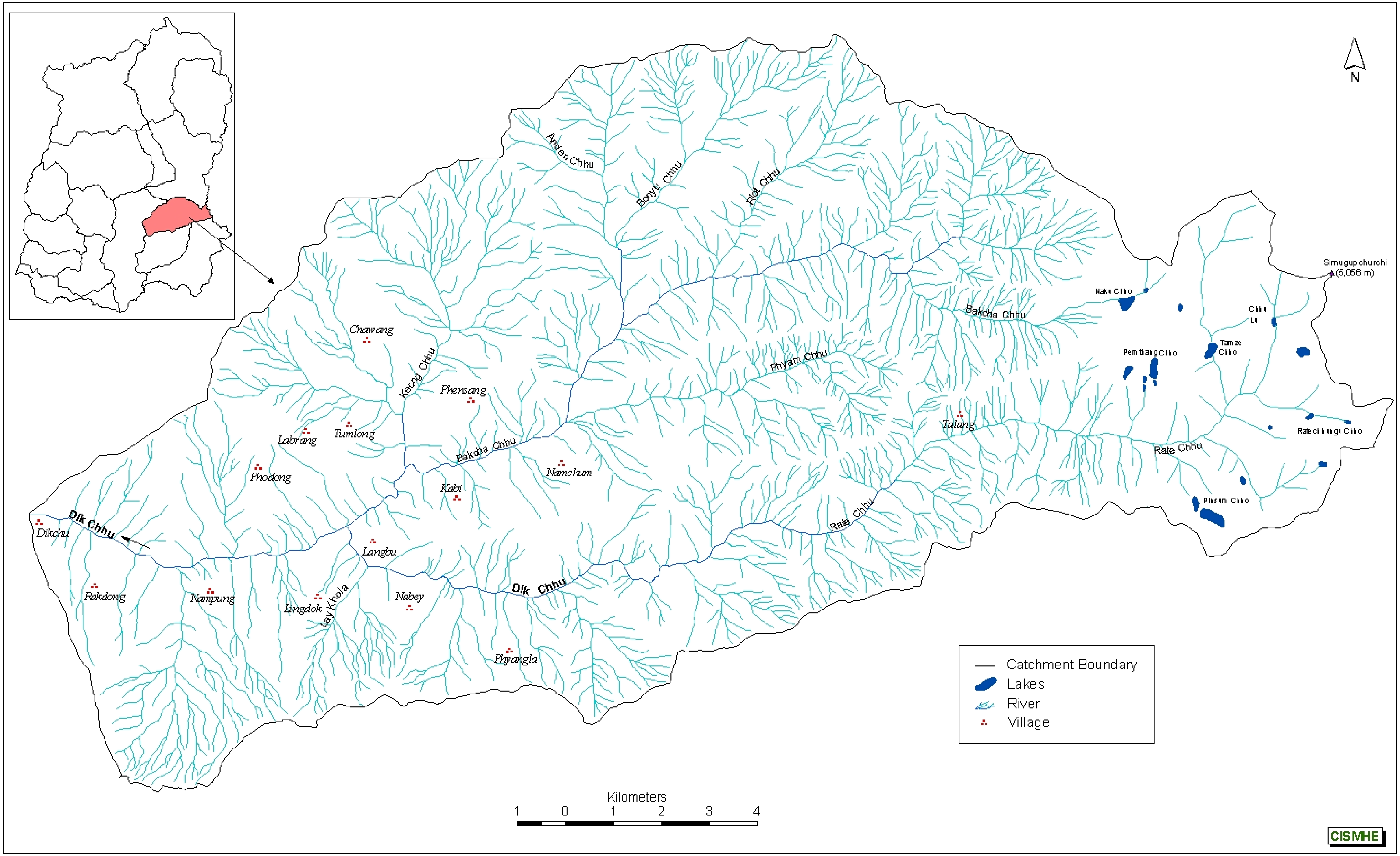


Fig. 4.10 Drainage map of Dik Chhu watershed of Teesta river basin in Sikkim

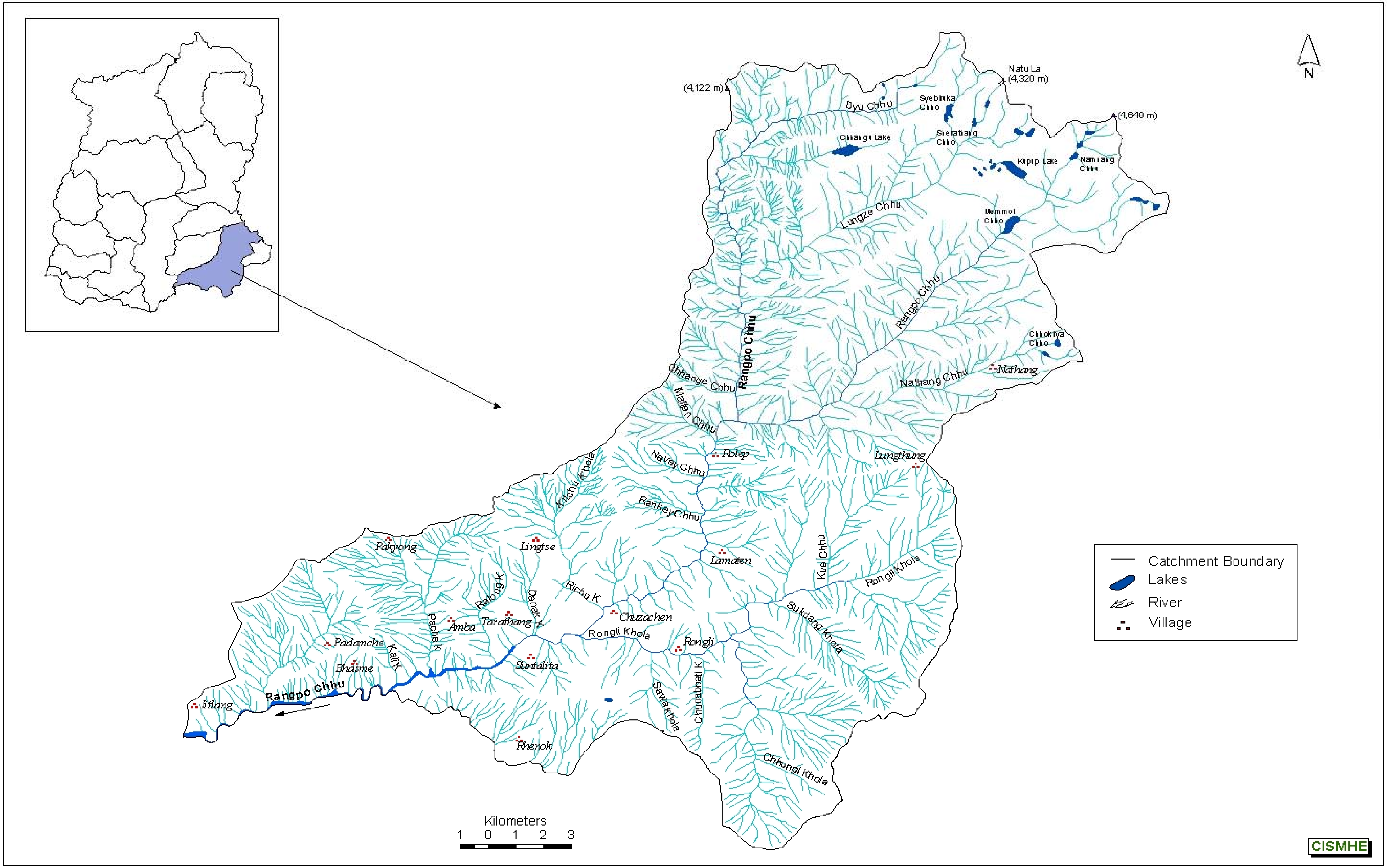


Fig. 4.11 Drainage map of Rangpo Chhu watershed of Teesta river basin in Sikkim

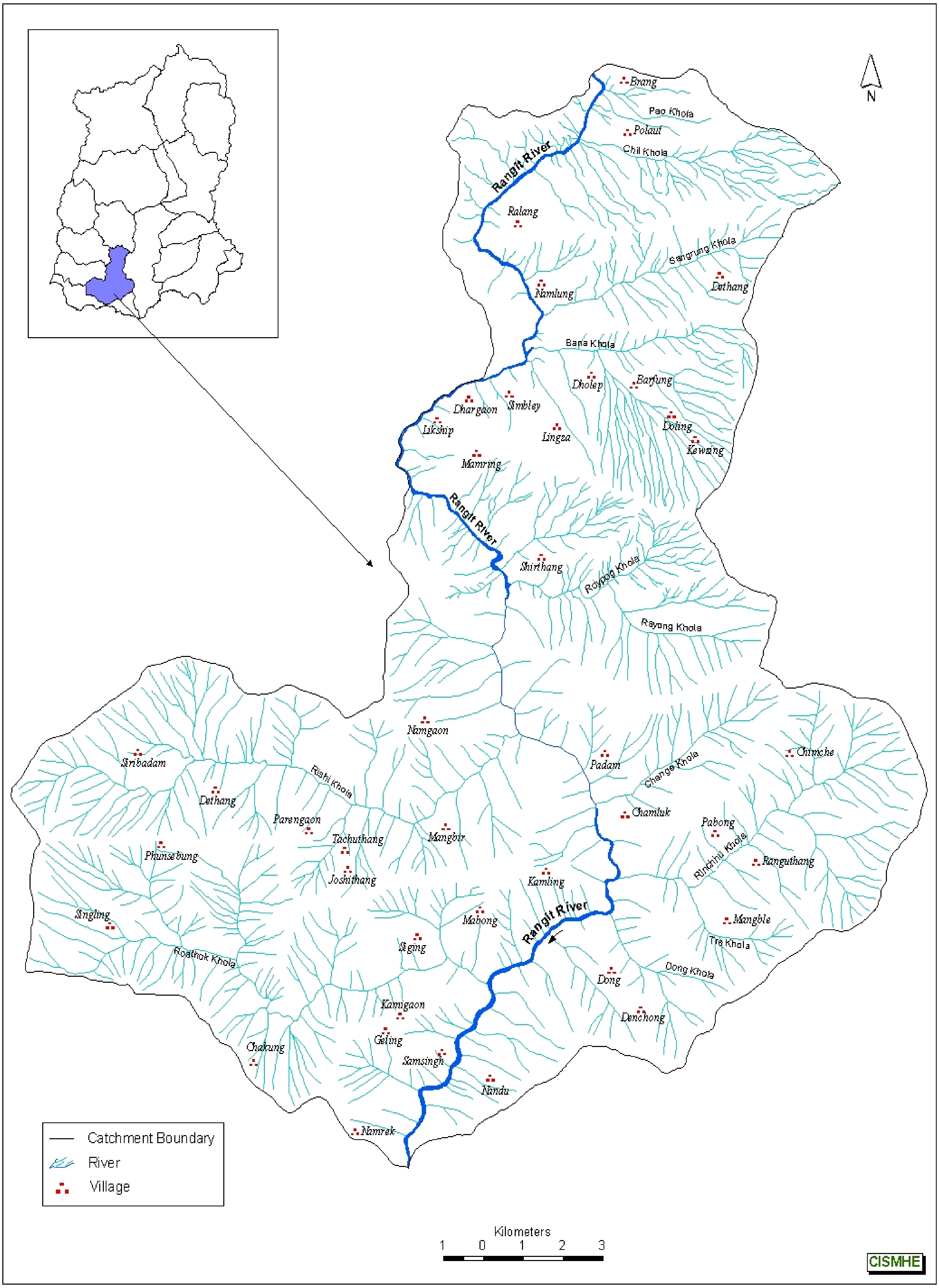


Fig. 4.12 Drainage map of Rangit River watershed of Teesta river basin in Sikkim

like Chil Khola, Sangrung Khola and Bania Khola. After their confluence, Rathong Chhu, the largest tributary of Rangit river confluences with the river at 602 m on the right bank.

Rathong Chhu is comprised of two forks i.e. Prek Chhu and Chokchurang Chhu (Figs. 4.7 and 4.9). Prek Chhu originates from Jemathang (4,740 m) and its headwater lies in Onglakthang glacier. It receives water from glacial lakes *viz*. Tikuchia Pokhari (4,800 m), Chamliya Pokhari (4,600 m) and Sungmoteng Chho (4,280 m) located on the lateral moraines lying on the left flank of Onglakthang glacier. Prek Chhu flows 11.7 km up to 3840 m where it receives water from a stream named Kokchhurong, which is fed by glacier at the base of Forked Peak (6,220 m). From this confluence Prek Chhu flows 9.9 km up to 2,175 m where Chokchurang Chhu confluences with it on the right bank. Chokchurang Chhu originates from East Rathong glacier at 4,600 m from where it flows for 6.9 km up to 3,780 m where Rungli Chhu (> 4,000 m) joins it on the right bank. From here the stream flows 1km up to 3,770 m and receives water from Tikip Chhu on its right bank. Then it flows for another 2.3 km and receives water from Koklung Chhu which flows 7.2 km from its origin at 5,000 m on its right bank. From this confluence the river flows 1.7 km where Gomathang Chhu confluences it on the right bank at 3140 m. Gomathang Chhu has its headwaters in a glacial lake complex. Mujur Pokhari (4,260 m), Simana Pokhari (4,540 m), Lachhmi Pokhari (4,320 m) and Thumlo Jumle Pokhari (4,400 m) are some of the glacial lakes in this region that contribute significantly to the discharge of Gomathang Chhu. Gomathang Chhu after receiving water from

Dhop Chhu on the right bank drains into Chokchurang Chhu on its right bank at 3,140 m. After flowing 4.5 km from this confluence Chokchurang Chhu receives water from Baliajhore Chhu (4,300 m) on its right bank at 2340 m and then flows 1.2 km to join Prek Chhu on its right bank at 2,175 m. From this confluence Prek Chhu travels 1.7 km up to 1,970 m and receives water from Pongmirang Chhu on its right bank. Then the stream flows down 11 km up to 920 m as Pathang Chhu where Phamarong Chhu flowing 7.5 km from 2,900 m joins it on the left bank near Pulung. Immediately downstream of this point, Rimbi khola confluences with Pathang Chhu on the right bank at 907 m.

Rimbi Khola originates from Lachhmi Pokhari and Lam Pokhari lakes as Chhinjyum Khola and drains the forested areas through Pale Khola on its left bank and Longman Khola on its right bank (see Fig. 4.7). From this point, the stream flows as Rimbi Khola and receives water from a number of streams like Thar Khola, Heri Khola near village Rimbi, Nambu Khola and Lingsur Khola on either side. After this confluence, it flows as Rathong Chhu. Rathong Chhu after flowing 6.6 km joins Rangit river on its right bank at 602 m. From this confluence Rangit river flows 3.9 km up to 499 m where Kalej Khola joins it on the right bank.

Kalej Khola originates from 3,898 m peak as Barmo Khola where Yam Khola joins it on the right bank (Fig. 4.13). Along its 34 km traverse in WE direction, it receives water from a number of tributaries on either side. Mardom Khola, Simpok Khola, Simchar Khola, Bega Khola, Dentam Khola, Hi Khola and Rangsang Khola are some of the

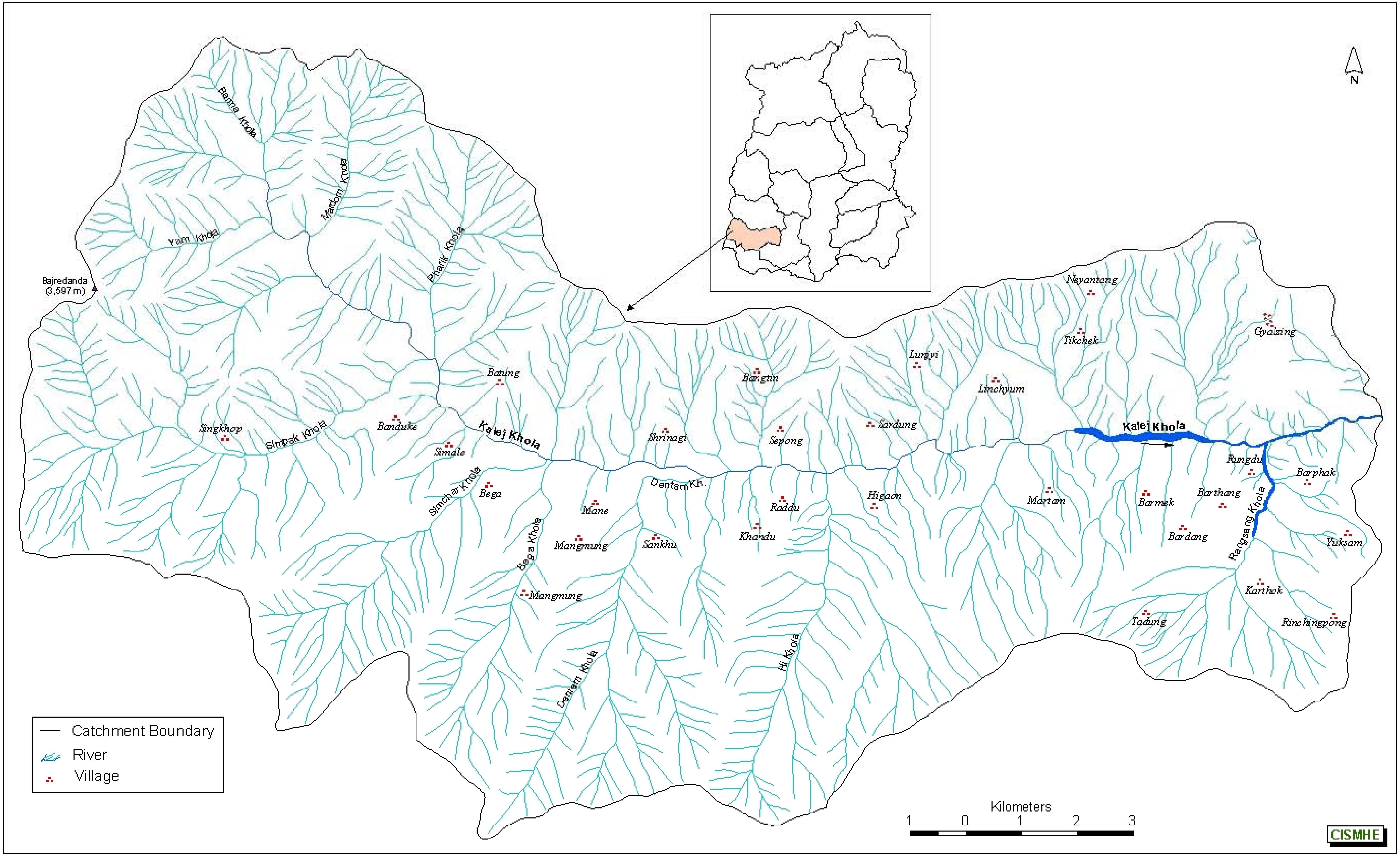


Fig. 4.13 Drainage map of Kalej khola watershed of Teesta river basin in Sikkim

main streams that join Kalej Khola in this stretch. Kalej Khola ultimately drains into Rangit river on its right bank at 499 m. Rangit river flows 4.2 km up to 460 m where Rayong Khola joins it on the left bank (see Fig. 4.12). Further downstream Rishi Khola joins it on the right bank at 421 m. From this confluence downstream Rangit river receives water from Change Khola, Rinchhu Khola and Roathok Khola. Ramam (or Rangbang) Khola is another tributary that joins Rangit river on its right bank. Ramam Khola drains from forested areas through smaller streams like Ribdi Khola, Riyong Khola and Rani Khola (Fig. 4.14). After the confluence of Rani Khola, Ramam Khola flows for another 10.8 km and joins Rangit river. Rangit river changes its course towards east thereafter. After this the river is also known as Great Rangit river and defines the inter-state boundary between West Bengal and Sikkim. Manpur Khola is only significant tributary on its left bank in this stretch before Rangit river finally merges with Teesta river at Melli Bazar (Fig. 4.15).

4.9 DIK CHHU SUB-SYSTEM

Dik Chhu is a canoe shaped basin. Dik Chhu is a left bank tributary of Teesta river which flows 35 km EW to confluence with Teesta on its left bank at 538 m. The drainage network is mostly dendritic and several streams join the main channel all along its course. Dik Chhu originates from Rate Chhungo Chho (> 4,420 m) as Rate Chhu receives water from two streams, one flowing from Chhu Lu lake joining at 3,800 m and another draining the Tamze Chho lake (> 3,900 m) on its right bank at 3,720 m (Fig. 4.10). Further

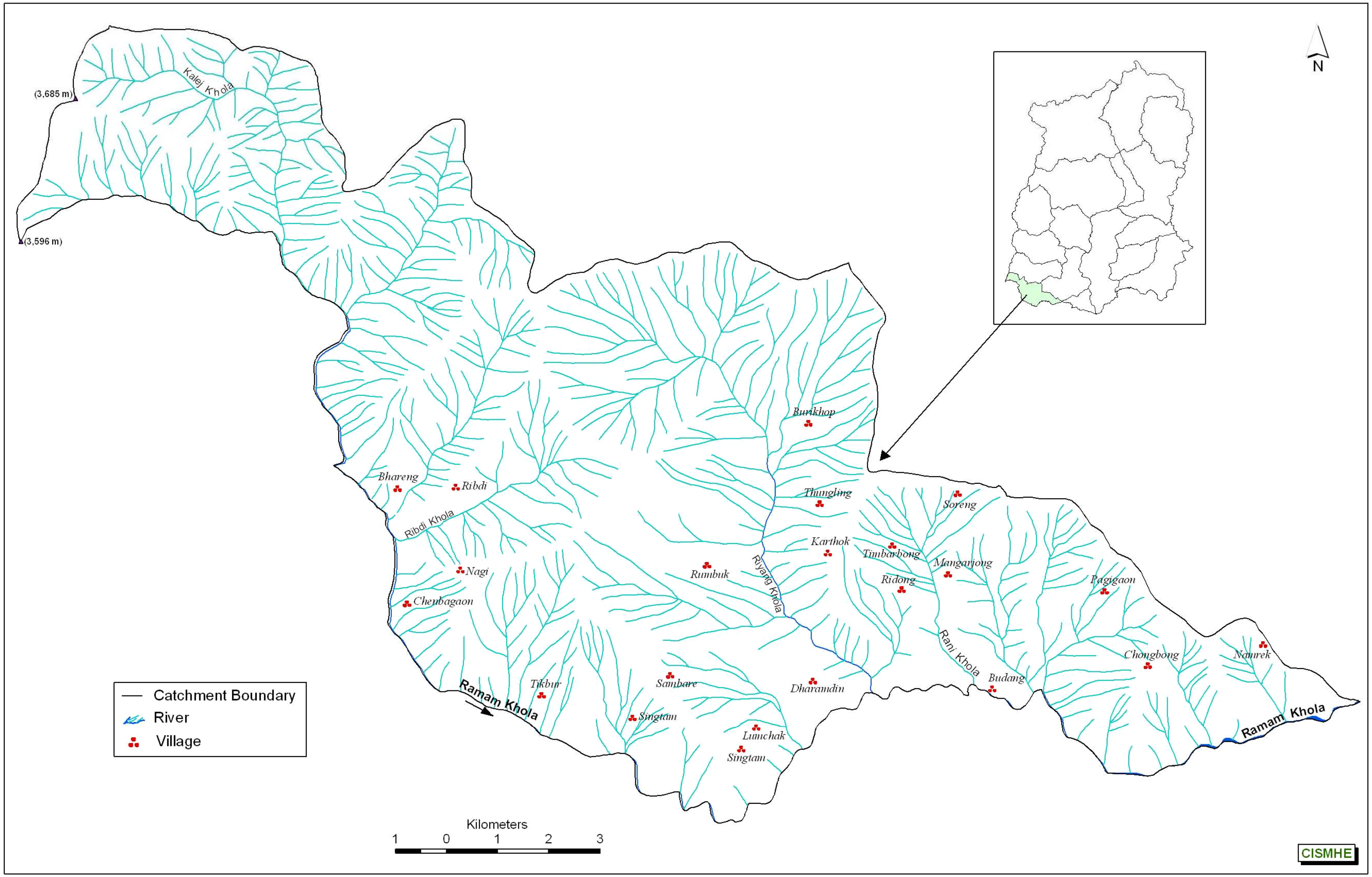


Fig.4.14 Drainage map of Ramam Khola watershed of Teesta river basin in Sikkim

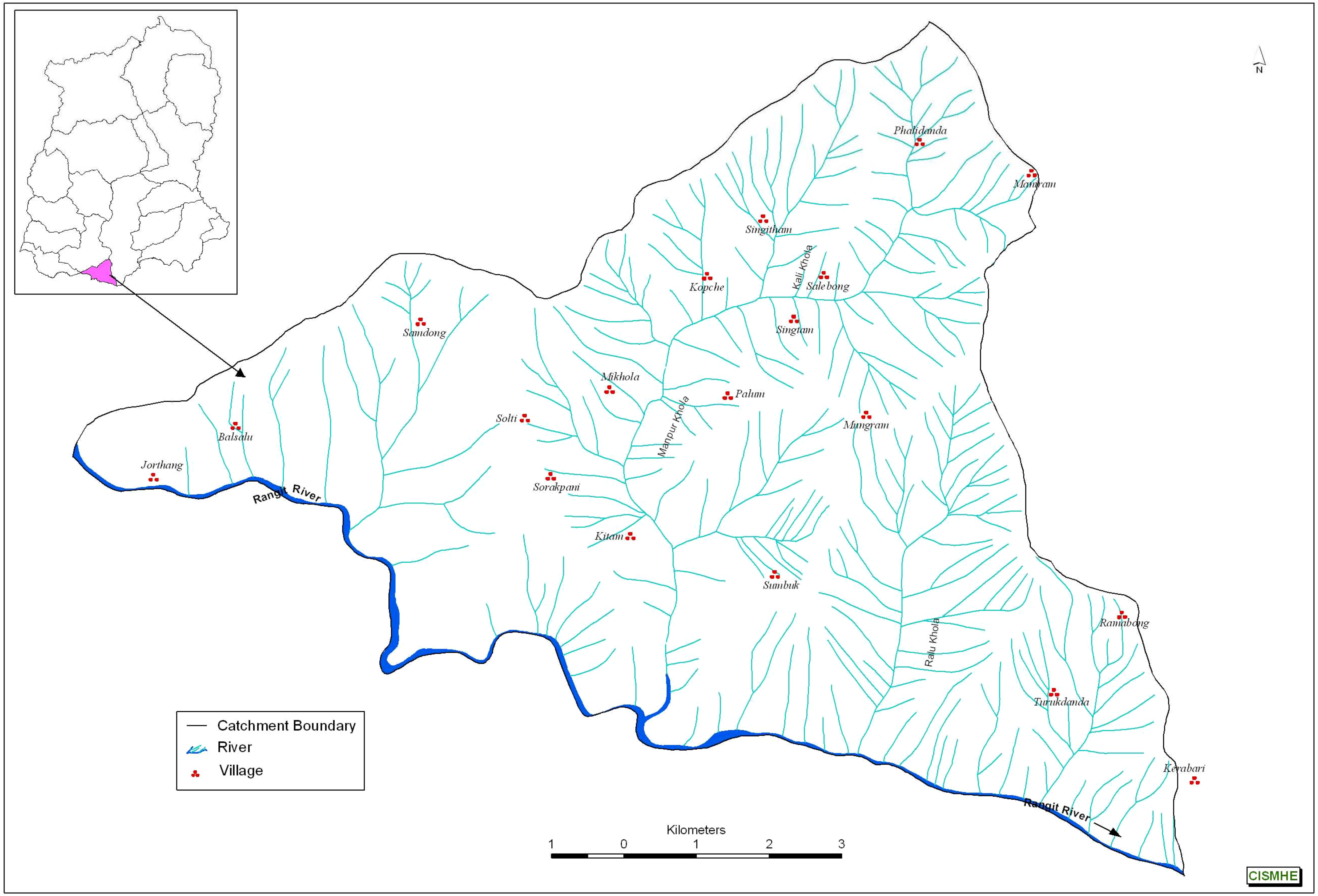


Fig. 4.15 Drainage map of Manpur Khola watershed of Teesta river basin in Sikkim

downstream, a stream flowing from Chho Pinsung lake joins it at 3,590 m on its left bank. From this point Rate Chhu flows for a distance of about 1.3 km up to near Pithang Chen (1,539 m), receiving small streams on either side. From this point downstream, the river flows as Dik Chhu. After Pithang Chen, Dik Chhu traverses a distance of about 4.5 km before it is joined by its main tributary Bakcha Chhu on its right bank.

Bakcha Chhu originates from a ridge (4,507-4,603 m) and flows in EW direction for a distance of about 8.5 km before it receives drainage on its right bank from Riot Chhu at 1,560 m. Bonyu Chhu originating from 4,360 m is the main right bank tributary of Bakcha Chhu in this stretch and joins Bakcha Chhu near Sirdong. Bakcha Chhu, then receives water from Phyam Chhu on its left bank at 1,330 m. Phyam Chhu has its headwaters in Zethang ridge (3,585-3,621 m). From 1,330 m Bakcha Chhu flows 3.8 km and receives water from Keong Chhu on its right bank at 1,030 m. Bakcha Chhu flows down 2 km from this point and confluences with Di Chhu on its right bank at 930 m.

From Dik Chhu - Bakcha Chhu confluence, Dik Chhu flows for another 4 km to join Teesta river on its left bank at 538 m.

4.10 RANGPO CHHU

The drainage pattern in Rangpo basin is mostly rectangtular. The tributaries of Rangpo Chhu exhibit dendritic pattern. All the types of dendritic drainage pattern *viz*. broad-dendritic, narrow-dendritic, paniculate-dendritic, pinnate-dendritic and asymmetrical-dendritic are seen in the basin. The rectangular pattern indicates structural control on the drainage network. Rangpo Chhu originates from glacial lakes near Indo-China border as Byu Chhu and Lungze Chhu (see Fig. 4.10). Byu Chhu flows in EW direction as a stream coming out of Chhangu lake (3,750 m). After this confluence, Byu Chhu flows as Rangpo Chhu. It takes southward turn near Kyongnosla and is joined by Lungze Chhu on the left bank. Lungze Chhu also has its headwaters at the southwest slope of 4,400 m peak on the Indo-China border. In its initial course, it drains two glacial lakes *viz*. Syebiruka lake (4,040 m), Chho Thuiba and Sharathang Chho (3,880 m). Rangpo Chhu along its southward flow receives drainage from Chhange Chhu on its right bank. Rangpo Chhu is then joined by Nathang Chhu on the left bank at 1,300 m.

Nathang Chhu with its headwaters at Chhokhya Chho (3,920 m) receives water from its largest tributary on its right bank at 1960 m i.e. Rangpo Chhu.

The stream Rangpo Chhu (E), which is a tributary of Nathang Chhu, originates from the northern end of Namnag Chho complex (3,960m). It receives water from another stream flowing from Jelep Chho lake complex comprised of three lakes. From Menmoi Chho lake at 3,669 m, a stream flows as Rangpo Chhu (a tributary of Nathang Chhu). Later Rangpo Chhu after flowing for 5.3 km receives water from a stream flowing from Neo La peak (4,122 m). Rangpo

Chhu then flows for another 3.7 km to join Nathang Chhu on right bank at 1,960m. Nathang Chhu then flows in SW direction to join main Rangpo Chhu on its left bank at 1,300 m.

Nathang Chhu drains into Rangpo Chhu almost at right angle and after this Rangpo Chhu flows in EW direction for a short distance and then resumes its southward course and receives water from Malten Chhu on its right bank at 1,160 m. Along its journey further S-SW, it receives water from Navey Chhu near Rolep and Soge Chhu, Rankey Chhu and Ri Chhu joining on either bank. Rangpo Chhu then receives drainage from Rongli Khola another major tributary, on its left bank at 644 m. After its confluence Rangpo Chhu flows mainly in westward direction.

Rongli Khola drains snowfields on the southern slope of Lungthung (3,835 m) and Pangolakha (3,062 m) peak. Before draining into Rangpo Chhu, it receives water from a number of small streams *viz*. Kae Chhu, Lingtam Khola, Sukdang Khola, Chunabhati Khola and Sawa Khola on either side.

Rangpo Chhu, after the confluence of Rongli Khola at Rongli receives water from Danak Khola on its right bank at 550 m. Thereafter, Rangpo Chhu flows through a wide valley and receives water from Ralong Khola, Pache Khola, Kali Khola and Rishi Khola on either side.

Rishi Khola has its origin in the forested areas of West Bengal and drains into Rangpo Chhu on its left bank near Rhenok.

After the Rishi Khola confluence, Rangpo Chhu flows for a distance of about 4.5 km as a meandering channel and receives water from Kashyem Khola, coming from West Bengal side on its left bank. On the right bank, it receives water from Diking Khola and after which Rangpo Chhu flows for another 4 km to drain into Teesta river on its left bank at 300 m at Rangpo.

Teesta river traverses a distance of 19.6 km from Rangpo (300 m) to Melli Bazar (230 m), the point where Rangit river joins the Teesta river. During this traverse it receives water from Tumthang Khola, Kanam Khola, Seti Khola and Rabi Khola on its right bank.

4.11 TEESTA RIVER BETWEEN MANGAN AND SINGTAM

In this stretch Teesta river traverses a distance of 29 km from Dikchu (538 m) to Singtam (350 m). Rangphap Chhu, Kau Khola, Samyong Chhu, Ring Chang Khola, Brum Khola, Brum Chhu, Rangpo Chhu from Maenam Gompha (2,666 m), Ben Khola and Papung Khola are some of the significant streams that drain into Teesta river in this stretch on either bank (Fig. 4.16).

4.12 RANI KHOLA (RONGNI CHHU)

Rani Khola is 36 km long and in its initial stretch it flows as Rora Chhu (Fig. 4.17). Several small streams join Rani Khola all along its course on either side. Rora Chhu originates from the western slope of a peak (3,924 m) in East Sikkim. Rora Chhu is joined by Yali Chhu at 1,400 m, and Rishi Khola at 1,240 m on its left bank. Further

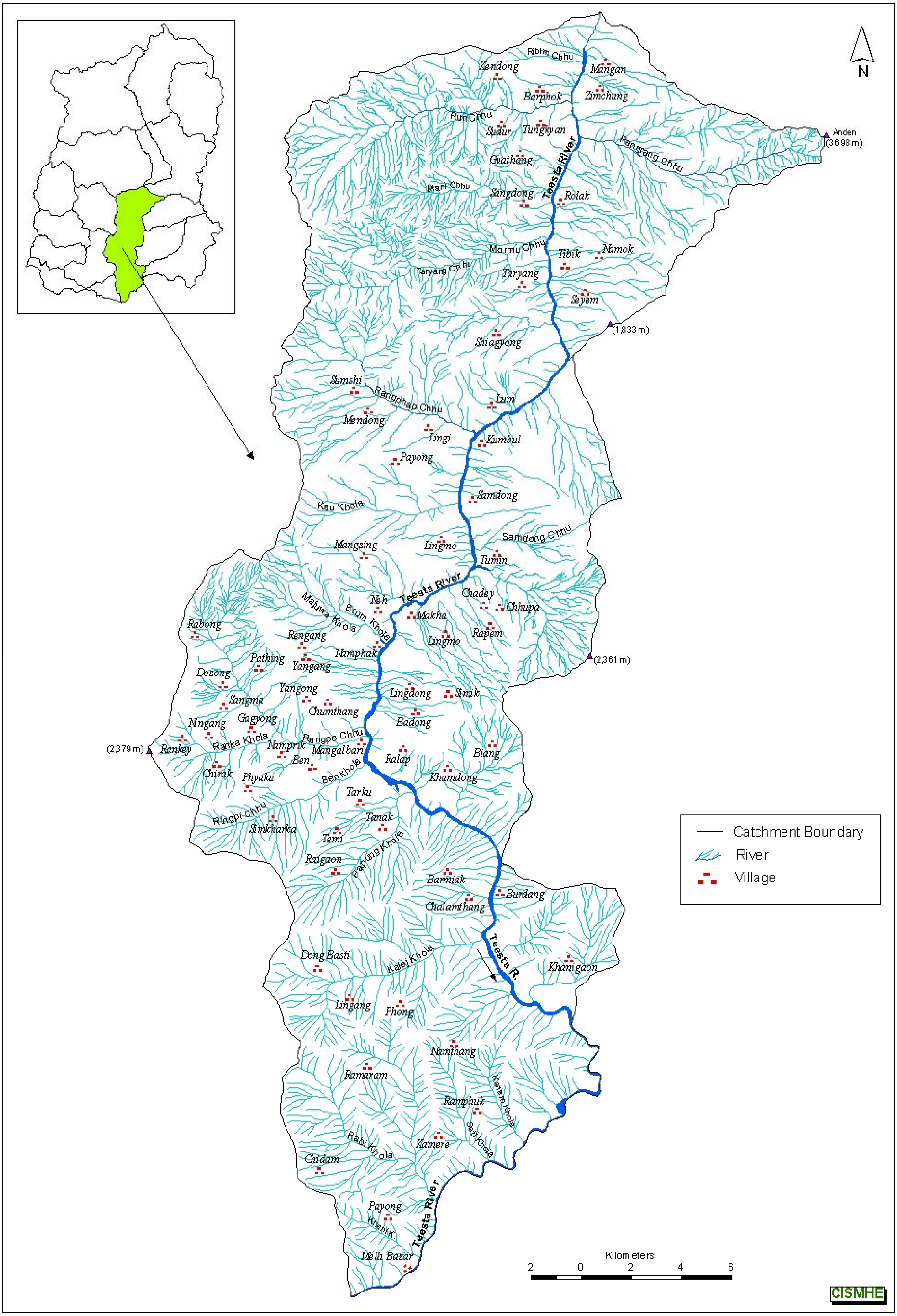


Fig. 4.16 Drainage map of Teesta (Lower Part) watershed of Teesta river basin in Sikkim

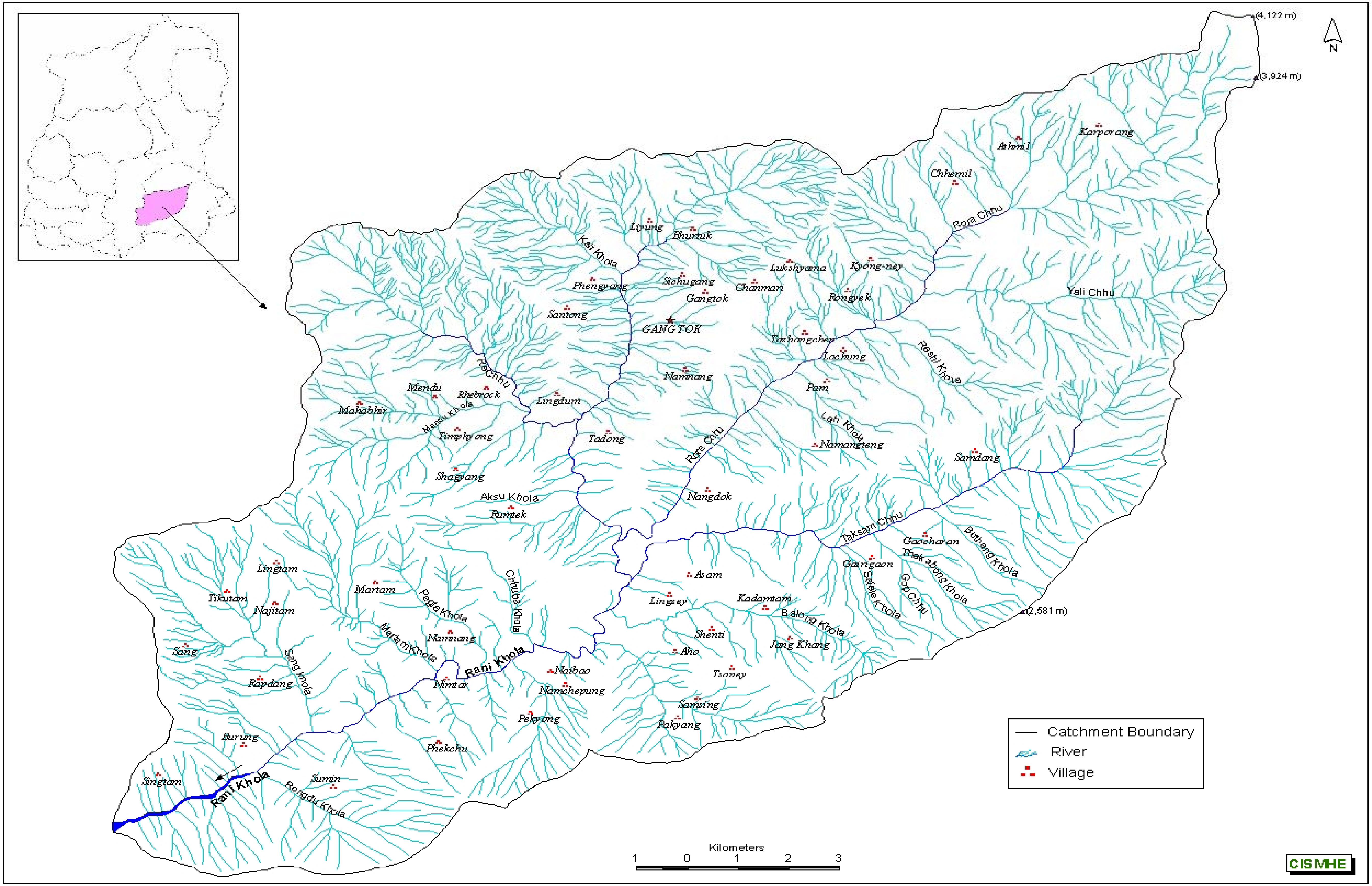


Fig. 4.17 Drainage map of Rani Khola watershed of Teesta river basin in Sikkim

downstream, Lah Chhu near Pam on the left bank and Tarang Rang Chhu (Kali Khola) join it on the right bank. Downstream of the confluence of Tarang Rang Chhu, Rora Chhu flows as Rani Khola.

After flowing for about 1 km Rani Khola receives water from Aho Khola and Andheri Khola on its left bank. Chhuba Khola, Pagh Khola, Martam Khola and Sang Khola join it on the right bank. After the confluence of Rani Khola on the left bank at 390 m, Rongni Chhu confluences with Teesta river on its left bank at 350 m near Singtam.

4.13 TEESTA RIVER BETWEEN TEESTA-RANI KHOLA CONFLUENCE AND TEESTA-RANGPO CHHU CONFLUENCE

In this stretch Teesta river flows for about 9.1 km from Teesta-Rani Khola confluence (350 m) to Teesta-Rangpo Chhu confluence (300 m) (see Fig. 4.16). After flowing 3.3 km from Rani Khola confluence Teesta receives water from Kalej Khola on its right bank at 320 m; Kalej Khola originates from 2,640 m peak and flows 8.9 km. From this confluence the river flows 1.1 km where another stream flowing 4.2 km joins it at 300 m. Further downstream at 1.5 km a right bank stream flowing 3.76 km from 1,720 m peak drains into the river at 300 m. From this point Teesta flows 1 km and receives water from a 6.4 km long stream, flowing from 2,560 m peak, on its left bank at 300 m. From here the river flows down for 2.1 km where the left bank tributary Rangpo Chhu confluences it at 300 m near Rangpo town.

4.14 TEESTA RIVER PROFILE

A number of big and small streams join Teesta river on its either side from its origin at 5,280 m up to the confluence of Rangit river with it, near Melli Bazar at 200 m. In order to understand the Teesta river system, a longitudinal profiles of Teesta river and its tributaries was drawn with the help of SOI toposheets at 1:50,000 scale. The confluence points of prominent tributaries of Teesta along with its longitudinal profile are shown in Fig.4.18.

The longitudinal profiles of major tributaries of Teesta river basin in Sikkim and their relationship with the Teesta river channel is shown in Fig.4.19. It is evident from this figure that the thalwegs of Rangit Chhu, Talung Chhu and Lachung Chhu are lower than the Teesta river some distance upstream from the points of their confluences. This indicates that at some point of time these tributaries were more vigorous in down-cutting than the Teesta river.

The longitudinal profile of the Teesta river was also analysed using Hack's gradient index (Hack, 1973 a, 1973b). Gradient index is related to the 'stream power or competence' and, therefore, can be related to the bed material. The gradient indices were calculated using the formulae used by Hack (1973a) and Seeber and Gornitz (1983). The gradient index for the entire river (K) in the mountains was calculated using the formula $K = (H_i-H_j)/\ln L_j-\ln L_i$, where H_i= the height elevation of the river bed (the first contour the river crosses after emerging from the glacier), H_j= the height of the river bed at the entrance onto the plains, L_i= length of the river at the highest contour

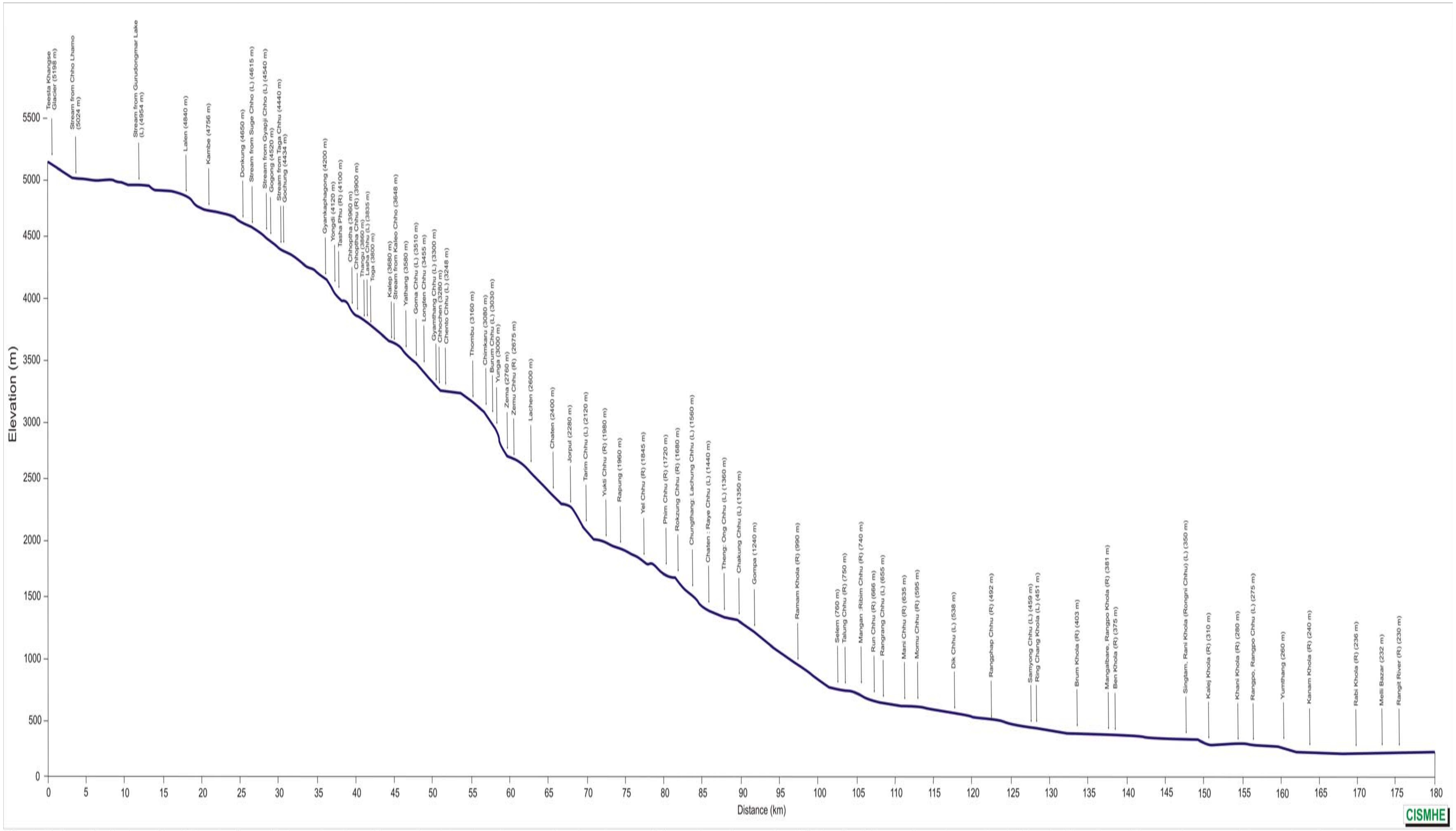


Fig. 4.18 Longitudinal profile of Teesta river with important localities and points of confluence of major streams. (R)- confluencing on the right bank, (L) - confluencing on the left bank. Elevation of the confluence points are given in meters

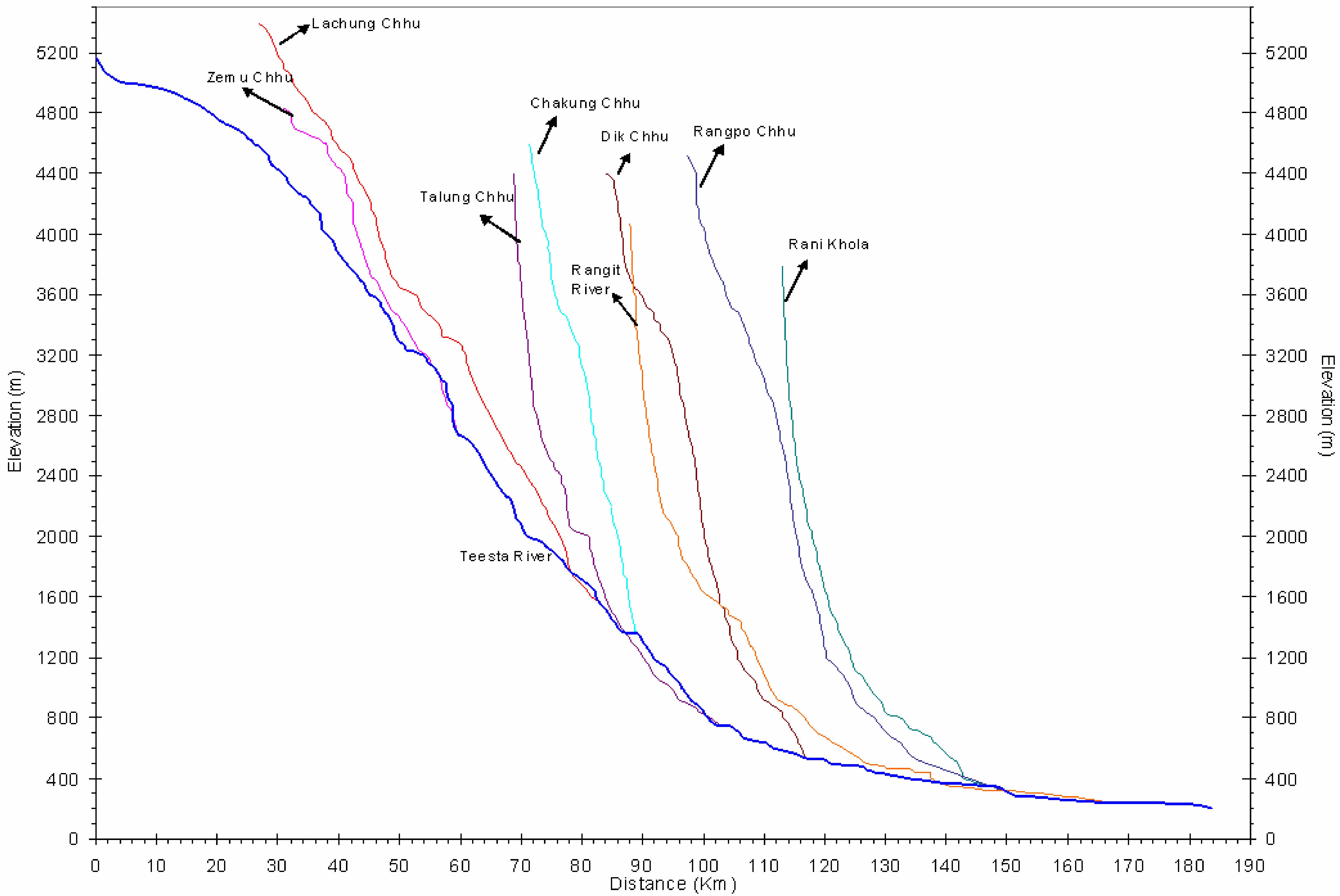


Fig.4.19 Longitudinal profiles of the Teesta river and its major tributaries

(0.1 km for convenience of calculation), L_j= length of the river at the entrance on the plains. The gradient indices (SL) for the segments of the river between consecutive contours were calculated using the formula SL=(dH x L)/dL, where, dH = elevation difference between the two end points of a reach, dL= planimetric length of a given reach and L = length of the stream from the headwaters to the middle point of a given reach. These SL values of the individual reaches were reduced to relative ratios by dividing SL by K. The following points are indicated from the SL/K values:

i) SL/K = 1.0 shows that the gradient of the given reach is the same as the gradient of the logarithmic profile of that reach of the river,

ii) SL/K < 1.0 depicts a gentler reach and a value greater than 1.0 is for steeper reach,

iii) an increasing trend in the values of SL/K for consecutive reaches is associated with a steepening of river bed,

iv) a decreasing trend is related to a river bed that is becoming gentler, and

v) a sharp increase in the SL/K values is related to knick-points in the longitudinal profile of the river.

The longitudinal profile of the Teesta river with the bars showing SL/K values for different reaches is given in Fig. 4.20. It is evident from the figure that there are several knick points along the thalweg profile of Sikkim *viz*. near Yongdi (4,000-4,200 m), Chhochen (3,250-3,500 m), Zema (2,700-3,000 m), Jorpul (2,000-2,200 m),

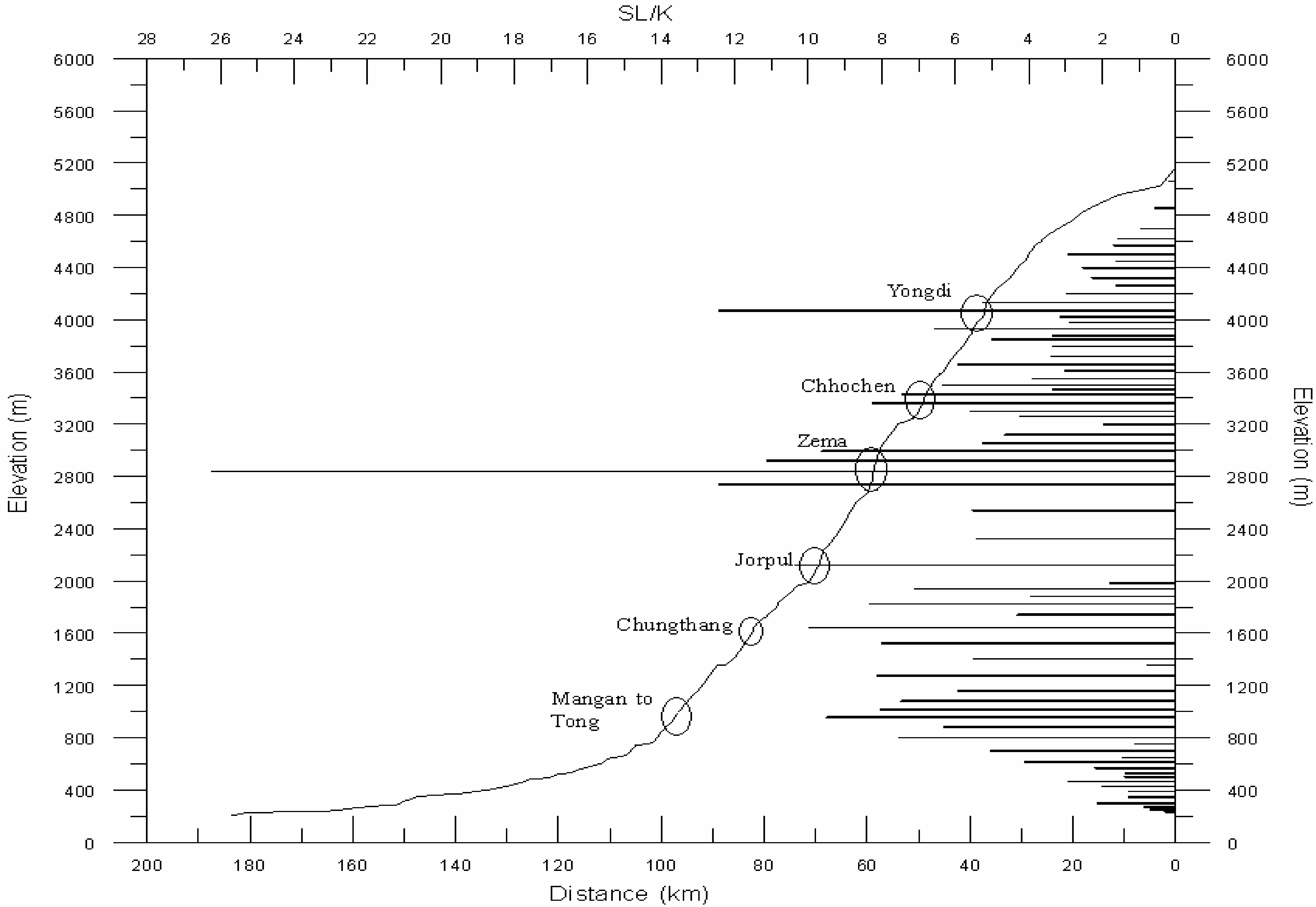


Fig.4.20 Longitudinal profiles of the Teesta river showing SL/K indices and marked knick points (horizontal bars)

Chungthang (1,500-1,700 m), Mangan-Tong (800-1,200 m), etc. Of these the prominent knick-point is the one near Zema between 2,700 and 3,000 m. The regions with marked knick-points indicate the presence of major structural features in those regions.

The drainage network, particularly the rectangular pattern in Rangpo Chhu and Rangit river basins in the south of MCT, underscores the structural peculiarities of the region. It indicates that the intersecting sets of joints or faults trending NW-SE and NE-SW are controlling the drainage network.

4.15 IMPLICATIONS

The drainage network in Sikkim shows that the water will be available in Teesta and its major tributaries Rangit and Rangpo all along their courses.

The thalwegs of Rangit Chhu, Talung Chhu and Lachung Chhu are lower than the Teesta river some distance upstream from the points of their confluences indicating that these tributaries were more vigorous in down-cutting than the Teesta river.

The knick points indicate certain regions of structural discontinuities along the Teesta river. Therefore, due attention must be given to these regions when any developmental project is proposed there.

CHAPTER - 5

NODAL POINTS OF WATER RESOURCE IN TEESTA BASIN

5.1 GEOMORPHIC PROFILE

The terraces and floodplains, valley-side slopes and landslide slopes, alluvial cones of different types and generations, tors, kettle shaped depressions, terrace-isles, sickle shaped ranges, bevelled plains, undulating plains and deeply-dissected valleys, glacial or periglacial deposits, related sedimentary structures, crevasses, etc. are the distinctive geomorphological feature of Teesta river basin in Sikkim. The landforms and landform assemblages in the terrain of Teesta river basin and its innumerable tributaries are the result of continuous denudation and deposition processes that are constantly modifying the newly formed land forms in the upper reaches and burying the existing land forms in the lower reaches. Based upon the geomorphological features as well as ecological and climatic regimes, Teesta basin in Sikkim can be demarcated into five distinct geo-eco-climatic zones *viz*.

i) Frigid zone above 4,000 m (glacial, periglacial and fluvio-glacial processes)

ii) Cold zone between 2,500 and 4,000 m (periglacial, fluvio-glacial and fluvial processes at higher altitudes,

iii) Cold temperate zone between 2,000 and 2,500 m (fluvio-glacial, and fluvial processes at higher altitudes),

iv) Warm temperate zone between 1,000 and 2,000 m (fluvial processes), and

v) Sub-tropical zone up to 1,000 m (fluvial processes at lower altitudes).

First three eco-climatic zones jointly constitute the major part of the North Sikkim district comprised of Upper Teesta basin and stretches for about 100 km from east to west. This portion is marked by innumerable glaciers and glacial lakes, alpine meadows, deodar-oak, birch-rhododendron and juniper forests (sub-alpine to alpine forest), terraces along the Teesta river and numerous tributary valleys of varied origin and valley-aspects harbouring rich floral and faunal wealth. This northern part of Teesta basin with varied and diverse environments is responsible for unique and conspicuous landforms within the Teesta river basin. The glaciated areas in this part are engaged in the erosional activities through abrasion scouring, frost action, freeze-thaw cycle, etc. Upper Teesta basin is also characterized by huge accumulation of debris in the form of debris cones, rock-glaciers and alluvial fans, debris avalanches and other hazards. These debris are transported mainly in monsoon season and during snow-melt period. Transportation rates of these debris become 20 times than normal during any catastrophic event. The watersheds located in the Upper Teesta basin contribute huge amounts of silt. The movement of glaciers over their beds, reduce the rock surface to rock flour by their frictional activity. The rock flour after mixing with melt water forms the glacial milk which ultimately transformed into thin mud during peak melt discharge. The changes in glacial-phase of the Upper Teesta basin section require special attention in planning for watershed management, especially landslide and flood control in lower reaches. The fluctuations in ice-cover in this region are generally accompanied by

i) production and transport of debris,

ii) floods and siltation of reservoirs,

iii) vegetation cover, and

iv) associated cooling effects of the glaciers in Sikkim Himalaya.

Therefore, the fluctuations in such activities in the Upper Teesta basin are required to be monitored and evaluated for the formulation of any precautionary and mitigative measures.

The factors like orientation of slopes, precipitation along with other local aspects have given rise to intra-valley variation in the elevation of snow-line in the Upper Teesta basin. The south facing slopes have a lesser ice-cover.

Middle and lower parts of the basin are marked by subdued relief, slope-wash slides and slips, scourge and filling, abandoned channels, etc.

5.2 NODAL POINTS OF WATER RESOURCE

High mountain ranges in Sikkim Himalaya particularly the North Sikkim are characterized by snow and numerous glaciers. These glaciers are the perennial source of water for Teesta river and regulate the run off. Since most of the glaciers are inaccessible and are located in rugged terrain of North Sikkim, remote-sensing data was procured for the mapping and analysis of glaciers. For this purpose digital IRS-ID LISS-III, PAN data as well as LANDSAT-7 ETM have been obtained from NRSA, Hyderabad and University of Maryland, Glocal Land Cover Facility, U.S.A. The remote sensing studies helped in generation of glacier inventory map of Sikkim and glacier index map. The glaciers are depicted as white in the FCC of IRS-ID LISS-III data as well as PAN data (Fig. 5.1). The present study aims at merging the PAN data with LISS-III data, which would enable the interpretation of glaciers much easier and more accurately. In the Phase-II of the present study an inventory of prominent glaciers and glacial lakes of entire Teesta basin has been prepared.

The inventory of prominent glaciers and glacial lakes was prepared by digital image processing of merged IRS-1D LISS-III and PAN data with the help of enhancement techniques of satellite data using ERDAS Imagine 8.7. The processed image would then be transferred to Geographical Information System (ArcGIS 9.0, GeoMedia Professional 5.2, etc.) for the generation of different coverages or layers. Similar studies have earlier been carried out at RRSSC, Nagpur in 1991 using IRS-1B LISS-II data of November 1990.

The glaciers of Sikkim occur as compound glaciers termed as glacier complexes, where a number of glaciers originate from a common permanent ice-cover. The glaciers of Teesta basin have been delineated into seven glacier complexes (Fig. 5.2). These are Chhombo, Yumthang, Lamgpo, Zemu, Talung, Rathang and Rel glacier complexes. These complexes constitute the nodal points of water resource in Sikkim and cover about 17% of Sikkim. Yumthang glacier complex is the largest glacier complex with

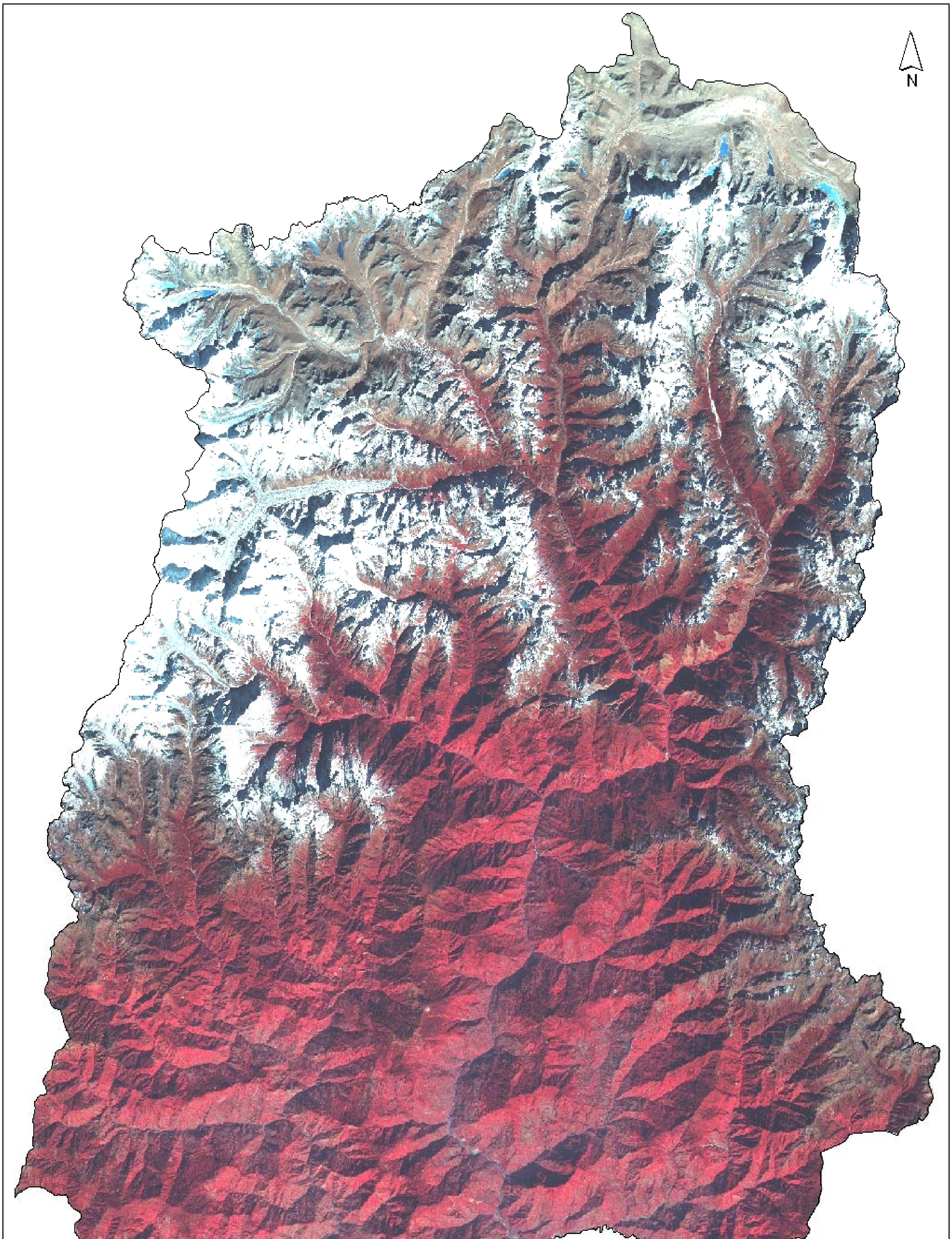


Fig. 5.1 False Color Composite (FCC) of Teesta river basin in Sikkim

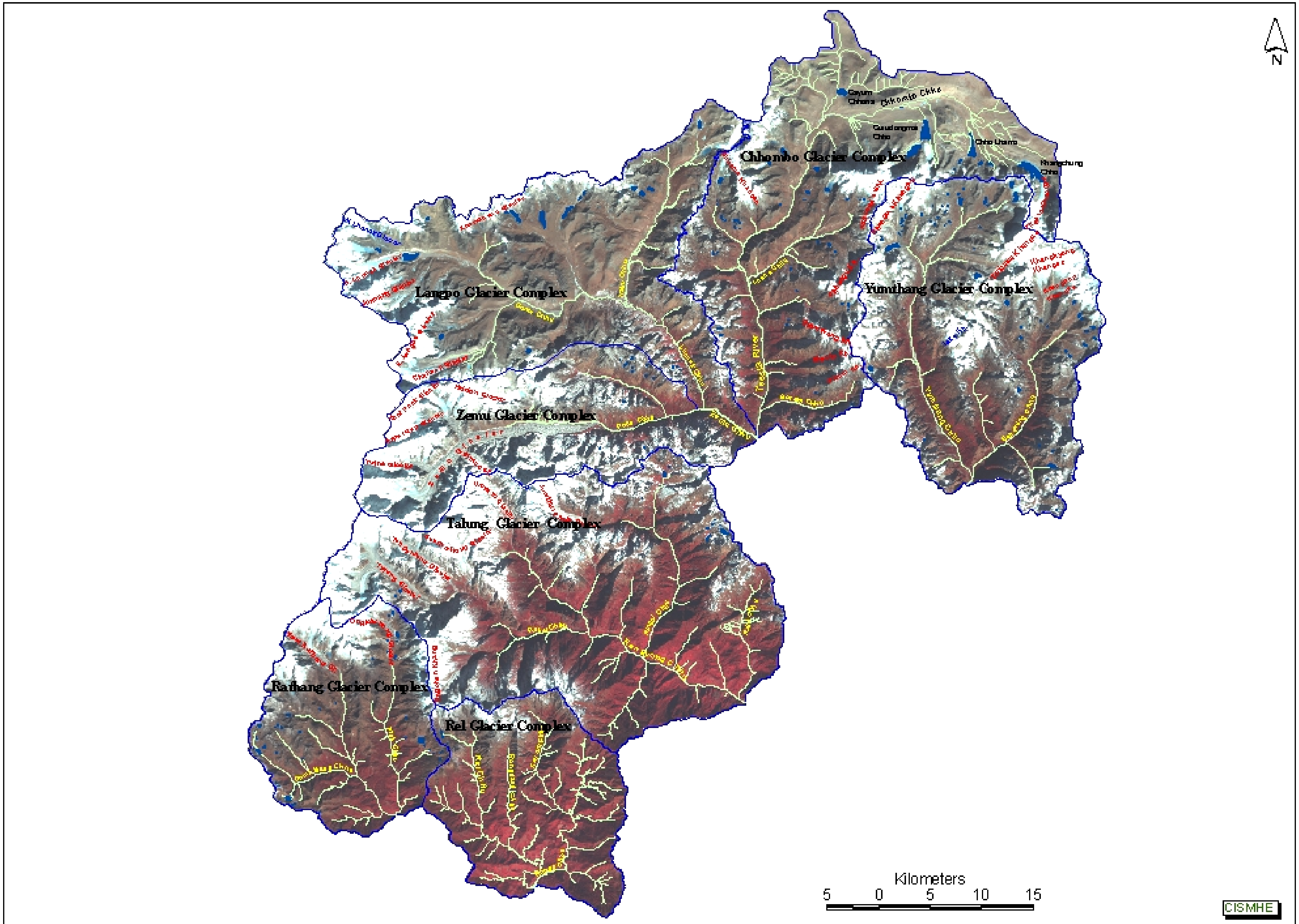


Fig.5.2 Index map of Glacier Complexes in Sikkim

maximum number of major glaciers (12) and has about 11% total area under glaciers.

5.2.1 Chhombo Glacier Complex

This glacier complex constitutes the source of Teesta river and is comprised of at least 11 major glaciers. Teesta river originates as Chhombo Chhu from a glacial lake, Khangchung Chho (5,380 m) located at the snout of Teesta Khangse glacier which descends from Pauhunri peak (7,056 m) (see Figs 4.1 and 5.2), which is one of the highest peaks in north-eastern part of North Sikkim. Along its course in this glacial region, Chhombo Chhu drains another glacial lake *viz.* Chho Lhamo (5,320 m). Chhombo Chhu flows in north-western direction up to Chho Lhamo and further downstream, it flows in E-W direction after draining the water of Gurudongmar Chho (5,270 m). It continues its westward journey up to Oakra village where it receives drainage from Gayum Chho, draining Gayum Chhona lake, on its right bank. Thereafter, Chhombo Chhu is known as Teesta river and flows generally in southward direction for a considerable distance up to Tong village. After passing by Donkung and Gogang villages, it drains water of glacial lakes *viz.* La Chho, Sugu Chho and Gyapji Chho on both the banks. Tasha Phu is first significant tributary which drains into Teesta river on its right bank near Yongdi village (4,200 m) draining the Tasha Khangse glacier. Further downstream it is joined on its right bank by Chhopta Chhu little ahead of Thangu village (3,920 m). Lasha Chhu is first major tributary on the left bank joining Teesta near Thangu. It drains the slopes of Yulhe Khangse glacier and glacial lake Sebu Chho. Teesta river is later joined on its left bank by Kalep Chhu at Kalep village (3,650 m). Kalep Chhu drains glaciated region in the vicinity of Shawaphu (4,966 m). Goma Chhu and Jongten Chhu are small streams that drain into Teesta river near Chotengang and Samdong (3,455 m) on right and left banks, respectively. At Chhochen it is joined by Gyamthang Chhu on its left bank, which originates from Gyamthang Khangse glacier. Further downstream Chento Chhu from Chento Khangse and Burum Chhu from Burum La are some of the tributaries that join Teesta on its left bank near Schacham and Yunga villages. At Zema it is joined by its major tributary Zemu Chhu on its right bank. Therefore, Teesta river from its origin at Pauhunri up to its confluence with Zemu Chhu at Zema, constitutes a distinct watershed as well as glacier complex comprised of 11 glaciers and a number of glacial lakes. Teesta Khangse (source of Teesta), Yulhe Khangse, Chhunga Khangse, Tasha Khangse, Lachen Khangse, Chhopta Khangse, Gyamthang Khangse, Chenta Khangse, Burum Khangse and an unnamed glacier constitute the main source of water resource in this glacier complex. Gurudongmar Chho (151.42 ha), Khangchung Chho (102.95 ha) and Chho Lhamo (127 ha), Gayum Chhona (50 ha) and La Chho (30 ha) are some of the big glacial lakes that contribute to the discharge of Teesta. Gurudongmar Chho and Khangchung Chho are considered as one of the highest glacial lakes in the Himalaya. The glaciers cover more than 96 sq km of area while glacial lakes cover more than 46 sq km of area. Teesta Khangse is the longest glacier (6.10 km) while Gurudongmar Chho, Chho Lhamo and Khangchung Chho are the largest lakes having an area more than one sq km.

5.2.2 Yumthang Glacier Complex

Yumthang glacier complex is comprised of glaciers of Yumthang Chhu and Sebzung Chhu. Yumthang Chhu is formed by the confluence of Dongkya Chhu and Sebu Chhu at Yume Samdong (4,500 m) (see Figs 4.2 and 5.2). Sebu Chhu originates from Changme Khangphu glacier while Dongkya Chhu drains Ramthangphui Khangse and Tenbawa Khangse glaciers. Dongkya Chhu before its confluence with Sebu Chhu also receives drainage from Tenbawa Chhu on its left bank which originates from Khangpup Khangse.

Sebozung Chhu originates above Chhubakha (4,100 m) and receives drainage from Khangkyong Khangse, Khangpup Khangse and a number of glacial lakes. Along its downward course, it is joined by Toklung Chhu, which originates from Toklung Khangse on its right bank. Sebozung Chhu upstream of Lachung village is known as Lachung Chhu. Lachung Chhu then travels westwards to meet Teesta river at Chungthang.

Yumthang glacier complex is comprised of 12 prominent glaciers covering an area of 148 sq km. These are Ramthangphui, Changme, Rulak, Burum, Debo, Tenbawa, Khangkyong, Khangpup (E), Khangpup (W), Toblung, Lako and Sebophyak glaciers. Sanglaphui Chho, Sebu Chho, Kasang Chho and Sima Chhokha are some of the prominent lakes of this complex.

5.2.3 Langpo Glacier Complex

Lhonak Chhu is main drainage of this complex with North and South Lhonak glaciers being the source of this drainage system (see Figs 4.3 and 5.2). These two glaciers on the eastern faces of Lhonak and Jonsang peaks form the origin of Lhonak Chhu as Goma Chhu and is marked by a number of glacial lakes that drain into Goma Chhu. Goma Chhu flows in W-E direction and is joined on its right bank by Phutung Chhu which drains Langpo and Changsang glaciers. Goma Chhu is then joined by Khora Chhu on its left bank which drains Khora Chhobuk (glacial lake) and Khora Khang glacier. Further downstream, it receives drainage from Naku Chhu to form Langpo Chhu. Naku Chhu rises at Naku La and drains a number of glacial lakes, with Thang Chho being the major glacial lake. It flows in southward direction to merge with Goma Chho near Puckchhang. Langpo Chhu, thereafter, takes a southward turn and flows as Lhonak Chhu to join Zemu Chhu near Jakthang on its left bank.

Langpo glacier complex is comprised of 10 glaciers covering an area of 153 sq km of which North and South Lhonak glaciers, Jonsang, E. Langpo, Chanson and Khorakhang are the prominent glaciers. Lhonak Chho and Khora Chho are two most significant glacial lakes of this complex.

5.2.4 Zemu Glacier Complex

Zemu Chhu originates as Poke Chhu from Zemu glacier, which is the largest glacier in Teesta basin and is about 25 km in length (see Figs 4.3 and 5.2). Zemu glacier lies on the eastern face of

Kanchendzonga peak (8,598 m) and is joined by Simvo and Siniolchu glaciers on its right flank and Nepal Gap and Tent Peak glaciers on its left. It is joined by Hidden glacier on its left. Poke Chhu flows in W-E direction and receives drainange on its left bank from Thomphyak Chhu. Thereafter, it flows as Zemu Chhu to drain into Teesta river near Zema village. This glacier complex is comprised of 6 glaciers covering an area of 113 sq km. Green lake is most prominent glacial lake of this region.

5.2.5 Talung Glacier Complex

Talung glacier complex is comprised of glaciers of Rukel Chhu viz. Tongshiong glacier and Talung glacier (see Figs 4.6 and 5.2). These glaciers are located on the eastern faces of Kanchendjunga and Gocha peaks (6,115m). Rukel Chhu flows in S-W direction for some distance where it receives drainage from Tingchen Khang glacier on its right bank. Rukel Chhu then flows as Rangyong Chhu in W-E direction. Rangyong Chhu is joined by Umram Chhu on its left bank. Umram Chhu receives drainage from an unnamed glacier. Further downstream, Rangyong Chhu receives drainage from Ringpi Chhu on its left bank and Ringyong Chhu on its right bank. Ringpi Chhu drains the southern slopes of Siniolchu (6,888 m), Yajuknamteng (5,643 m) and Lamo Angdang (5,862 m) and also receives drainage from Shingo Chho and other unnamed glacial lakes. Rangyong Chhu keeps flowing in S-W direction to join Teesta river on its right bank near Mangan.

Talung glacier complex is comprised of 9 glaciers of which Tongchiong, Talung, Umram, South Simvo, Jumthul Phuk and Tingchen glaciers are prominent glaciers. Together these glaciers cover more than 150 sq km of area. Kishong Chho and Rangen Chho are the two prominent glacial lakes of this complex.

5.2.6 Rel Glacier Complex

Rel glacier complex is comprised of 3 unnamed glaciers covering 6.5 sq km of area and a glacial lake, Leduwa Pokhari. This complex constitutes the source of Rel Chhu, which is an important tributary of Rangit river in West Sikkim.

In addition to the above described seven glacier complexes, there are a number of glacial lakes and snow-fields also in East Sikkim that contribute significantly to the water of resource of Sikkim. Chhangu, Kupup, Namnang, Menmoi Chho, Sherathang and Syebiruk are the prominent glacial lakes in this region. These glacial lakes and snow-fields are drained through Rangpo Chhu and Dik Chhu.

All the glacier complexes cover more than 710 sq km of area, of which constitute about 10% of the total geographic area of Sikkim. Glacial lakes also cover more than 21 sq km of area with Gurudongmar lake being the largest lake and Chho Lhamo lake, the highest lake in Teesta basin.

5.2.7 Rathang Glacier Complex

Rathang glacier complex is comprised mainly of glacier of Prek Chhu, Choktsering Chhu and Rungli Chhu. East Rathang and Onglathang glaciers and two unnamed glaciers source of Rungli Chhu and Tikip Chhu are the 4 glaciers that constitute this glacier complex. These glaciers cover more than 50 sq km of area. There are a number of glacial lakes *viz*. Mujur Pokhari, Lachchami Pokhari, Thulla Jumle Pokhari, Lam Pokhari, Chamliya and Tikuchia Pokhari. The four glaciers and a number of glacial lakes constitute the major point of water resource in West Sikkim.

CHAPTER - 6

TEESTA RIVER BASIN CHARACTERISTICS

6.1 INTRODUCTION

The main Teesta while flowing from north to south divides the state into two parts. Teesta drainage basin in Sikkim cover an area of 7,015 sq km of Sikkim and 81 sq km of the state is under Jaldhaka river watershed, which is not the part of Teesta basin. In order to understand the profile and behaviour of the prominent tributaries of Teesta river basin in Sikkim, Teesta basin was divided into its major tributary watersheds. The entire Teesta basin falling in Sikkim has been delineated into 17 watersheds following the conventional methodology of delineation based upon drainage order classification. For this, Survey of India toposheets at 1:50,000 scale were used, with ridge line demarcating the boundaries between adjacent watersheds. These watersheds vary in size and shape depending upon the drainage pattern in a particular watershed.

The analysis of entire data was done watershed-wise e.g. slope, relief, draining pattern, landuse, soil, etc. The results, therefore, are also presented watershed-wise. The seventeen watersheds are : i) Rangpo Chhu, ii) Rani Khola, iii) Teesta (Lower Part), iv) Dik Chhu, v) Lachung Chhu, vi) Yumthang Chhu, vii) Chhombo Chhu, viii) Zemu Chhu, ix) Rangyong Chhu, x) Lachen Chhu, xi) Prek Chhu, xii) Rel Chhu, xiii) Rathong Chhu, xiv) Kalej Khola, xv) Ramam Khola, xvi) Rangit river and xvii) Manpur Khola (Fig. 6.1). Jaldhaka river watershed drains into West Bengal and not the part of Teesta basin.

The form parameters of these watersheds are given in Table 6.1 and discussed below.

Table 6.1 Physiographic and morphometric attributes of the watersheds in Teesta basin in Sikkim

Assigned Number	Name	Area (ha)	Relief Ratio	Elongation Ratio	Shape
1	Rangpo Chhu	44,802.5	115.9	0.62	L-shaped
2	Rani Khola	25,331.1	129.8	0.62	Canoe shaped
3	Teesta (Lower Part)	59,900.7	10.3	-	Elongated
4	Dik Chhu	24,095.5	147.0	0.61	Canoe shaped
5	Lachung Chhu	60,527.7	68.3	-	Irregular shaped
6	Yumthang Chhu	57,280.8	97.4	0.96	Elliptical
7	Chhombo Chhu	70,001.5	77.4	0.79	Horse shoe shaped
8	Zemu Chhu	99,110.1	73.8	0.79	Rhomb shaped basin
9	Rangyong Chhu	82,050.5	155.2	0.76	Oval shaped (elliptical)
10	Lachen Chhu	16,344.9	75.4	-	Elongated rectangular
11	Prek Chhu	31,345.7	186.4	0.93	Circular
12	Rel Chhu	30,706.1	208.5	0.84	Elliptical
13	Rathong Chhu	27,706.4	143.5	0.71	Canoe shaped
14	Kalej Khola	20,838.6	147.5	0.71	Arcuate
15	Ramam Khola	15,019.5	122.8	-	Elongated
16	Rangit River	28,836.3	11.7	-	Irregular shaped
17	Manpur Khola	8,149.5	191.5	-	Triangular

- Elongation ratio was not determined where the watershed is not a closed basin

The important characteristics of the watersheds, which were analysed, are the shape of the watershed, relief and surface slope. Relief is analysed by a relief ratio. Relief ratio is defined as the ratio between the total relief of a basin (elevation difference of lowest and highest points of a basin) and the longest dimension of the basin parallel to the principal drainage line. Relief ratio allows comparison of the relative relief of any basins regardless of differences in the scale of topography.

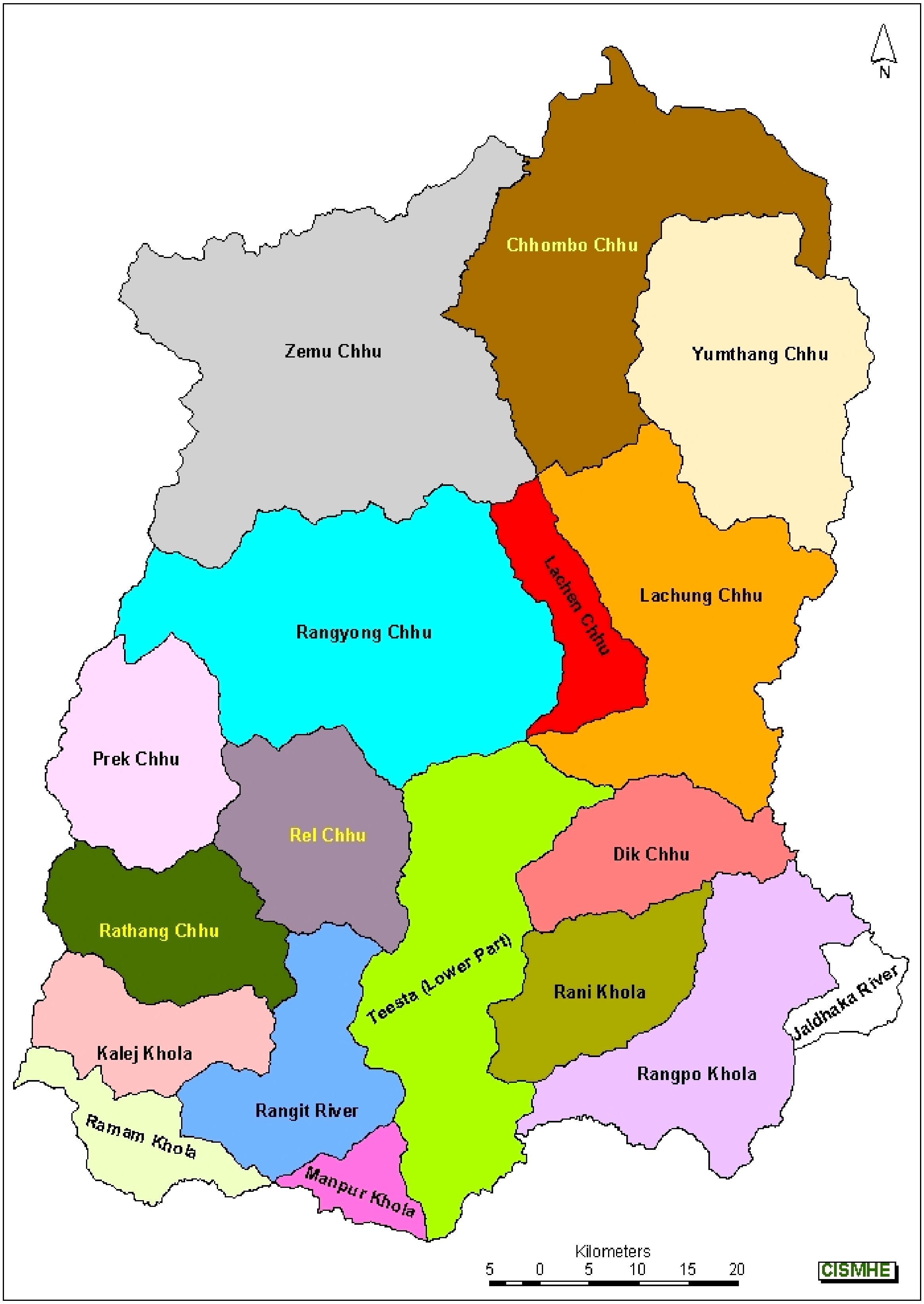


Fig.6.1 Watershed Boundaries of Teesta Basin in Sikkim

The shape of the watershed is expressed by an elongation ratio. Elongation ratio is the ratio between the diameter of a circle with the same area as the basin and the maximum length of the basin as measured for the relief ratio. Wherever this ratio approaches 1 the shape approaches a circle.

The area, relief ratio and elongation ratio are given in Table 6.1 and arranged in decreasing order in Fig.6.2. Zemu Chhu, Rangyong Chhu and Chhombo Chhu are the largest watersheds in the Teesta basin. However, Zemu Chhu and Chhombo Chhu have low relief ratio compared to Rangyong Chhu. Manpur Khola watershed is the smallest watershed in the basin. Rangit river and Teesta (lower part) watersheds have low relief ratio. However, when calculation of the ratio along the main channels is done, the slopes alongside the channels have large elevational ranges. Yumthang Chhu, Prek Chhu, Rel Chhu have high elongation ratios supporting their near circular shapes. On the other hand, lower elongation ratio is observed for Dik Chhu, Rani Khola and Rangpo Chhu watersheds indicating that the basins are elongated.

i) Chhombo Chhu Watershed

Chhombo Chhu watershed is source watershed of Teesta river with a horse-shoe shaped basin having catchment area of 70,001.5 ha and elongation ratio of 0.79. The elevational range covered by the main channel is 2925 m (from 5,280 m to 2,675 m) with relief ratio of 77.4. Zemu Chhu watershed lies at the west of this watershed and

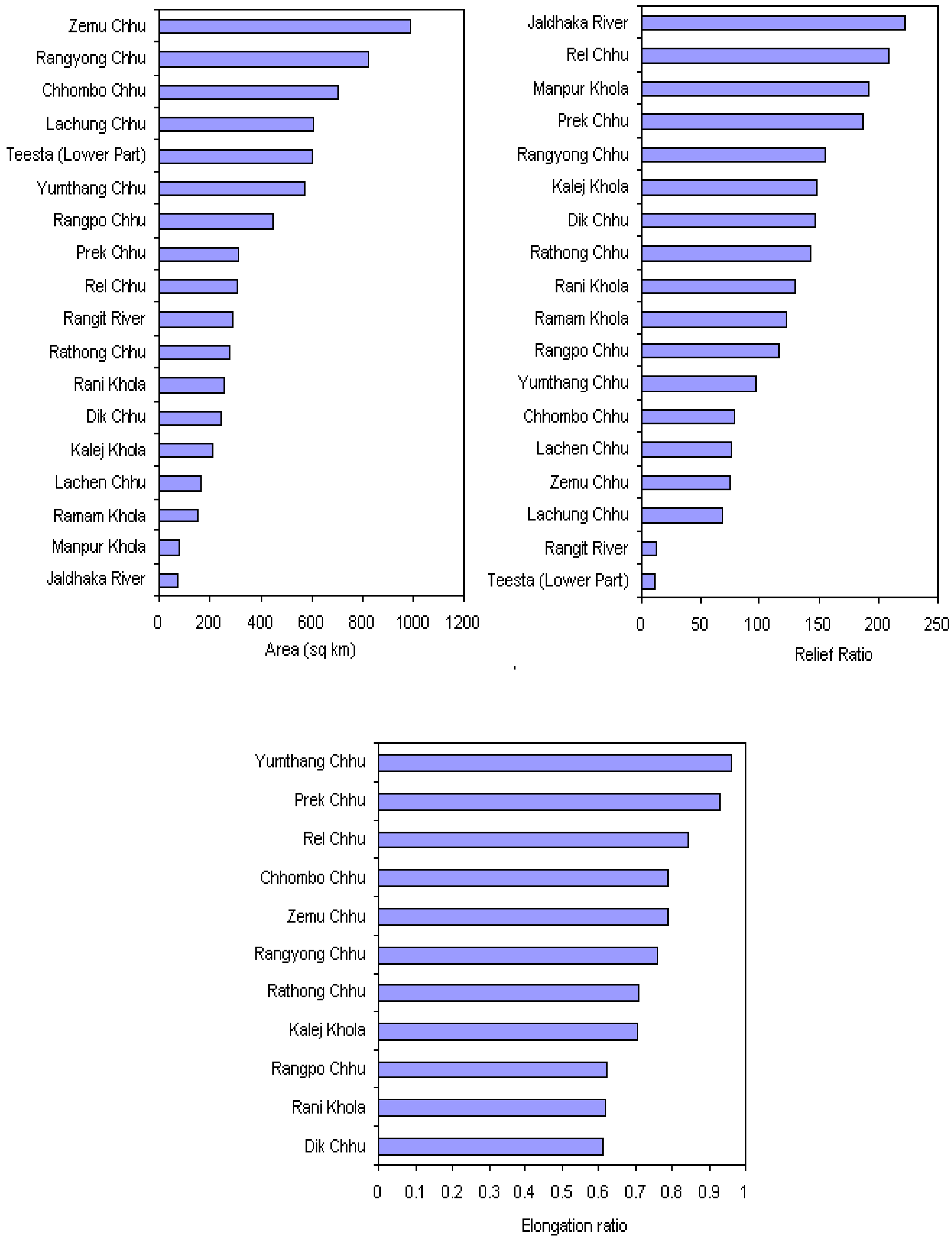


Fig.6.2 The area, relief and shape (Elongation ratio) of the watersheds in Teesta basin in Sikkim

Yumthang Chhu and Lachung Chhu watersheds are situated at its south. The main river flows as Chhombo Chhu from its source Teesta-Khangse glacier up to Oakra and then as Teesta river downstream. The streams are fed mostly from glaciers or glacial lakes. In its northern stretch the watershed is mostly covered with moraines and landslide debris. The slopes of the hills in the southern part of the basin are susceptible to failure. Water availability is very high in this watershed.

ii) Yumthang Chhu Watershed

Yumthang Chhu watershed is an elliptical basin with geographic area of 57,280.8 ha and elongation ratio of 0.96. The elevational range covered by the main channel is 2,735 m (from 5,600 m to 2,865 m) with relief ratio of 97.4. Two major glacier-fed rivers Yumthang Chhu and Sebozung Chhu flow in this watershed. The watershed is mostly covered with moraines and landslide debris. The water availability is also good in this watershed.

iii) Zemu Chhu Watershed

Zemu Chhu watershed is a rhombus shaped basin with catchment area of 99,110.1 ha and elongation ratio of 0.79. The elevational range covered by the main channel (Goma Chhu-Langpo Chhu-Lhonak Chhu-Zemu Chhu), running from NW to SE, is 3,322 m (from 5,997 m to 2,675 m) with relief ratio of 73.8. Chhombo Chhu watershed lies at the east of this watershed and Rangyong and Lachen watersheds are situated at its south. The streams are fed mostly from glaciers or glacial lakes. The largest glacier of Sikkim Himalaya, named Zemu glacier, lies in this watershed. Zemu Chhu flows from west to east and receives water from the Zemu glacier. The watershed is mostly covered with moraines and landslide debris. Water availability in this watershed is very high.

iv) Lachung Chhu Watershed

Lachung Chhu watershed has geographic area of 60,527.7 ha. This is a watershed with irregular geometry and contains the wedge shaped Chakung Chhu sub-watershed, the oval shaped watershed representing parts of Lachung Chhu basin and left slope of parts of Teesta river channel. The elevational range covered by the main channel is 2,115 m (from 2,865 m to 750 m) with relief ratio of 68.3. Because three major rivers and several streams flow in this watershed, the water availability is very high in this region. Several terraces alongside the Teesta river and the gentle slopes along left bank of Teesta provided suitable platforms where settlements have been developed and can undergo further growth.

v) Lachen Watershed

Lachen Chhu watershed is an elongated rectangular watershed representing the right bank slope of the Teesta river between Zemu Chhu-Teesta confluence (2,675 m) and Talung Chhu-Teesta confluence (750 m) with catchment area of 16,344.9 ha. This eastern facing slope is very steep and densely vegetated, however, at the south of Chungthang there are some pockets where settlements have been developed on the old fan lobes, terraces or stabilized landslides. The Teesta river channel covers an elevational range of 1925 m whereas the watershed covers maximum elevational range of 3064 m. The main channel, Teesta river, flows from NW to SE, then from N to S and NE to SW and covers a distance of 42 km. Rangyong watershed lies to the west of this watershed. Lachung Chhu watershed lies in the east and south and Chhombo Chhu and Zemu Chhu watersheds lie in the north. Major streams which flow in this watershed are Yel Chhu, Phim Chhu, Chyaga Chhu, Rokzung Chhu and Ramam Khola. The streams are spring fed. Water availability in this watershed is high.

vi) Rangyong Chhu (Talung Chhu) Watershed

Rangyong Chhu watershed, also known as Talung Chhu in some stretches, is an oval shaped basin with watershed area of 82,050.5 ha and elongation ratio of 0.76. The elevational range covered by the main channel (Rukel-Rangyong Chhu), running from

NW to SE, is 6,588 m (from 7,338 m to 750 m) with relief ratio 155.2. Lachen watershed lies at the east of this watershed and Prek Chhu, Rel Chhu and Teesta Lower watersheds lie at the south of this watershed. The streams are fed mostly from glaciers. Major streams flowing in this watershed are Rangyong Chhu, Rukel Chhu, Umram Chhu, Ringyong Chhu, Ringpi Chhu and Rahi Chhu. At places the watershed is covered with old landslide cones where settlements have been developed. Some new landslide scars are also present. Water availability in this watershed is high.

vii) Prek Chhu Watershed

Prek Chhu watershed is circular shaped with total catchment area of 31,345.7 ha. The main channel, Prek Chhu, flows from NNW to SSE and covers an elevational range of 4,010 m (from 6,670 m to 2,660 m) with relief ratio of 186.4. The elongation ratio is very high (0.93). This is bounded by Rangyong watershed in the north, Rel Chhu watershed in the east, and Rathong Chhu watershed in the south. Major streams which flow in this watershed are Prek Chhu, Kok Churong Chhu, Chokesering Chhu, Rungi Chhu, Tikip Chhu, Yangsa Chhu, Gomathang Chhu, Dhap Chhu and Bhaliajhoreni Chhu. The streams are either glacier fed or lake fed or fed from both the sources. Important glaciers present in this watershed are Onglakthang glacier, Umram glacier, South Shimvo glacier, Tongshiong glacier, Talung glacier and East Rathong glacier. Important lakes present in this watershed are Lachchmi Pokhri, Mujur

Pokhri and Lam Pokhri. Water availability in this watershed is very high. Water of this watershed is drained into Rathong Chu watershed.

viii) Rel Chhu Watershed

Rel Chhu watershed is an elliptical shaped basin having a geographic area of 30,706.1 ha. The elevational range covered by the watershed is 4,883 m (from 5,485 m to 602 m) with relief ratio of 208.5. The elongation ratio of this watershed is 0.84. This watershed is bounded by Rangyong watershed in north, Teesta lower watershed in the east, Pake Chhu watershed in northwest, Rathong Chhu watershed in the southeast and Rangit river watershed in the south. The main channels in this watershed are the Rangit Chhu, a channel flowing from north to south and the Rel Chhu channel flowing from NW to SE. Other major streams are Barme Chhu, Lungdung Chhu, Karsangla Chhu, Kayaru Chhu, Ramam Khola and Rel Chhu. The streams are glacier and spring fed. Some major landslide scars are present along Rel Chhu and Rangit Chhu. Water availability in this watershed is very high. Water of this watershed is drained into Rangit river watershed.

ix) Rathong Chhu Watershed

Rathong Chhu watershed is a canoe shaped basin with catchment area of 27,706.4 ha. The elevational range covered by the watershed is 3,798 m (from 4,400 m to 602 m) with relief ratio of

143.5. The elongation ratio of this watershed is 0.71. This watershed is bounded by Prek Chhu watershed in the north, Rel Chhu watershed in the northeast, Rangit river watershed at the east and Kalej Khola watershed in the south. The main channel, Rimbi Khola-Rathong Chhu, flows from NW to SE. Other major streams are Lungman Khola, Heri Khola, Nambu Khola, Lingsur Khola, Phamrung Chhu, Pathang Chhu. There are several waterfalls at the southern slope of the sickle shaped Langphare Danda ridge. The streams are mostly spring fed. An important lake in this watershed is Chhejo Pokhari which is situated at 1,810 m. Some major landslide scars are present along Rel Chhu and Rangit Chhu. Water availability in this watershed is very high. This watershed receives water from Prek Chhu watershed and drains into Rangit river watershed.

x) Dik Chhu Watershed

Dik Chhu watershed is a canoe shaped basin covering an area of 24,095.5 ha. The main channel, Dik Chhu, is 35 km long and flows from east to west. The elevational range covered by the main channel is 4,214 m (from 4752 m to 538 m) with relief ratio of 147. The elongation ratio is 0.61. Bakcha Chhu is the major tributary of Dik Chhu. The major source of water to these channels is from snowmelt, glacial lakes and seasonal rain. Important landslide that creates problems for the transportation network is B2. Besides there are some sinking zones alongside the road.

xi) Rangpo Chhu Watershed

This is a L-shaped basin covering planimetric area of 44,802.5 ha, with elongation ratio of 0.62. Rangpo river and its tributaries constitute main drainage of this watershed and lies between Rani Khola watershed in north and Jaldhaka river watershed in south-east. The main river, named Rangpo, flows from north to south and then from east to west defining a L-shaped pattern at the left bank of Teesta river. The river covers an elevational range of 4,452 m (from 4,735 m to 300 m). Along the N-S course of Rangpo several streams flowing from NE-SW joins it on the left bank. These streams separated by NE-SW trending ridges define sub-watersheds with high water availability. The right bank slopes are very steep with small streams and therefore with low water availability.

xii) Rangit River Watershed

Rangit River watershed is with irregular geometry and includes the right bank and left bank slopes of the Rangit river between Rel Chhu- Rangit River confluence (602 m) to Ramam Khola-Rangit river confluence (300 m) excluding the Rathong Chhu and Kalej Khola watersheds. The total geographic area of this watershed is 28,836.6 ha. In this watershed the Rangit river changes its course from NW-SE to NE-SW at several points and covers a distance of 38 km with relief ratio of 11.7. The maximum elevational range is 2,429 m along the right bank in the southern part of this watershed. This watershed is bounded by Rathong Chhu, Kalej Khola, Ramam Khola watersheds in the west, Teesta (lower part) watershed in the east, Manpur Khola watershed in the southeast and Rel Chhu watershed in the north. This watershed receives water from Rel Chhu, Rathong Chhu and Kalej Khola watersheds. Major streams flowing in this watershed are Chil Khola, Sangrung Khola, Bania Khola, Rayang Khola, Change Khola, Rishi Khola, Tre Khola, Dong Khola and Roathok Khola. These streams are spring fed. Water availability in this watershed is very high. The water from this watershed drains into Manpur Khola watershed. There are several landslide scars in this watershed. Both the right and left banks of the Rangit river has provided suitable locales for settlements.

xiii) Kalej Khola Watershed

Kalej Khola watershed is an arcuate shaped basin with catchment area of 20,838.6 ha. The elevational range covered by the watershed is 3,399 m (from 3,898 m to 499 m) and relief ratio of 147.5. The elongation ratio of this watershed is 0.71. This watershed is bounded by Rathong Chhu watershed in the north, Ramam Khola watershed in the south and Rangit river watershed in the east. The main channel, Kalej Khola, initially flows from NW to SE and then towards east. Other major streams are Mardom Khola, Pharik Khola, Simpok Khola, Simchar Khola, Bega Khola, Dentam Khola, Hi Khola. This watershed has large number of waterfalls in the left and right of Kalej Khola. The streams are mostly spring fed. Water availability in this watershed is high. The water of this watershed drains into Rangit river watershed. Settlements have developed alongside the main channel from its mouth (499 m) up to 2,000 m.

xiv) Ramam Khola Watershed

Ramam Khola watershed is an elongated watershed with catchment area of 15,019.5 ha. This watershed represents the left bank slope of the Ramam Khola basin; its right bank slope is in West Bengal. The elevational range covered by the main channel Ramam Khola is 3,385 m (from 3,685 m to 300 m) with relief ratio of 122.8. This watershed is bounded by Kalej Khola watershed at the north. The main channel, Ramam Khola, initially flows from NW to SE and then towards east. Other major streams flowing in this watershed and joining Ramam Khola on its left bank are Kali Khola, Ribdi Khola, Riyang Khola and Rani Khola. The streams are spring fed. Water availability in this watershed is high. The water from this watershed drains into Rangit river at the point where it meets with Rangit river and Manpur Khola watersheds.

xv) Manpur Khola Watershed

Manpur Khola watershed is triangular shaped with catchment area of 8,149.5 ha. It represents the left bank slope of Rangit river between Ramam khola-Rangit and Rangit-Teesta confluence. Manpur Khola, a spring fed stream, is the major channel in this watershed with a total fall of 1,290 m (from 2,255 to 260 m) and relief ratio of 191.5. Rangit river flows from west to east at the base of this watershed covering a distance of 20 km. This watershed is bounded by Rangit river watershed in the west and Teesta (lower part) watershed in the east. Another stream which flows in this watershed is Ralu Khola. Water availability in this watershed is high near the basal region. The water from this watershed drains into Teesta river. Settlements have been well developed in this watershed.

xvi) Teesta (Lower Part) Watershed

Teesta (Lower Part) watershed is an elongated basin covering geographic area of 59,900.7 ha. In this stretch Teesta river flows from north to south for 70 km. The elevational range covered by the main channel is 516 m (from 750 m to 234 m) with relief ratio of 10.34. The elongation ratio is 0.55. The slope at the right bank of the main channel is gentler compared to the steep slope alongside the left bank. Besides the Teesta river, major tributaries of this watershed are Ribim Chhu, Run Chhu, Ambithang Chhu, Rangrang Chhu, Mani Chhu, Mormu Chhu, Rangphap Chhu, Samdong Chhu, Rangchang Khola, Brum Khola, Rangpo Khola, Ben Khola, Papung Khola, Kanam Khola, Rabi Khola, and Khani Khola. Water from Dik Chhu, Rani Khola and Rangpo Chhu also flows into this watershed. The stretch of Teesta river in this watershed has good water availability because this is at the southernmost part of Sikkim. However, the streams on the slopes, particularly at the southern part of the watershed, are recharged only through rain water and remain dry during the summer. This watershed has good number of terraces and fans alongside the river where settlements are established or can be established.

xvii) Rani Khola Watershed

This is a canoe-shaped basin covering an area of 25,331.1 ha and is aligned in NE-SW direction with elongation ratio of 0.62. It is bounded by the Dik Chhu watershed in the north, Rangpo Chhu watershed in its south and southeast and Teesta (lower part) watershed in the west. The main river draining this watershed is Rani Khola also known as Rongni Chhu which flows from NE to SW covering elevational range of 3,772 m (from 4,122 m to 350 m). A stream joining on the left bank either flows from east to west or from south to north or from southeast to northwest. A stream joining on the right bank either flows from north to south or from northwest to southeast. Two major tributaries of Rani Khola are Taksom Chhu and Re Chhu, which respectively joins it on the left and right banks. Gangtok, the capital town of Sikkim, is developed on the wedge between the Rani Khola and Taksom Chhu channels. The drainage network indicates that the stretch of Rani Khola downstream of Ranipul (where Taksom Chhu and Re Chhu confluence) will have high water availability.

xviii) Jaldhaka Watershed

Jaldhaka watershed is an arcuate shaped basin with watershed area of 7,561.5 ha. This watershed covers an elevational range of

2,752 m (from 4,752 m to 2,000 m) and relief ratio of 221.9. It represents upper part of the Jaldhaka river; rest of the basin lies in West Bengal. The streams are fed from lakes. Jaldhaka river (also called Di Chhu) is the major channel which flows down through an arcuate valley. Major lakes in this watershed are Bitang Chho, Lam Pokhri, Laba Chho, Nangpo Chho, Chham Chho, and Chumpo Chho. Water availability in this watershed is high. Jaldhaka river is a tributary of Brahmaputra river. Therefore, water from this watershed flows down through West Bengal to Brahmaputra river. As Jaldhaka river does not constitute the part of Teesta river basin, it has not been dealt in detail for different parameters.

6.2 GEOMORPHOLOGICAL PROFILE OF TEESTA BASIN

To understand the geomorphological characteristics of Teesta basin, base map was prepared from the merged scenes of IRS-1D LISS-III, PAN and SOI toposheets at 1:50,000 scale covering entire Teesta basin in Sikkim. Ten broad landforms could be identified in the basin (Figs 6.3 and 6.4). These are ridge, rocky cliff, escarpment, landslide zone, morainic zone, low mountain (< 1,000 m), narrow valley, middle mountain (1,000 - 2,000 m), high mountain (2,000 - 3,000 m), very high mountain (3,000 - 4,000 m) and extremely high mountain (> 4,000 m) along with glaciers. The ruggedness terrain in Teesta basin is evident from the 3-dimensional view of the basin (see Fig.6.5). More than 22% of the total basin area is comprised of very high mountains and as much as 16% area is under perpetual snow.

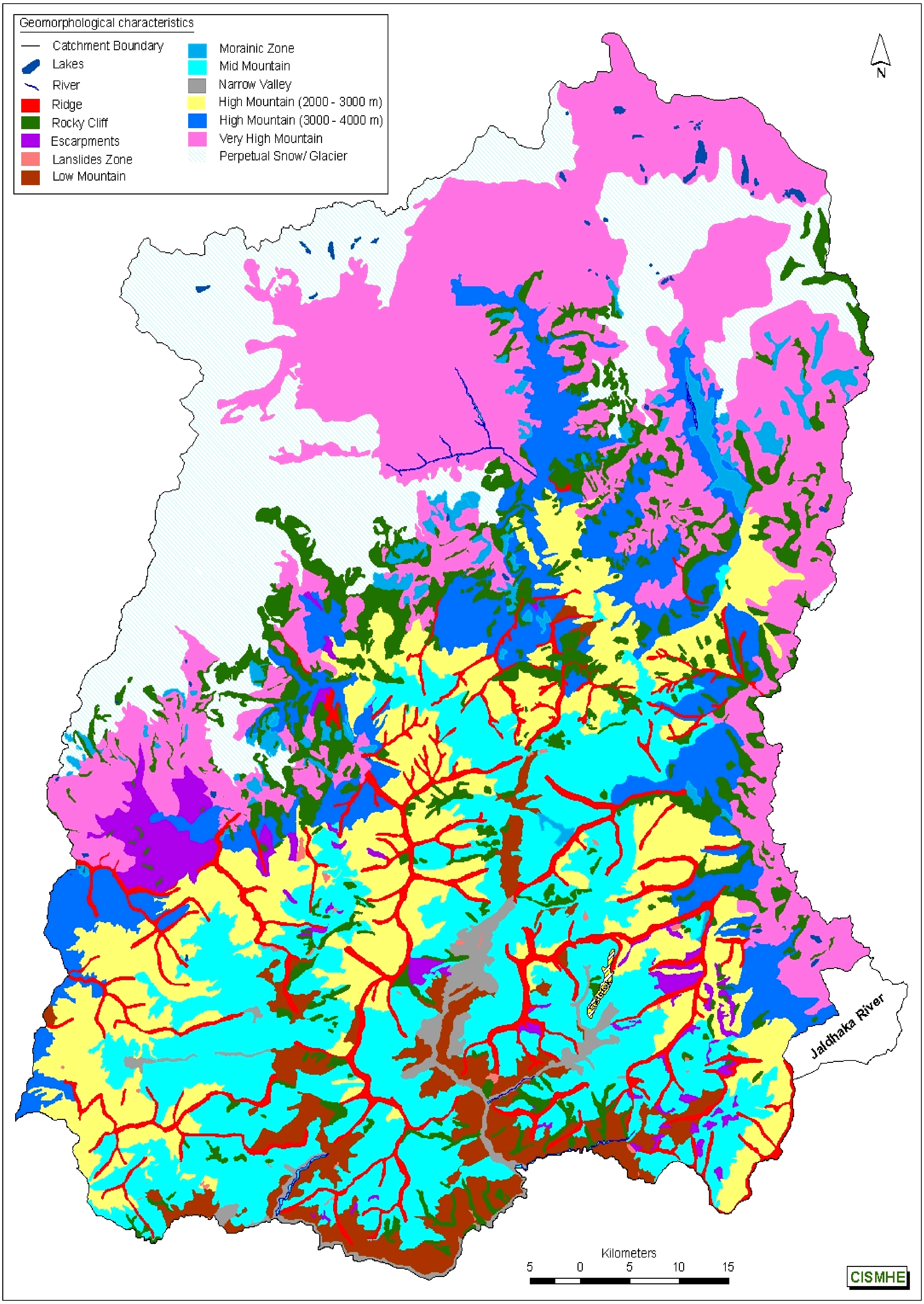


Fig.6.3 Geomorphology map of Teesta basin in Sikkim

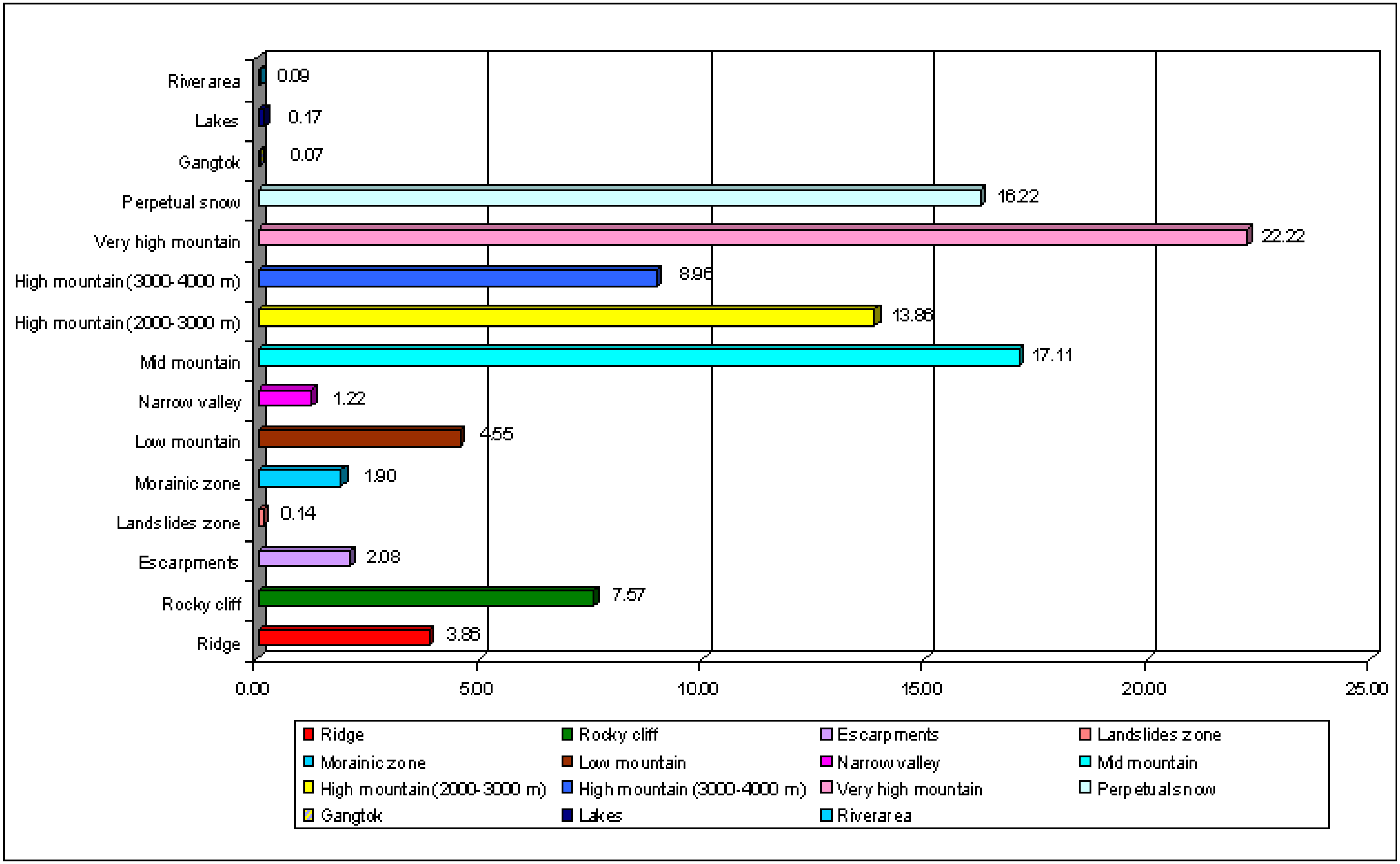


Fig. 6.4 Area (Per cent) under various geomorphology categories of Teesta basin in Sikkim

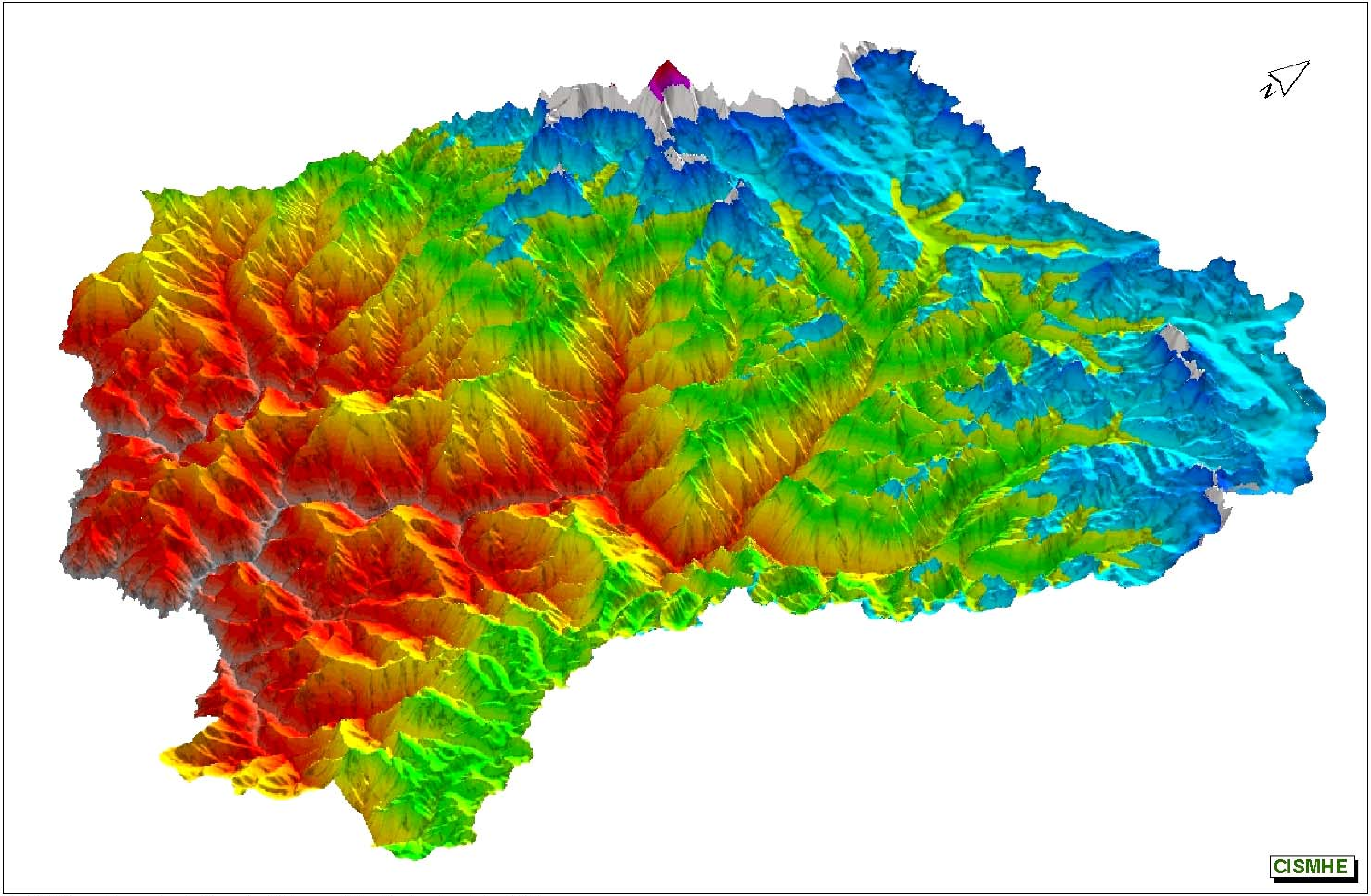


Fig.6.5 Three-dimensional view of relief map of Teesta river basin in Sikkim

Escarpment and narrow valleys comprise more than 3% of the total catchment area.

6.3 RELIEF AND ASPECT

The elevation in Teesta basin varies from 213 m to 8,598 m within distance of about 100 km. The river descends from 5,280 m up to the confluence of Rangit river with it at Melli Bazar along its traverse of about 175 km. Therefore, the river flows in a gradient of about 29 m/km. Nearly 1/4th of the basin area lies in the elevation range of 4,000 to 5,000 m (Figs 6.6 and 6.7). As more than 59% of the catchment area of Teesta basin lies about 3,000 m, Teesta basin in Sikkim, therefore, can be classified as high altitude basin. Even the area between 2,000 and 3,000 m elevation range constitutes 16% of the total basin area. Only 25% of the catchment area lies below 2,000 m, whereas sub-tropical elevation constitute only 6% of the basin.

The predominant aspect in the basin is southern aspect followed by eastern aspects (Fig. 6.8). Only 16% of the mountain slopes are north facing.

6.4 SLOPE

As already discussed the altitudes vary from 213 m to 8,598 m within an aerial distance of about 100 km, therefore, the catchment of Teesta river basin in Sikkim is characterised by steep to very very steep slopes (Figs 6.9 and 6.10). As evident from the figure, more than 52% of the basin lies in slope category of above 27% of the basin lies in slope category of above 27^{o} i.e. steep to very very steep

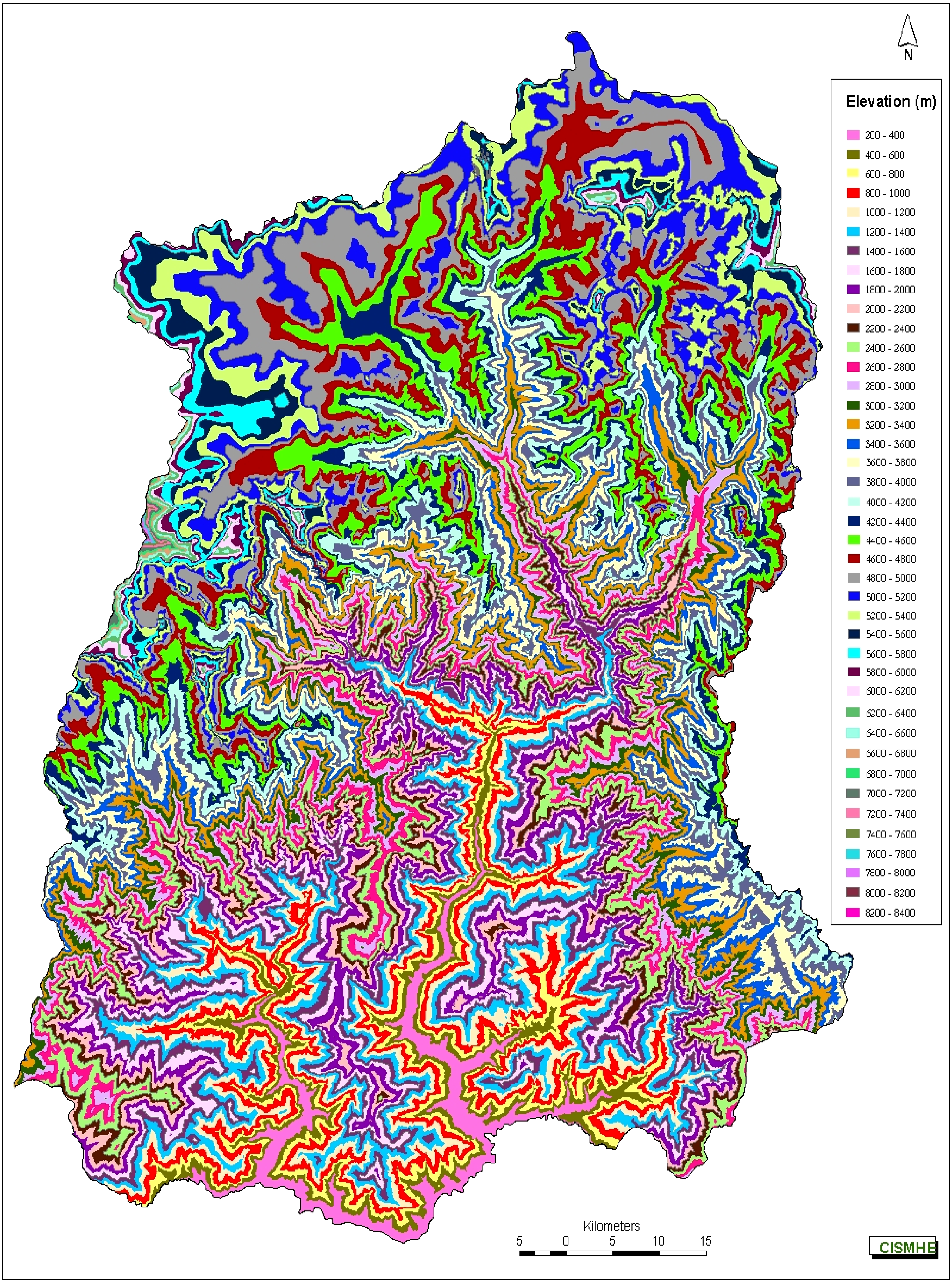


Fig. 6.6 Relief map of Teesta basin in Sikkim

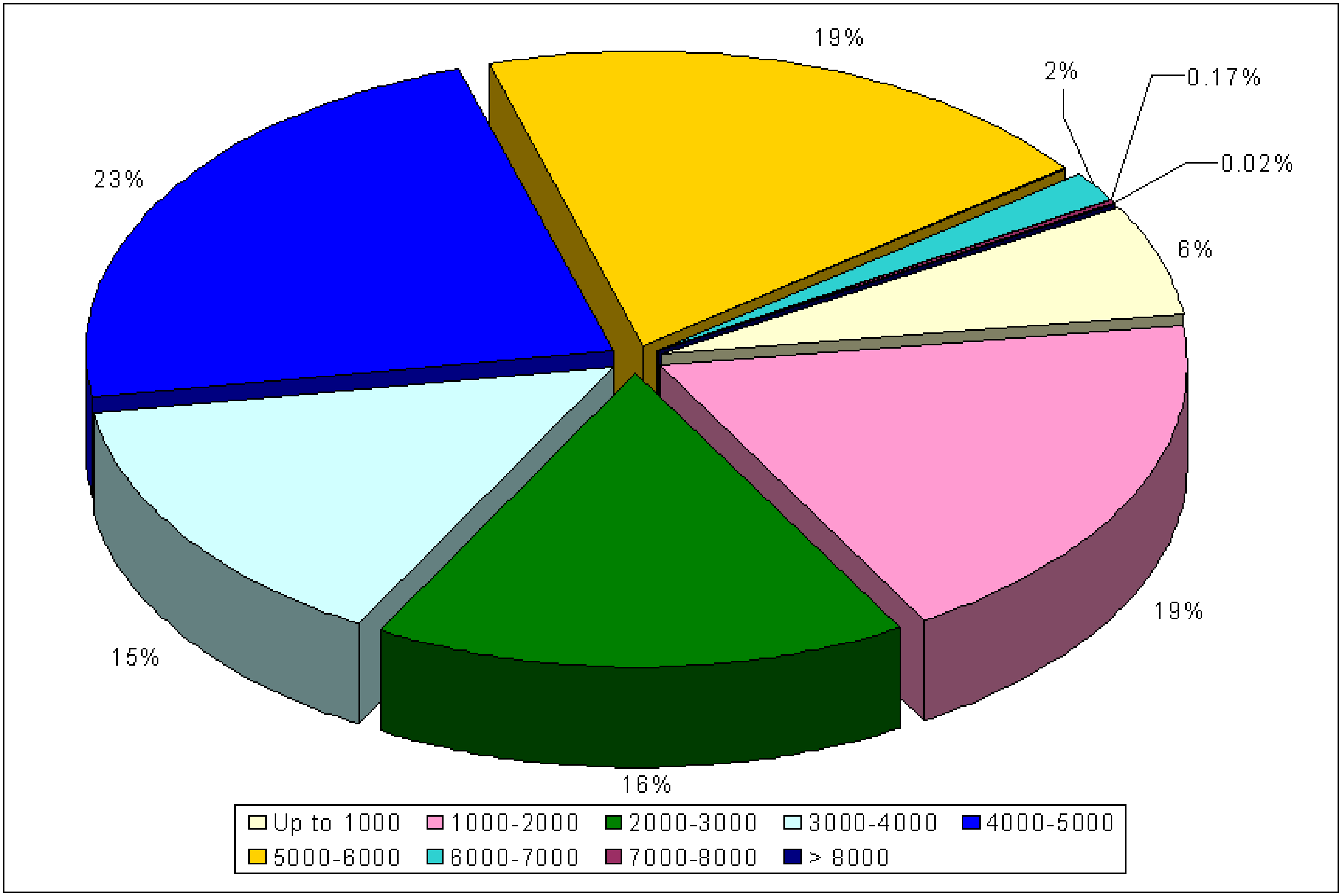


Fig.6.7 Area (per cent) under various elevation categories of Teesta basin in Sikkim

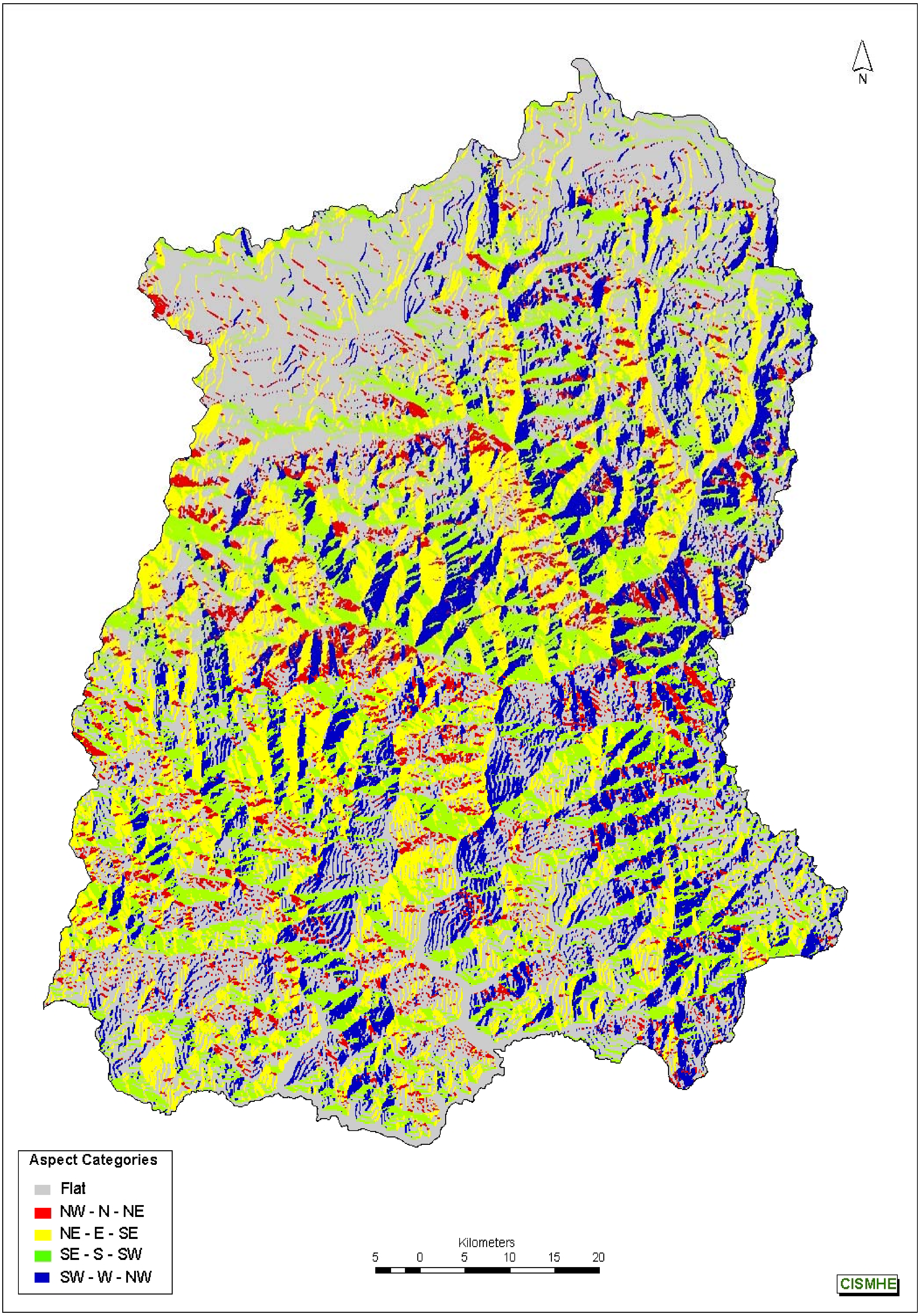


Fig. 6.8 Aspect map of Teesta river basin in Sikkim

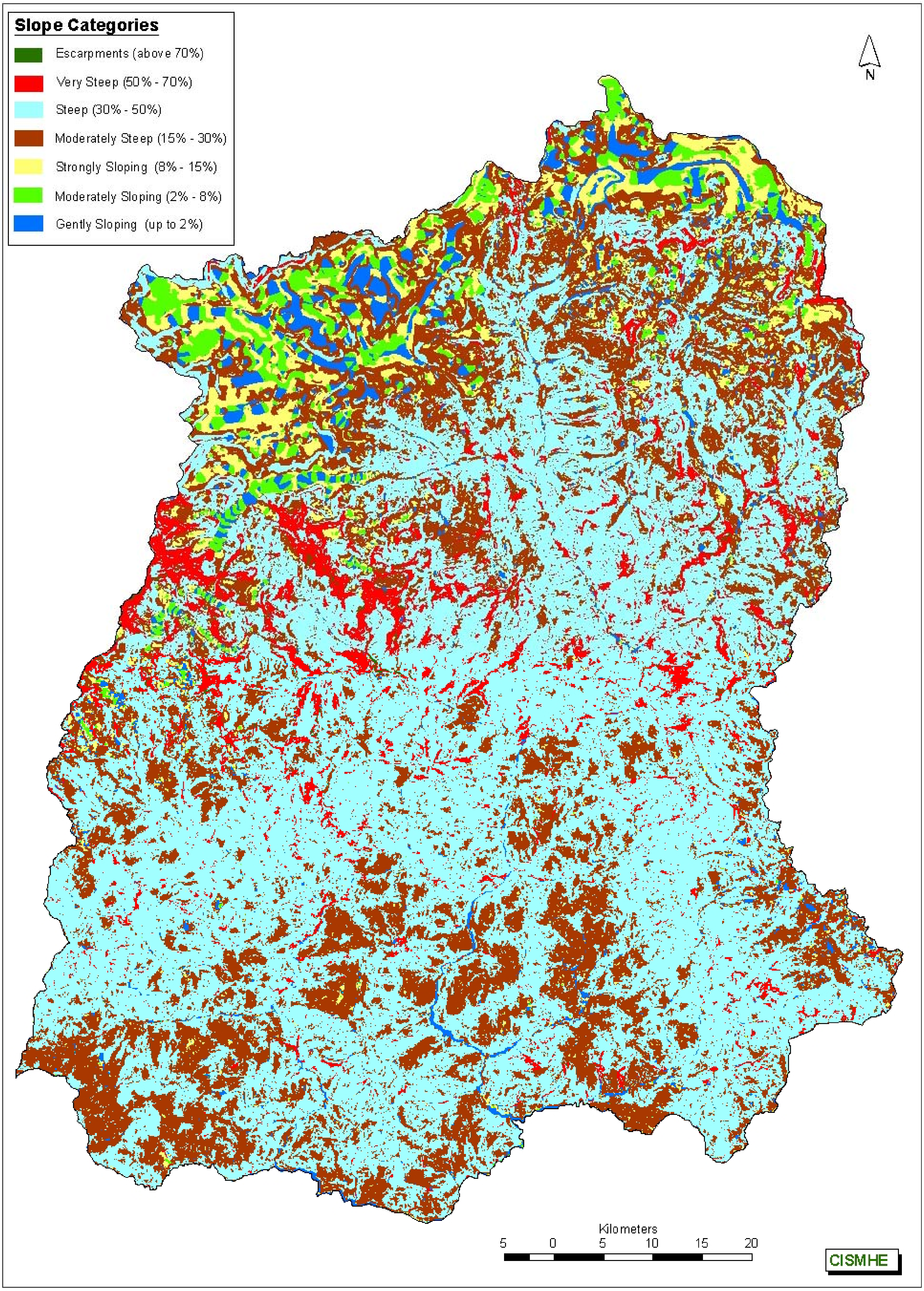


Fig 6.9 Slope map of Teesta river basin in Sikkim

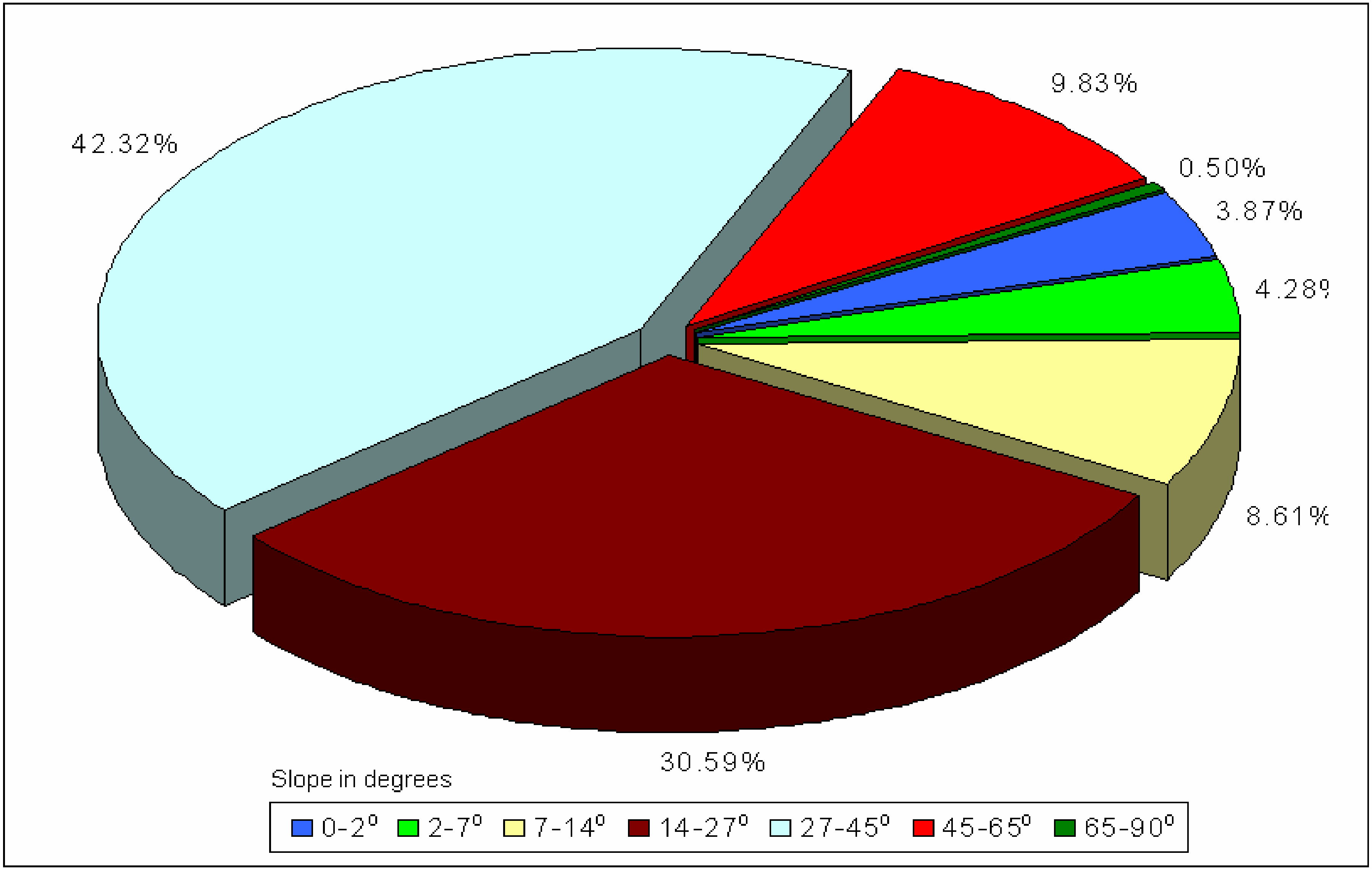


Fig.6.10 Area (per cent) under various slope categories of Teesta basin in Sikkim

slope class. As much as 10.32% of the catchment area is either rocky cliffs or are escarpments i.e. 65^o and above slope class. The catchment area under moderately steep slopes category is only 8.61% of the total. About 4.37% of the basin has area of gentle slope category. Maximum area under gentle slope category is recorded in Zemu valley followed by Chhombo Chhu, both incidentally are the main sources of water in Teesta river. Zemu valley is characterized by 25 km long Zemu glacier with a descending from Khangchendzonga peak with steep moderately steep in the initial stages and gentle gradient in most of its stretch. Chhombo Chhu also is characterized by wide U-shaped glacial valley with moderately steep to gentle gradient slope near the source of Teesta river up to its confluence with Gayum Chho near Oakra.

6.5 SOIL

Soil map prepared by NBSS & LUP, Regional Centre, Kolkata and the legends are given in Fig.6.11 and Table 6.2. The details regarding the soils of Teesta basin are given in Chapter 3 of Volume-II of this report.

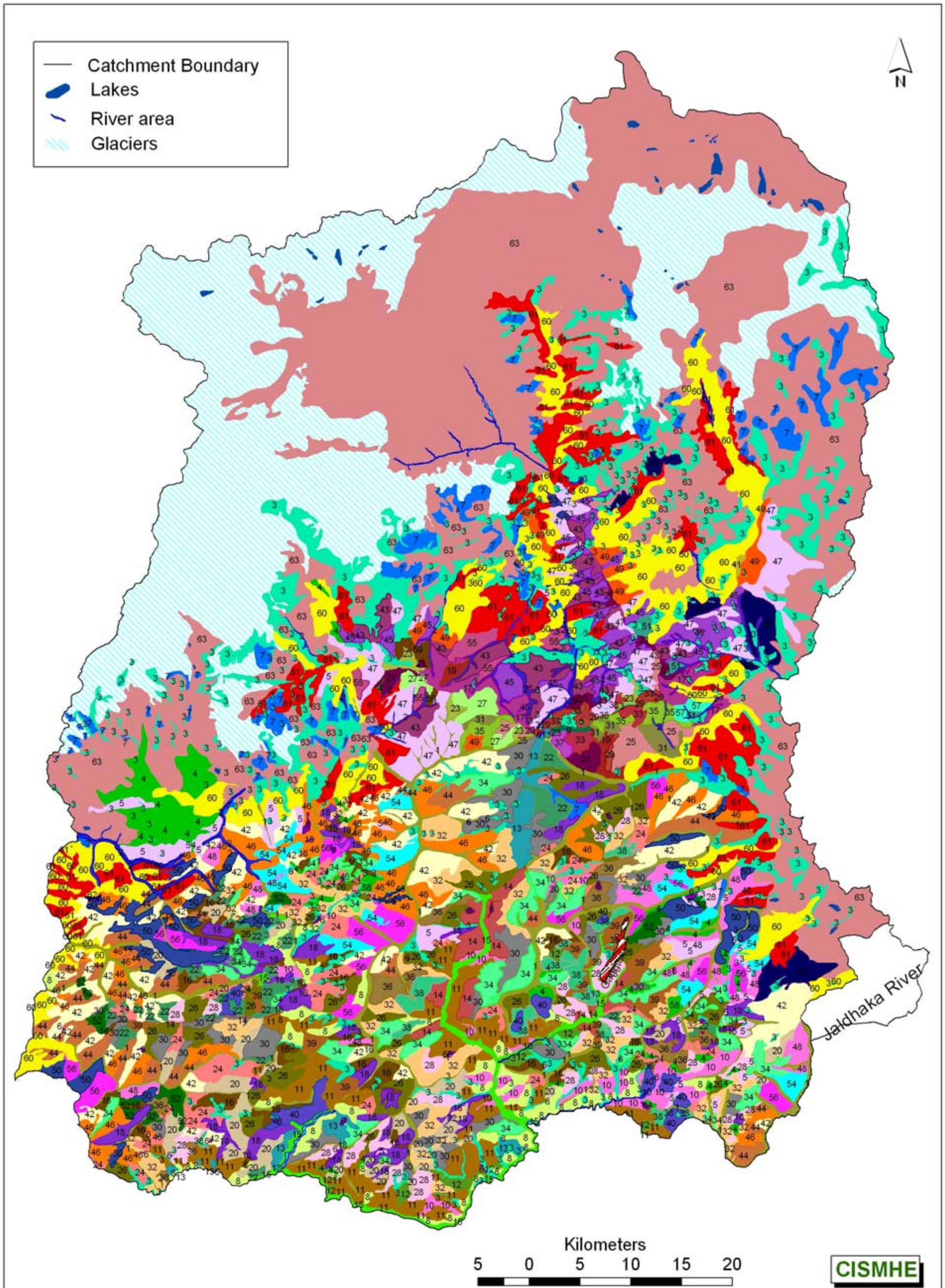


Fig.6.11 Soil map of Teesta Basin in Sikkim (For legend see Table 6.2)

Table 6.2 Legend to the Soil map

	Soil Unit	Soil Series
	1.	Maling-Rayong
	2.	Rubam-Salem
	3.	Rockoutcrops – Jorpul
	4.	Hilley-Singrep – Chatten
	5.	Bhusuk – Karporang - Tibik
	6.	Karporang - Hilley
	7.	Kalep - Rockoutcrop
	8.	Bhasme – Chautare - Legship
	9.	Singhik - Lingthem
	10.	Chalumthang – Rorethang - Bhasme
	11.	Mangjing – Singrep - Rorethang
	12.	Lingtse – Chautare - Chalumthang
	13.	Mangjing - Dharamdin
	14.	Dharamdin – Lingtse - Karfecter
	15.	Mangreg – Karfecter - Mangjing
	16.	Tumin – Phong – Chautare
	17.	Chatten - Theng
	18.	Phong – Khedi - Maniram
	19.	Pakel – Tibik - Rockoutcrop
	20.	Chakung – Tumin - Sajong
	21.	Singhik – Tibik - Lingthem
	22.	Chongrang – Legship - Singgyang
	23.	Singhik – Ruglo - Rapung
	24.	Doling - Khedi
	25.	Gyer – Manul – Lema
	26.	Dikling - Hilley
	27.	Nung – Lingthem
	28.	Samdur – Khedi – Bhusuk
	29.	Lingthem – Lema – Singhik
	30.	Rumtek - Tumin

	Soil Unit	Soil Series
	31.	Bitchu - Ruglo - Pakel
	32.	Bhusuk - Pirik - Namchi
	33.	Manul - Gyer - Rockoutcrop
	34.	Namchi - Synggyang
	35.	Ruglo - Lingthem - Theng
	36.	Doling - Samdur - Rockoutcrop
	37.	Singhik - Pakel
	38.	Rumtek – Pirik - Mangjing
	39.	Daragoan – Gaucharan – Dharamdin
	40.	Dharamdin – Martam – Karfecter
	41.	Mensithang – Lema – Bitchu
	42.	Damthang – Chongrang – Rockoutcrop
	43.	Tibik – Byuma - Mensithang
	44.	Singgyang – Maniram – Damthang
	45.	Chatten – Lema - Tibik
	46.	Maniram – Damthang – Jorpul
	47.	Ship – Theng – Pakel
	48.	Martam – Tarnu – Sajong
	49.	Rapung – Mensithang – Rockoutcrop
	50.	Sajong – Tarnu
	51.	Tibik – Bitchu – Rockoutcrop
	52.	Khedi – Maniram – Rongnek
	53.	Bitchu – Lachen – Chatten
	54.	Rongnek – Sajong
	55.	Ship – Lingthem – Rockoutcrop
	56.	Khedi – Dikling
	57.	Byuma – Ship
	58.	Gaucharan – Tarnu
	59.	Yumthang – Bitchu
	60.	Lachung – Puchikongma – Byuma
	61.	Yumthang – Thangu – Kalep
	62.	Maltin – Lachen – Rockoutcrop
	63.	Thangu – Rockoutcrop

CHAPTER – 7

REMOTE SENSING AND GIS TUDIES - LANDUSE/LANDCOVER MAPPING OF TEESTA BASIN

7.1 LANDUSE MAPPING

The satellite remote sensing technology has found its acceptance worldwide for rapid resource assessment and monitoring, particularly in the developing world. National Aeronautical and Space Administration (NASA) of USA has made most significant contributions with satellite based remote sensing. Since 1972, when Landsat -1 was launched, remote sensing technology and application has undergone a tremendous change in terms of sensor development, aerial flights with improved sensors, satellite design development and operations including data reception, processing, interpretation and utilisation of satellite images. All these developments have widened the applicability of remotely sensed data in various areas *viz*. forest cover, vegetation type mapping and their changes on a regional scale. These developments have indicated that if satellite data is judiciously used along with the sufficient ground data, it is possible to carry out detailed forest inventories and monitoring of landuse and vegetation cover at various scales.

Forests constitute the major proportion of Teesta basin in Sikkim and play an important role in maintaining the ecological balance and regulation of hydrological regime of Teesta river system. In addition, these forests form the first resource of Sikkim and provide wide range of forest related services for the welfare of human populace in Sikkim. As per the Status of Forest Report prepared by Forest Survey of India (2001), the forests of the country as a whole have been decreasing due to increasing demand for fuel wood, fodder, timber coupled with conversion of forest land to non-forest landuse for undertaking various developmental activities. As indicated in this report, however, no authentic information is available on the real time database on the status of these forests.

The satellite remote sensing technology with its synoptic coverage, with medium to high resolution data availability coupled with repetitive availability of coverage of a particular region, has provided an excellent opportunity to map the real time extent of forest cover a period of time. However, due to the constraint of low resolution data availability, no authentic data on forest cover of Sikkim is available. This was also due to the fact that the remote sensing technology and image processing technology was still in infancy in 1970s and 1980s. The only authentic information available on forest cover of Sikkim is of 1988, which was done by Regional Remote Sensing Service Centre, Kharagpur along with Forest Department, Government of Sikkim. However, the data used at that time was of IRS-IA LISS II, which was of very low resolution. Therefore, in this study an exercise has been taken up for the analysis of extent of forest cover depletion was undertaken. For the preparation of latest forest type maps of Teesta basin in Sikkim, LANDSAT 7 ETM+ data was used.

Landuse and landcover mapping of Teesta basin was carried out by standard methods of analysis of remotely sensed data, followed by ground truth collection, and digital image processing of satellite data. For this purpose digital data on CDROMs was procured from National Remote Sensing Agency, Hyderabad. Digital image processing of the satellite data and the analysis of interpreted maps were carried out at the Computer Centre at CISMHE using ERDAS Imagine 8.7 of Erdas Inc.

7.2 STUDY AREA

The study deals with the natural and managed ecosystems of Teesta basin in Sikkim in Eastern Himalaya. The region is characterized by extensive Tropical moist deciduous-semi-evergreen forest, Sub-tropical broad-leaf hill forest, Temperate forest, Mixed coniferous and Fir forests. The study area is also prone to landslides and changes in landscape features.

The objective of the study was to produce a detailed vegetation/ landuse map using hybrid digital classification technique. The study also aims to produce land cover data set appropriate for wide variety of applications.

7.3 DATABASE

The details of primary data in the form of digital data on CDROMs procured from NRSA for interpretation and analysis are given in Table 7.1.

Table 7.1 Database used for landuse/ landcover mapping of Teesta basin

Satellite	Sensor	Path/Row	Date	Data type & Bands
IRS-1D	LISS-III	107/051	19.01.2000	Digital (2,3,4,5)
IRS-1D	PAN	107/052	30.11.1999	Digital (A0)
IRS-1D	PAN	107/052	13.01.2002	Digital (B0)
IRS-1D	PAN	107/052	30.11.1999	Digital (C0)
IRS-1D	PAN	107/051	13.01.2002	Digital (D0)
LANDSAT 7	ETM+	139/41	26.12.2000	Digital (1,2,3,4,5,7)
LANDSAT 7	PAN	139/41	26.12.2000	Digital

For the secondary data, Survey of India topographic sheets 78 A/1 - A/16, 77 D/8, 77 D/12 and 77 D/16 on 1:50,000 scale were referred to for the preparation of base and drainage maps.

7.4 METHODOLOGY

Before processing any image for image enhancement, transformation or classification, pre-processing was done for band separation. Different bands were downloaded into the workstation using ERDAS IMAGINE 8.7. The images were checked for occasional shortcomings in the quality of radiometric and line dropouts. Band separation and windowing of the study area with the help of Survey of India (SOI) toposheets was performed. The registration of image was performed using the nearest-neighbour resampling algorithm (Jensen, 1996). The scene was geometrically corrected with toposheets using proper identification of GCPs with a root-mean-square (RMS) error of 0.0002 to 0.003 pixels. IRS LISS III and LANDSAT 7 ETM+ were radiometrically corrected using dark pixel subtraction technique. They were then co-registered with SOI toposheets using Polyconic projection. Geo-referencing of the composite image was done using digital vector layer of drainage, road network, water bodies and other permanent ground features extracted from SOI toposheets. Distinguishable Ground Control Points (GCPs) both on image and vector database were identified and using these GCPs the image was resampled and geo-coded. Sub-pixel image to map registration accuracy was achieved through repeated attempts. The image enhancement was performed by using different combinations for best image contrast for the full dynamic range for each band employing enhancement techniques like edge detection, filters, manipulation of contrast and brightness, histogram equalisation, etc. False Colour Composite (FCC) was prepared using enhanced data of Bands 2, 3 and 4 of LISS III, IRS-ID as well as of LANDSAT 7 ETM+ (see Fig. 5.1). The image was interpreted digitally using various digital image processing techniques. All operations were carried out using ERDAS IMAGINE 8.7 software. The general procedure for classification involved the following important steps *viz*. enhancement of scene, rectification and classification technique, etc. is given in Fig. 7.1.

In order to utilise the higher resolution of panchromatic image of IRS-ID, image fusion was done to enhance the lower multispectral LISS and ETM+ images. For this purpose a portion of high resolution

PAN image that corresponds with an area of interest in the multispectral LISS and ETM+ images were extracted. Thereafter, both the images were coregistered and LISS and ETM+ images were resampled for merging with PAN image. Merging or image fusion was done by spatial enhancement module of ERDAS Imagine 8.7.

The digital vector layers of state of Sikkim as well as the administrative boundaries of various districts and their sub-divisions and village boundaries obtained from Census of India 2001 maps procured from the Office of the Registrar General of India and boundaries of different watersheds of Teesta basin were prepared from the Survey of India (SOI) toposheets at 1:50,000 scale and the available district maps obtained from NATMO and Survey of India. These vector layers were used as masks to extract the sub-watersheds from the images for further processing. A mosaic image from was prepared from four different PAN scenes. As the scenes were of different dates for a particular year, mosaicing was done by histogram matching using band by band matching tool of ERDAS IMAGINE 8.7. It was from these mosaic images, mask of Sikkim was extracted. From the Sikkim mosaic image, masks of different districts and watersheds were extracted, which were then used for further digital image processing and enhancement.

In the preliminary analysis, image classification was done by unsupervised classification method by performing ISODATA training.

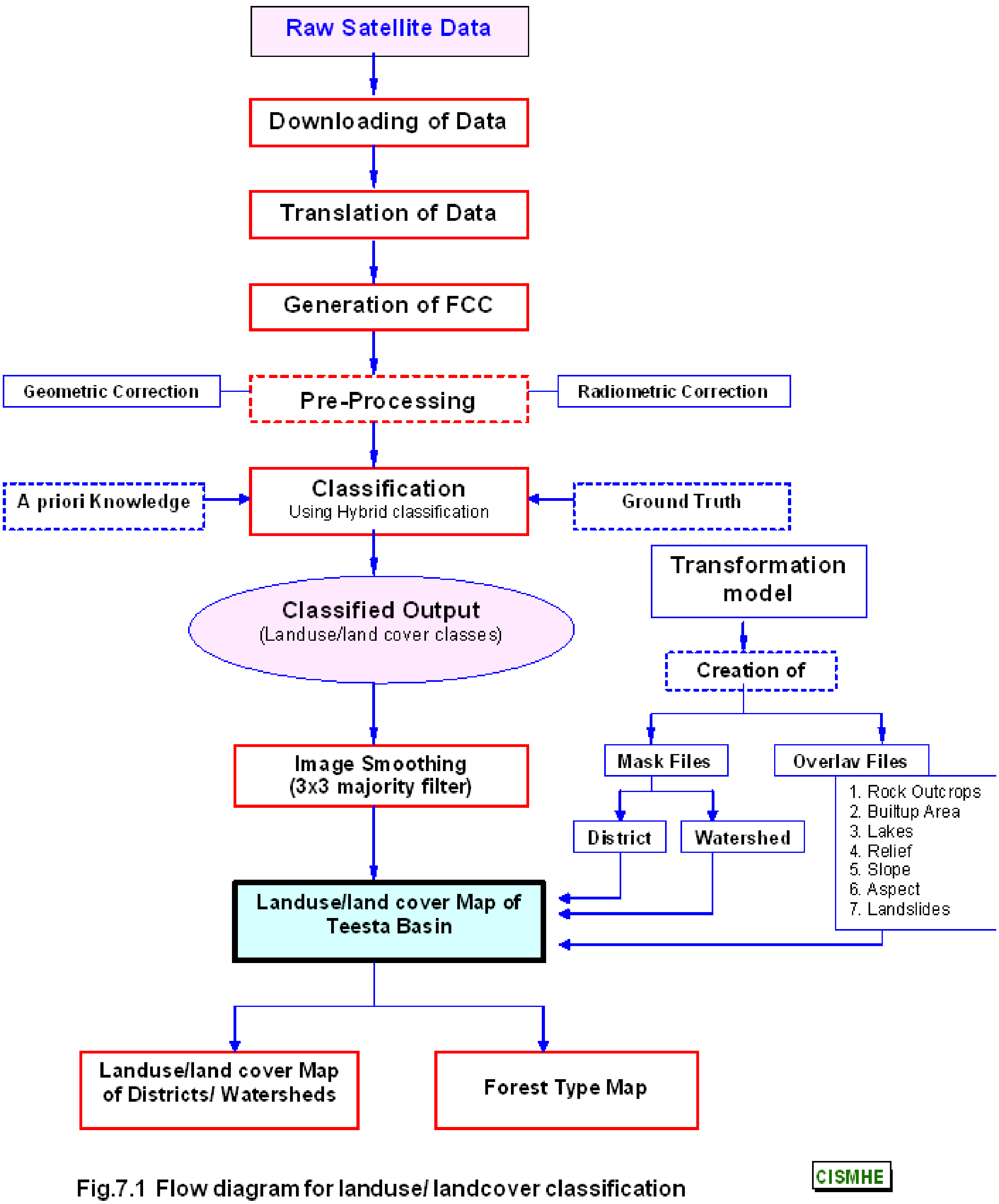


Fig.7.1 Flow diagram for landuse/ landcover classification

It helped in assigning the classification of the image into landuse categories. Later on, the boundaries of water bodies were separately mapped using SOI toposheets and merged with classified image. The doubtful areas or wrongfully interpreted areas owing to various physical features controlling the study area were marked for ground truthing. The ground truth collected during the field surveys was used for the supervised classification for the preparation and identification of landuses resulting in accurate classification of the areas. The classified map was regrouped and merged. The classified raster map, thus prepared, was then converted to vector format for GIS analysis and the preparation of required thematic maps using ArcGIS 9.0 and GeoMedia Professional 5.2. Reconnaissance surveys of different parts of Teesta basin were conducted in the months of May-June, 2002 and May-June, 2003. These trips were mainly undertaken to understand the terrain and vegetation structure of the study area. However, only a limited ground truthing could be done as the permission for entering the protected as well as forested areas in different parts of Sikkim was not granted by the Forest Department.

Remotely sensed vegetation indices have been recommended to remove variability caused by canopy geometry, soil background, sun view angles and atmospheric conditions when measuring biophysical properties (biomass, LAI and percent green vegetation cover) of vegetation at canopy scale (Blackburn & Steele, 1999; Boegh *et al.*, 2002; Elvidge & Chen, 1995; Gao *et al.*, 2000; Schowengerdt, 1983; Tucker, 1979).

As Teesta basin is entirely hilly, the classification of the undulating terrain is difficult. Different areas with brightness and intensity values of same class occasionally fall within shadow, partially shadow and non-shadow area. Therefore, it is difficult to extract useful information from these areas. In order to overcome this, technique of ratioing was used to enhance the image to a certain extent. Linear stretching technique was also used to overcome these difficulties. All these techniques were used in combination for judicious training of datasets during supervised training during classification. The classes in the shadow areas were assigned classes similar to the neighbourhood classified non-shadow area and linear stretching.

As the data sets were of different time periods, a number of difficulties were encountered in classification process. The most widely used vegetation indices are computed using data from the red and near infrared (NIR) portions of the electromagnetic spectrum (Treitz & Howarth, 1999). These vegetation indices operate by contrasting intense chlorophyll pigment absorptions in the red against the high reflectance due to multiple scattering in the near infrared (Elvidge & Chen, 1995; Hoffer, 1978; Todd *et al.*, 1998). Widely used vegetation indices such as normalized difference vegetation index (NDVI) (Tucker, 1979; Wiegand *et al.*, 1991), transformed vegetation index (TVI) (Richardson & Wiegand, 1977; Rouse *et al.*, 1973), simple ratio (SR) (Jordan, 1969; Maxwell, 1976) and difference vegetation index (DVI) respond to these differences in the near infrared and the visible regions (Lillesand and Kiefer, 1994; Schowengerdt, 1983). In addition, indices that control for variations in soil background effects as well as atmospheric induced variations have also been developed. These include the perpendicular vegetation index (PVI) (Richardson & Wiegand, 1977), weighted difference vegetation index (WDVI) (Clevers, 1988), soil adjusted vegetation index (SAVI) (Huete, 1988), transformed soil adjusted vegetation index (TSAVI) (Baret & Guyot, 1991) and modified normalized difference vegetation index (MNDVI) (Liu and Huete, 1995).

Based on broadband satellite images, vegetation indices such as Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR), Transformed Vegetation Index (TVI) and Transformed Soil Adjusted Vegetation Index (TSAVI) have been widely used to measure vegetation quantity, leaf area index (LAI) and percent green vegetation cover of vegetation at canopy scale (Blackburn & Steele, 1999; Boegh *et al.*, 2002; Elvidge & Chen, 1995; Gao *et al.*, 2000; Schowengerdt, 1983; Tucker, 1979). Although these indices have been successfully used in areas with open canopy cover or sparsely vegetated regions, they have not been successful in estimating quantity at high canopy density. Specifically, the widely used vegetation indices particularly NDVI derived from broad band satellite images such as NOAA or Landsat TM tend to saturate after a certain biomass density or LAI (Gao *et al.*, 2000; Sellers, 1985; Thenkabail *et al.*, 2000; Todd *et al.*, 1998; Tucker, 1977).

Accurate quantitative information on the distribution and phenology of vegetation formations is limited, yet is fundamental for the effective management of forest resources. The spatial distribution of NDVI values has been dominated by the high values in October and December. The senescence stages in April and May for deciduous forest can be clearly demarcated by the spatial distribution of NDVI values. The comparative analysis revealed the influence of seasonal variation on the vegetation. During January–March, the vegetation showed a growing trend. From April to June, the decrease in NDVI values is seen. The maximum NDVI image has been computed to represent the maximum foliage cover in the time period.

In the present studies, biophysical processing was carried out using Band 1 and Band 2 and NDVI was calculated for different months for which data sets were available. Maximum NDVI was calculated for the entire study period. For the mapping, maximum NDVI, and Band 1 (Red) and Band 2 (NIR) data sets were taken. The mapping involves using clustering algorithm based on the ISODATA algorithm. Each cluster was assigned a preliminary cover type considering the spatial and spectral pattern, multi-temporal statistics of each class and comparison with ancillary data and ground truth. Ancillary data included descriptive land cover information, NDVI profiles and class relationships to the other land cover classes. Related 'single category' classes were then grouped using a convergence of evidence approach. The cloud classes were masked out using supervised classification. The unsupervised classification was followed by post classification refinement. The hybrid approach was used to refine the classes. The classes were labeled using the spectral values from ground truth, available data sets and spectral analysis of the data sets. For evaluation of classification, comparisons were made at a regional level with the available forest database. The classes and statistics were in correlation to the ground reality.

7.5 CLASSIFICATION SCHEME

The classification scheme adopted for the preparation of landuse/landcover maps and related thematic maps on 1:50,000 scale is as follows. Two forest density classes were interpreted for the forest cover mapping. The forests with >40% canopy cover were delineated as dense forests and between 10% and 40% crown density as open forest. In non-forest agriculture with settlements, degraded land/barren and rockyland, snow/ice cover, glaciers, etc. were delineated.

Landuse/landcover	**Remarks**
Dense forest	Tropical Moist Deciduous Forest
(Crown density > 40%)	Sub-tropical Forest
	Temperate Forest
	Sub-alpine Forest
Open forest	Tropical Moist Deciduous Forest

(Crown density < 40%)	Sub-tropical Forest Temperate Forest Sub-alpine Forest Mixed Conifer Forest Fir Forest Pine Forest
Sub-tropical scrub	Scrub
Alpine Scrub	Temperate scrub Alpine scrub Alpine meadows

Agriculture/Settlements
Barren Rockyland/ Alpine Barren
Moraines
Snow
Glaciers/Ice fields
Lakes

An interpretation key was prepared based on the relationships between ground features and image elements like texture, tone, shape, location, pattern. Image interpretation was done for the entire Teesta basin. Interpreted details (polygons) were then transferred to base map. Since satellite data is geo-coded there was not much error in the geometry of the data and wherever necessary, local matching was done while transferring the details.

The base map, drainage map and landuse/landcover map prepared using the satellite data were digitized on computer for further processing and analysis using the GeoMedia Professional 5.2.

The Survey of India toposheets at 1:50,000 scale were used for the delineation of watersheds in Teesta basin in Sikkim. These watersheds were then overlaid on the drainage map, PAN-LISS merged enhanced images and landuse map of the catchment in order to extract the drainage and landuse of the respective watersheds. All the different theme layers, i.e. base map, drainage and landuse/land cover maps were then transferred to Geographic Information System (GIS) using GeoMedia Professional 5 for further overlay analysis.

The mask image of Teesta basin was divided into forest and non-forest areas in the beginning and was then classified separately. The digital data was rectified to match with Survey of India toposheets. False Colour Composites (FCCs) of each district were extracted from the FCC of Teesta basin. For the purpose of ground truthing, sufficient ground truth points were identified which covered entire range of image characteristics like tone, texture, association with other features, location, etc. As already stated hybrid classification approach was used. The density map was prepared using NDVI technique. For forest type map, queries were run using modeler and knowledge classifier modules of ERDAS Imaging 8.7. The layers used for classification were relief, slope, aspect, landslides and geological formations. Therefore, landuse/landcover maps were generated for all the watersheds and districts separately. Ground truth collection, however, could be done only for limited areas as the permission to undertake surveys in protected areas was not granted by the State Forest Department.

Some of the landuse/ landcover classes still could not be classified from the image due to the effect of shadow and cloud in upper reaches. This was, however, partly overcome by taking the help of Survey of India toposheets.

7.6 LANDUSE/ LANDCOVER

During the Phase-I, a preliminary level-1 landuse/ landcover map of only North Sikkim was prepared. However, in the Phase-II & III, a detailed level-2 landuse/ landcover map i.e. forest type map has been generated for the entire Teesta basin, which is based on limited ground truth collection.

Total forest cover of Teesta basin in Sikkim as per the landuse/ landcover map prepared from IRS-1D LISS-III of 2002 data is 2790.84 sq km i.e. 39.33% of total geographic area of Sikkim is under forest cover (see Table 7.2 and Figs 7.2, 7.2a & 7.3). Only 12.96% of area is under dense forest cover i.e. forest cover with crown density more than 40%, whereas area under open forest cover (crown density between 10 and 40%) is 26.36%. The forest cover prepared during the present study compares very well with one prepared by Regional Remote Sensing Service Centre, Kharagpur from IRS-1A

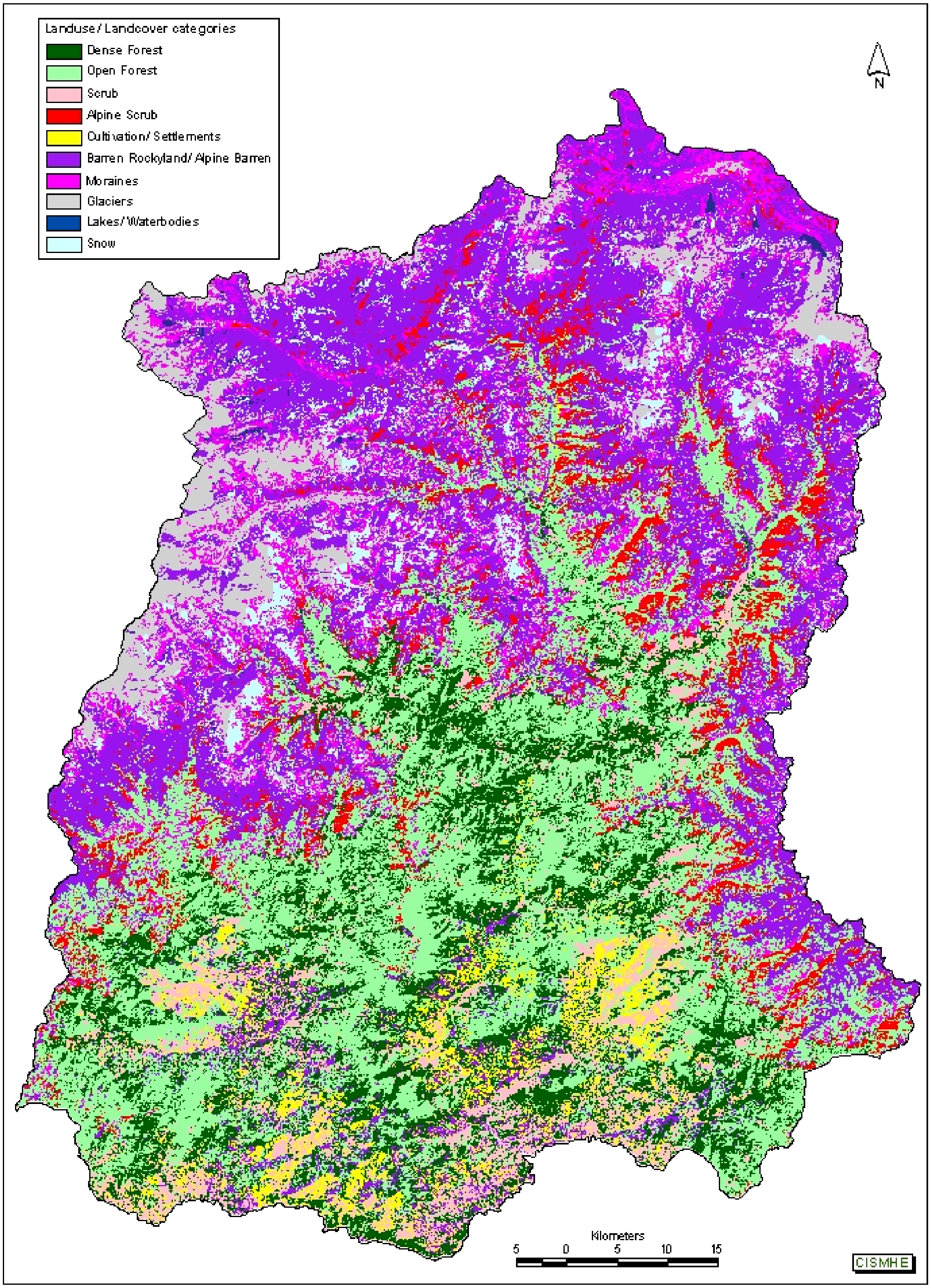


Fig.7.2 Landuse/ landcover map of Teesta basin in Sikkim

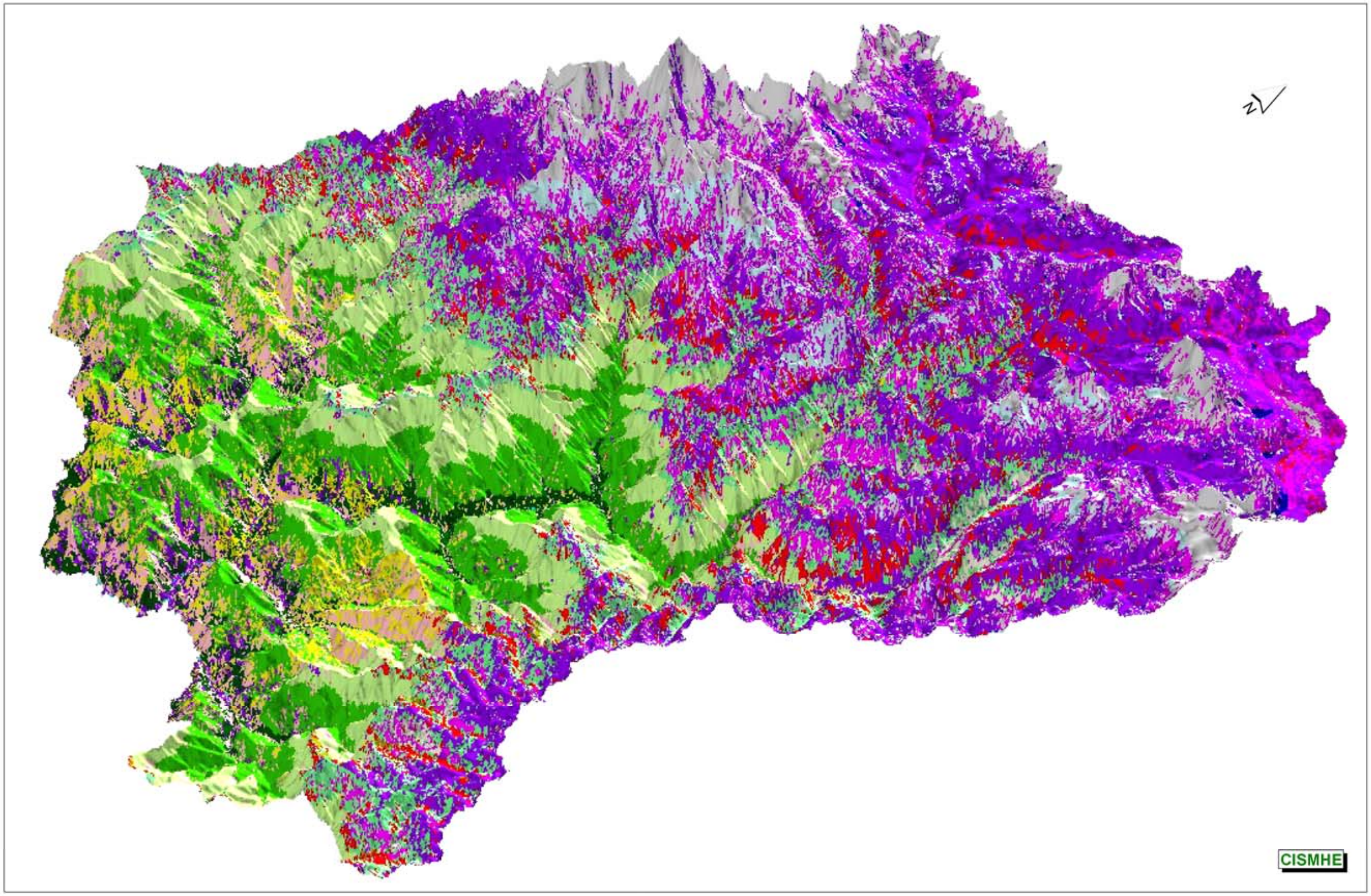


Fig.7.2a Three-dimensional view of landuse/ landcover map of Teesta river basin in Sikkim

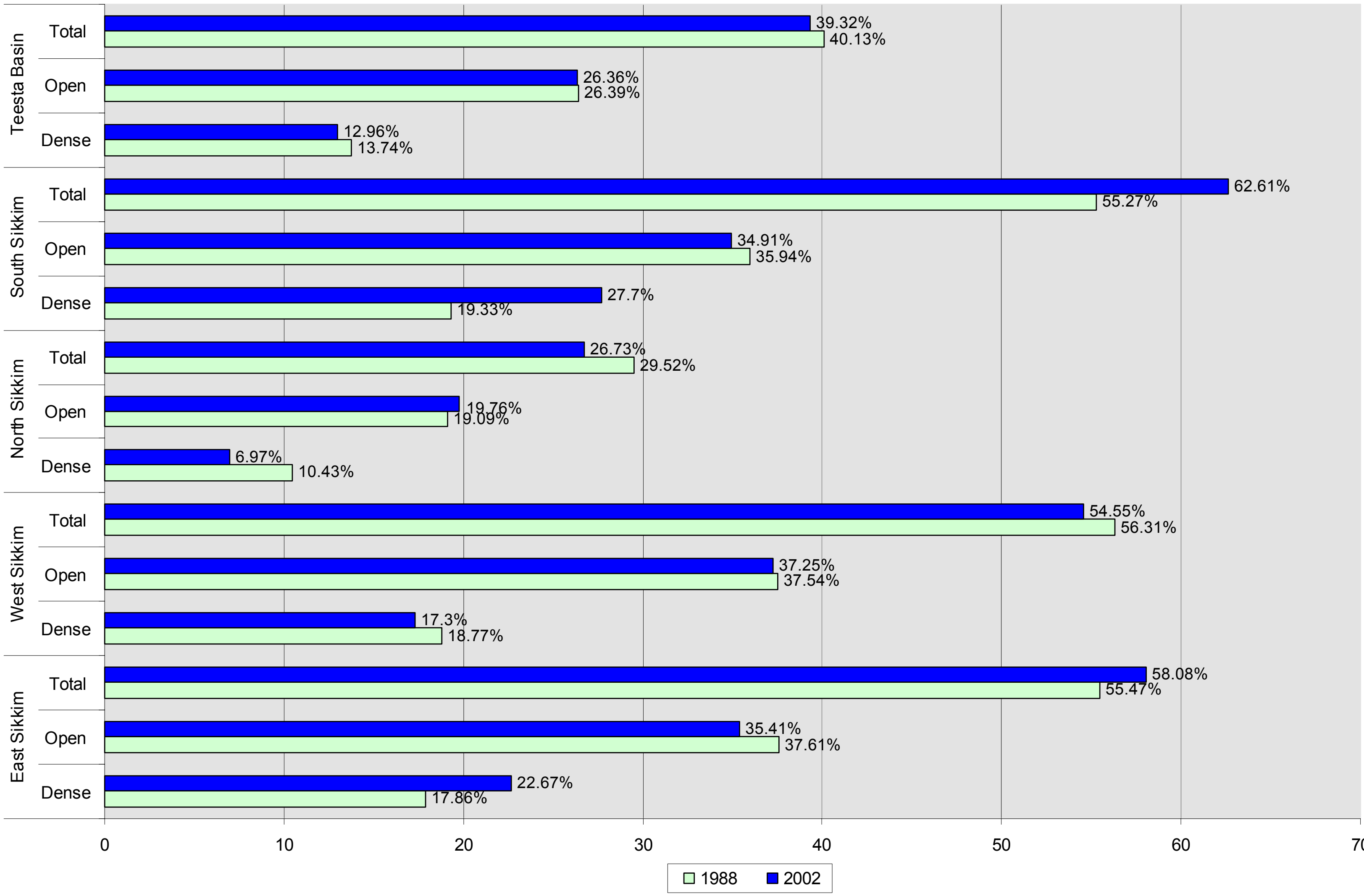


Fig.7.3 Per cent area under different forest cover density categories in Teesta river basin in the year 1988 and 2002

negligible decrease in forest cover since 1988, with dense forest cover decreasing by 5-7% while open forest cover has not shown insignificant change. However, within district, the forest cover has changed from dense category to open category. While East Sikkim and South Sikkim districts show increase in dense forest cover corresponding with decrease in open forest cover category. In West Sikkim district dense forest cover has decreased from 218.84 sq km to 204.02 sq km (6.77% decrease). It is in North Sikkim, dense forest cover has decreased appreciably. It has decreased by 33.24% and total area under forest also has decreased by 9.51%. Due to the non-availability of digital data of 1988 processed by RRSSC, Kharagpur and State Forest Department of Sikkim, it was not possible to analyse the spatio-temporal changes in forest cover change since 1988. The discrepancy in differences in forest cover in 1988 and 2002, is generally due to the different data sets used for processing. The data of 1988 was of low resolution whereas the current data is of very mji9 quality and resolution. The comparisons, therefore, are not very valid. However, the present data of 2002 is discussed watershed-wise below.

Table 7.2 District-wise forest cover (sq km) in Teesta basin

District	Geographic Area (sq km)	Dense Forest		Open/Deg. Forest		Total Forest	
		1988	2002	1988	2002	1988	2002
East Sikkim	954	170.40	216.84	358.79	338.74	529.19	555.58
West Sikkim	1166	218.84	204.02	437.69	439.33	656.53	643.35
North Sikkim	4226	440.94	294.37	806.60	835.04	1247.54	1129.41

South Sikkim	750	144.96	204.62	269.57	257.88	414.63	462.50
Total	**7096**	**975.14**	**919.85**	**1872.65**	**1879.99**	**2847.79**	**2790.84**

7.6.1 Chhombo Chhu

Chhombo Chhu watershed, being a high altitude watershed, has little forest cover, i.e. only 8% of its area is under forest that too is of open category (Figs 7.4 - 7.6). Alpine scrub cover about 9% of its area. The watershed has more than 52% of its area under barren rockyland landcover comprised of scree slopes and rocky outcrops with no vegetation at all. In addition moraines constitute about 15% of the area whereas glaciers and permanent snowfields cover 9.9% area and snow accounts for more than 5% of watershed area. Due to the presence of number of glacial lakes like Chho Lhamo, Gurudongmar Chho, Khangchung Chho, etc., these account for about 1% of watershed area.

7.6.2 Yumthang Chhu

Like Chhombo Chhu, Yumthang Chhu watershed also does not have much forest cover and only 11% of its area under forest cover of open category (see Figs 7.6 - 7.8). Alpine scrub accounts for 8% of watershed area. About 45% of watershed area is under barren rockyland and moraines cover about 13% of total area. Snow and glaciers cover 9.6-10% and 13% of watershed area, respectively. The area under settlements/ cultivation is negligible.

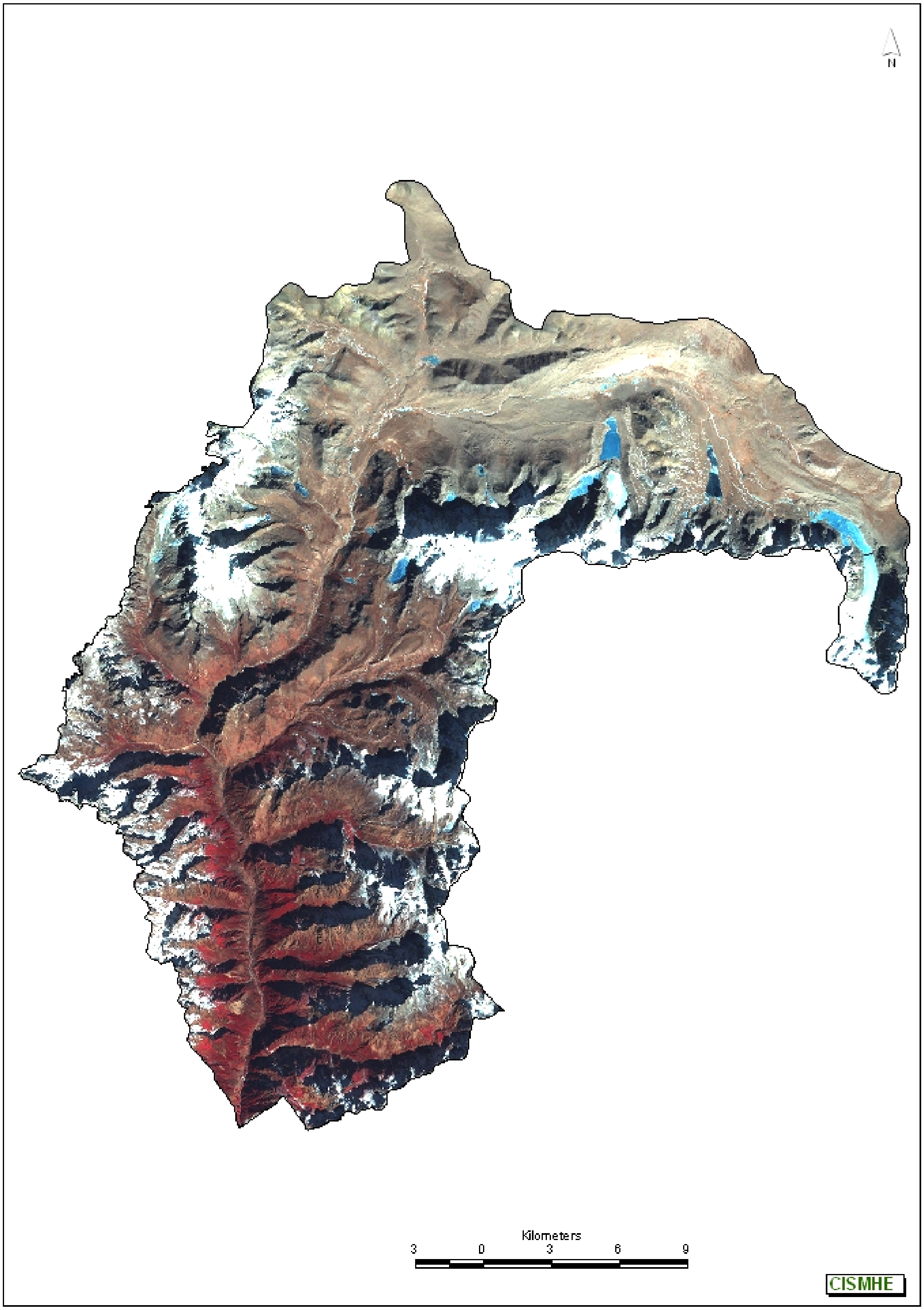


Fig. 7.4 False Color Composite (FCC) of Chhombo Chhu watershed of Teesta river basin in Sikkim

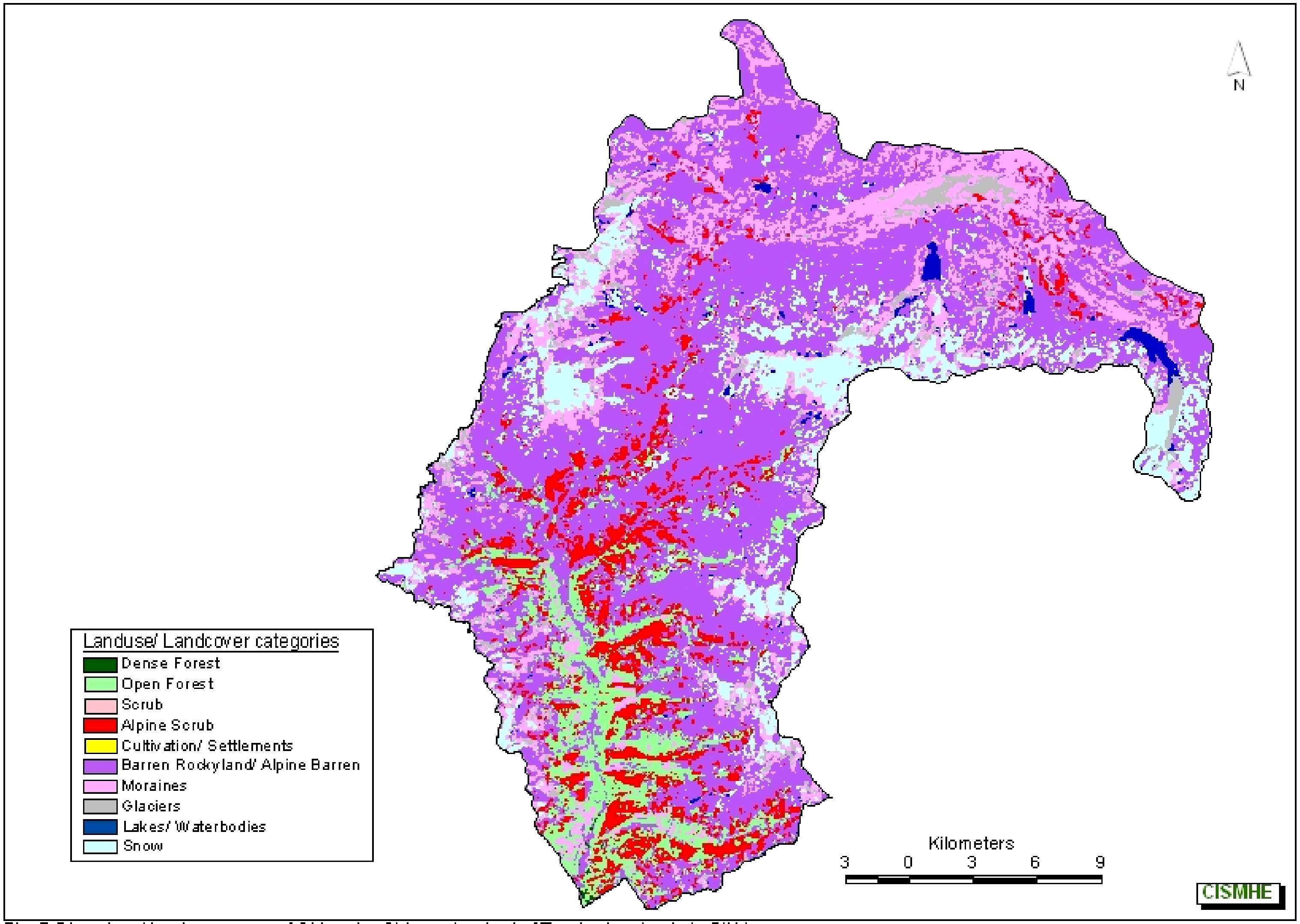


Fig. 7.5 Landuse/ landcover map of Chhombo Chhu watershed of Teesta river basin in Sikkim

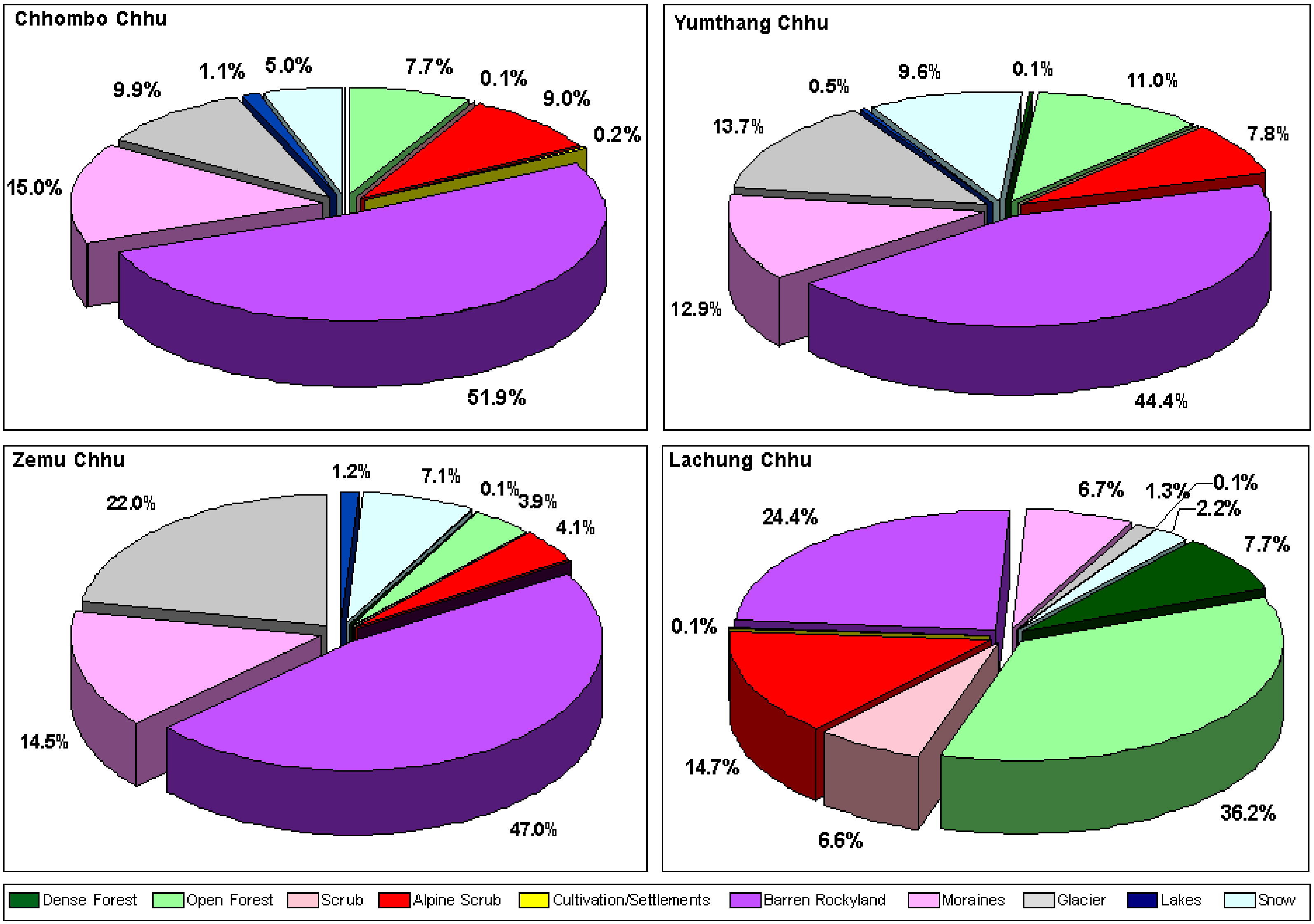


Fig. 7.6 Area (per cent) under various Landuse\Landcover categories of watersheds Chhombo Chhu, Yumthang Chhu, Zemu Chhu and Lachung Chhu of Teesta river basin in Sikkim

Fig. 7.7 False Color Composite (FCC) of Yumthang Chhu watershed of Teesta river basin in Sikkim

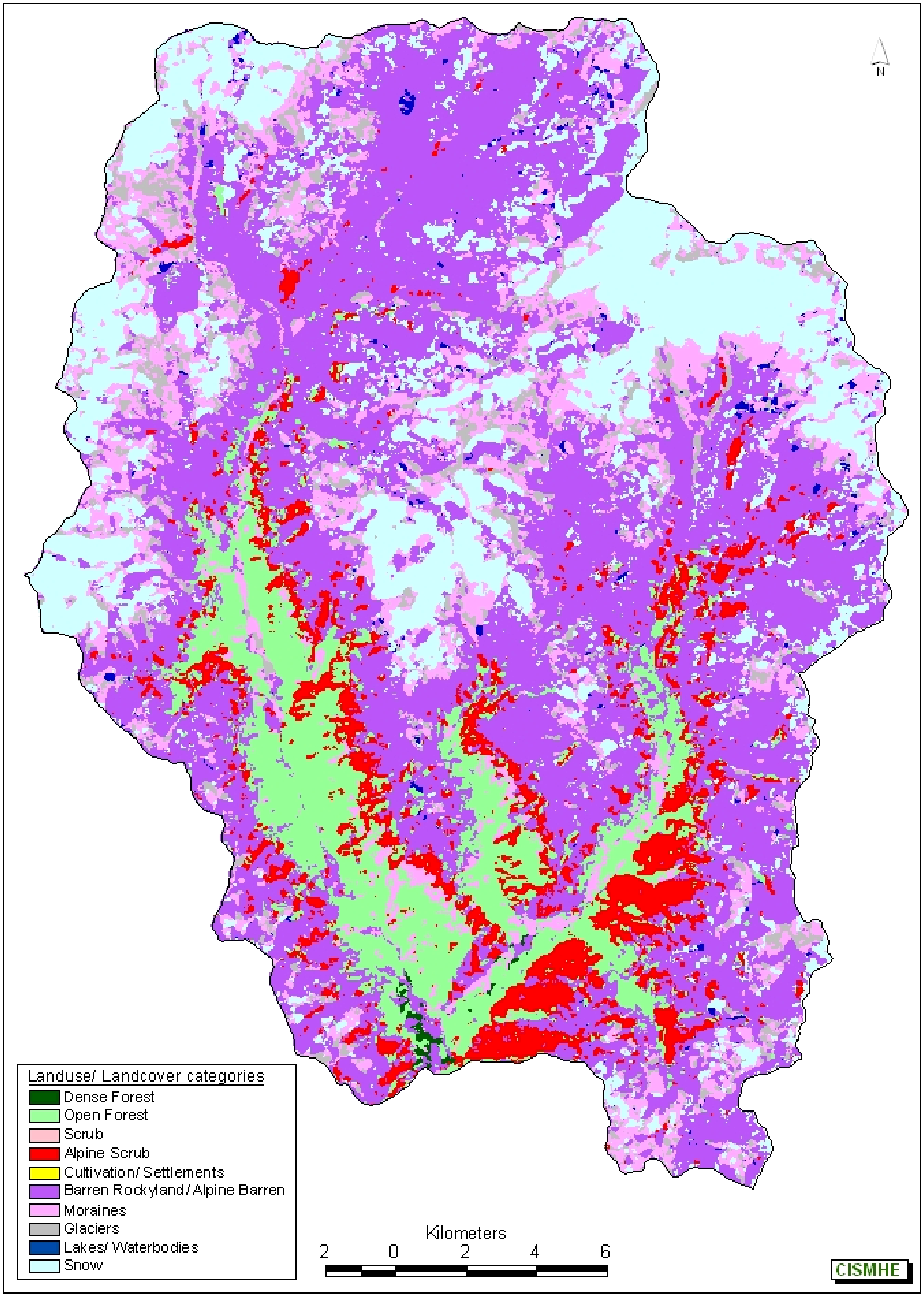


Fig. 7.8 Landuse/ landcover map of Yumthang chhu watershed of Teesta river basin in Sikkim

7.6.3 Zemu Chhu

Zemu Chhu is the largest watershed with an area of 991.40 sq km. It harbours very little forest cover i.e. only 4% of its area is covered by forests (see Fig.7.6 and Figs 7.9 - 7.10). Alpine scrub also covers only 4% of area. Barren rocky areas constitute more than 47% of watershed area. Glaciers and snow cover about 22% and 7.1% of watershed areas, respectively. A significant amount of area is covered with moraines (14.5%) while glacial lakes also cover about 1.23% of watershed area.

7.6.4 Lachung Chhu

Lachung Chhu is another high altitude watershed in North Sikkim. This watershed has good forest cover i.e. more than 44% of watershed area is under forest (see Fig 7.6 and Figs 7.11 - 7.12). Out of this 8% area is under dense forest cover comprised mainly of mixed conifer forest, whereas 36% area is under forests of open category. In addition, 15% area is under alpine scrub forest. As much as 26% of watershed area is under barren/rockyland category, and moraines constitute 7% of total area.

7.6.5 Lachen Chhu

This is a small watershed located at middle altitudes. More than 64% of Lachen Chhu watershed is covered with forests (Figs 7.13 - 7.15). Dense forests cover 20% of watershed area whereas open forest account for 44% of area. Further, about 11% area is under scrub category (alpine as well as temperate scrub). A little more than 10% of area is barren (comprised of rocky outcrop, scree slopes, etc.). Similarly glacial moraines also cover about 8.3% of watershed area. More than 6.3% of area is either under snow or glaciers and permanent snowfields.

7.6.6 Rangyong Chhu

It is the second largest watershed of Teesta basin located in the south-west of North Sikkim district. Nearly 37% of Rangyong Chhu watershed is covered with forests comprised of Mixed conifer, sub-alpine and fir forests. This constitutes major part of Khangchendzonga National Park. About 11.9% of forests area is of closed type whereas 25% of forests are of open category (Figs 7.15 - 7.17). The scrub landuse (both alpine and temperate scrub) cover about 8.9% of watershed area. Barren rockyland and moraines constitute 21% and 12.3% of watershed area. Snow and glaciers together cover 20.5% of total area.

7.6.7 Prek Chhu

Prek Chhu watershed is source tributary watershed of Rangit river in West Sikkim. It has a forest cover of 80.75% sq km (25.7%) (see Fig.7.15 and Figs 7.18 - 7.19). About 40% of Prek Chhu watershed is under barren/ rockyland landcover category. Glaciers, snow and moraines constitute 10.1%, 3.8% and 11.2% of total watershed area, respectively.

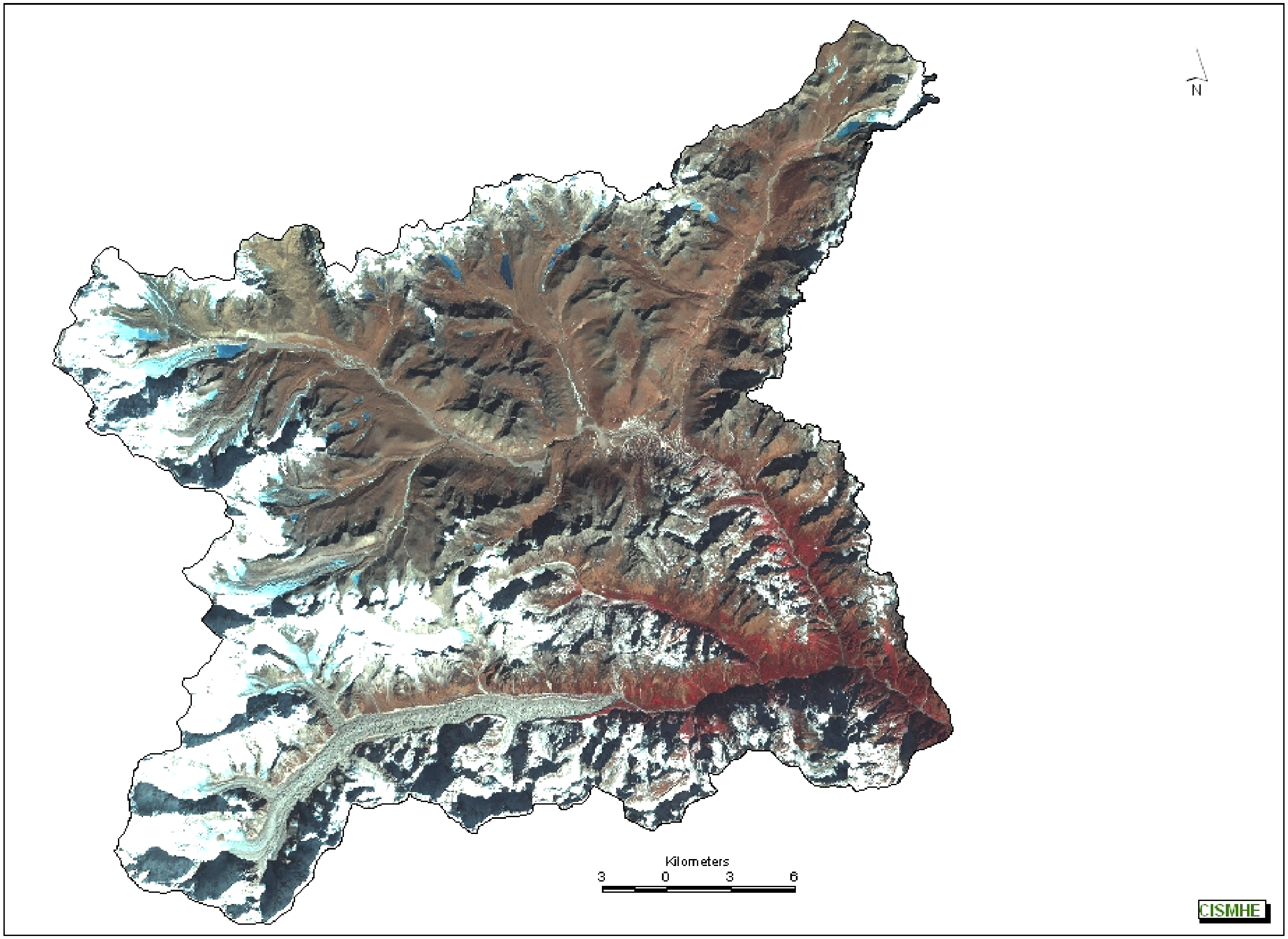


Fig.7.9 False Color Composite (FCC) of Zemu Chhu watershed of Teesta river basin in Sikkim

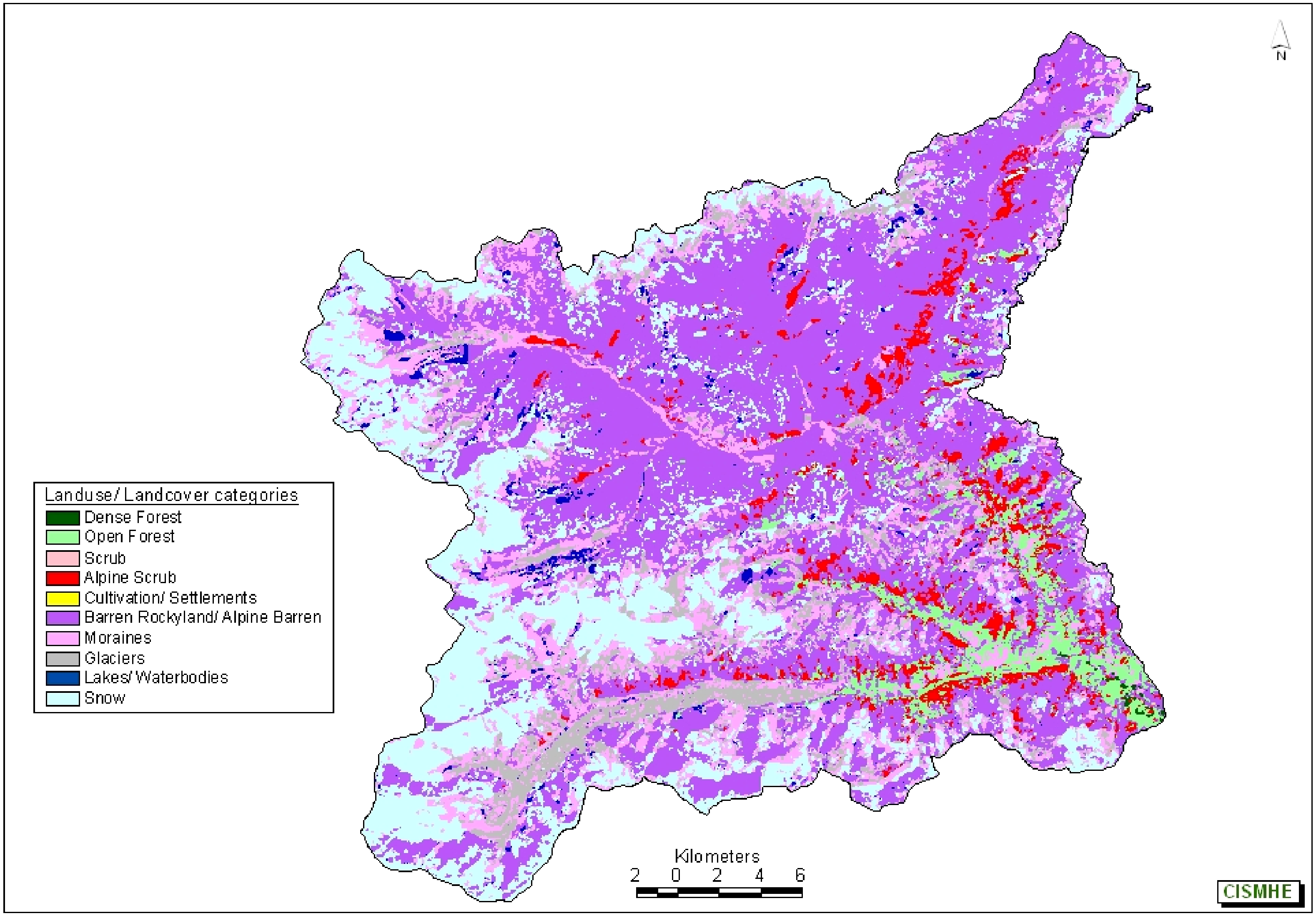


Fig. 7.10 Landuse/ landcover map of Zemu Chhu watershed of Teesta river basin in Sikkim

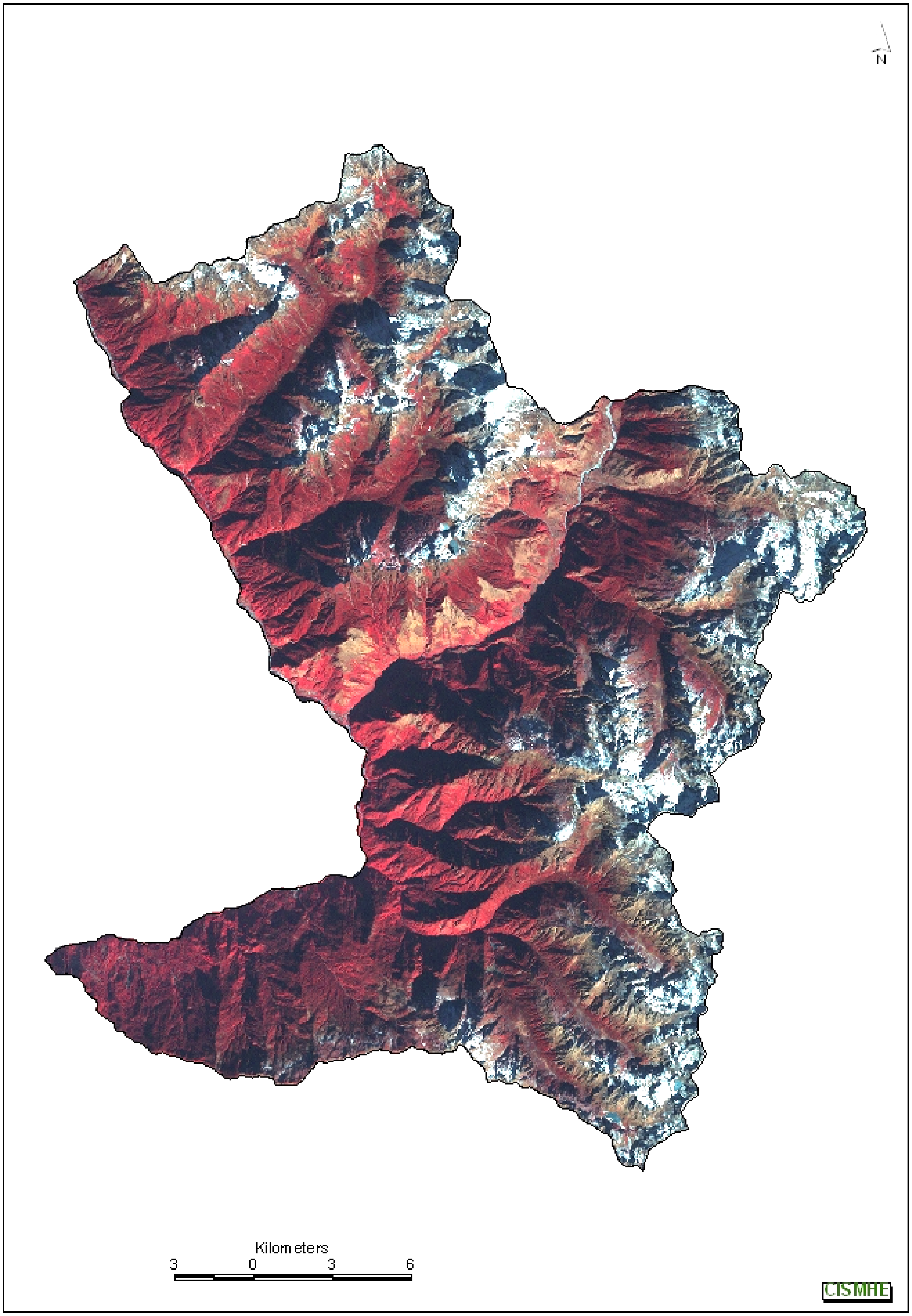


Fig. 7.11 False Color Composite (FCC) of Lachung Chhu watershed of Teesta river basin

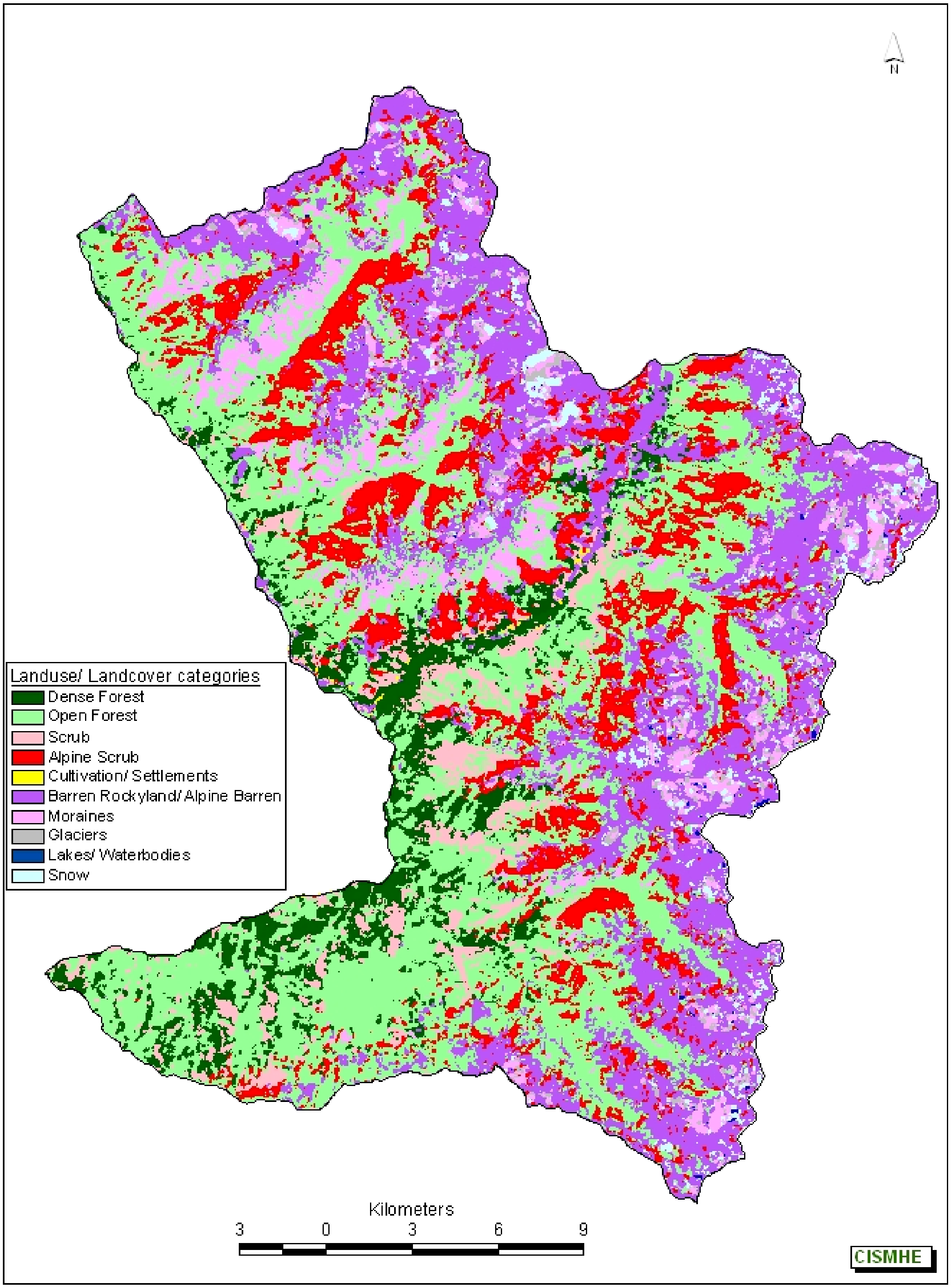


Fig. 7.12 Landuse/ landcover map of Lachung Chhu watershed of Teesta river basin in Sikkim

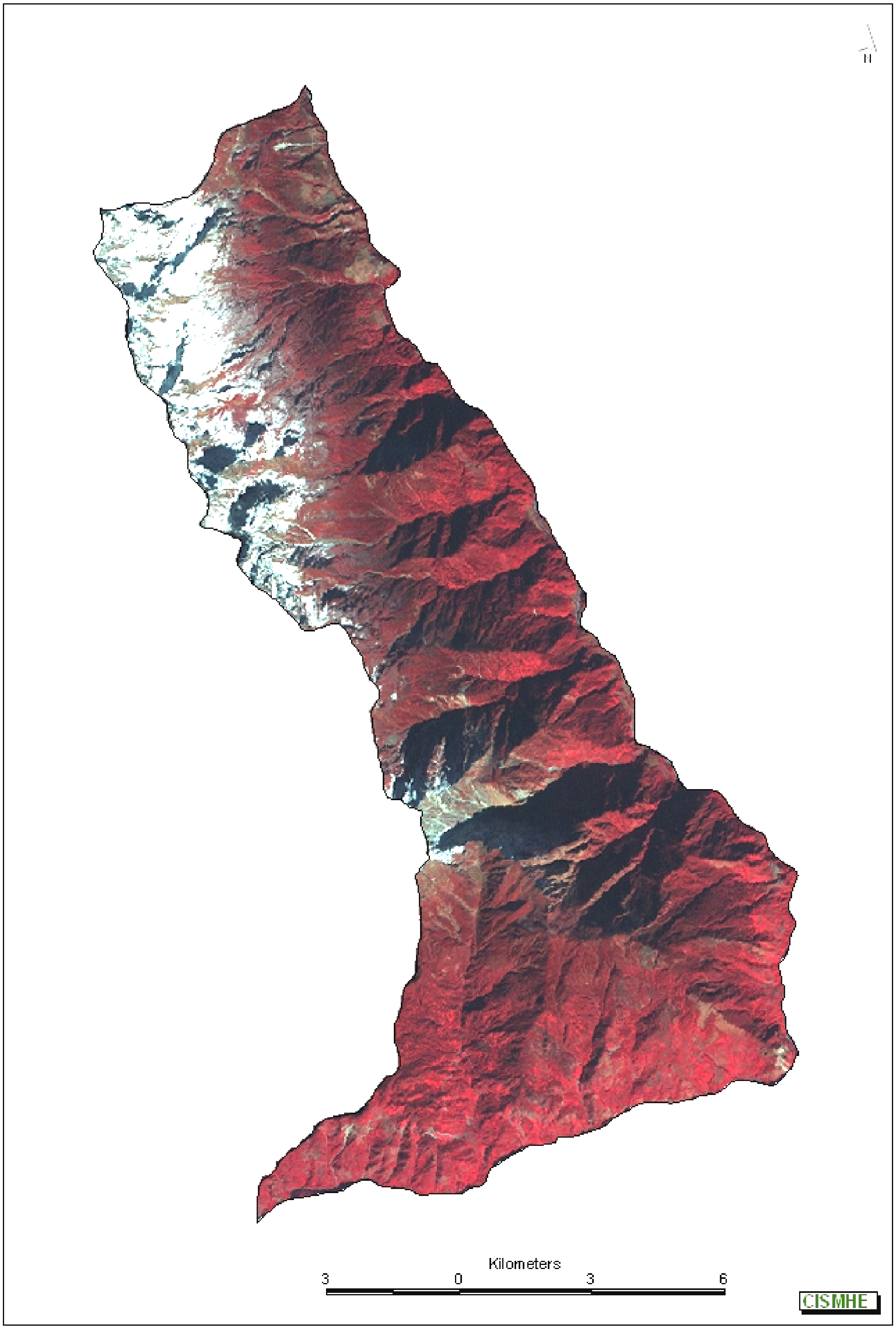


Fig. 7.13 False Color Composite (FCC) of Lachen Chhu watershed of Teesta river basin in Sikkim

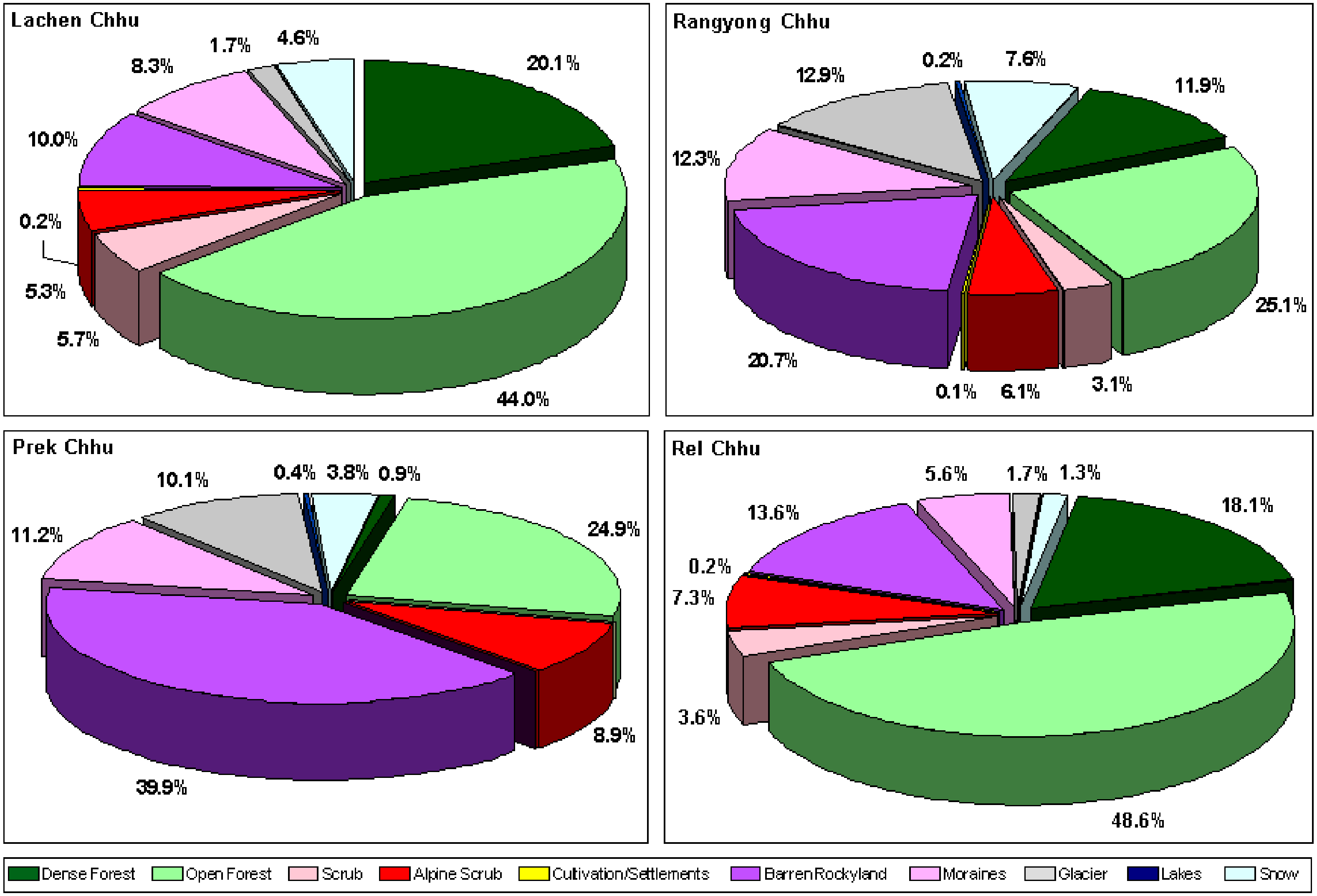


Fig. 7.14 Area (per cent) under various Landuse\Landcover categories of watersheds Lachen Chhu, Rangyong Chhu, Prek Chhu and Rel Chhu of Teesta river basin in Sikkim

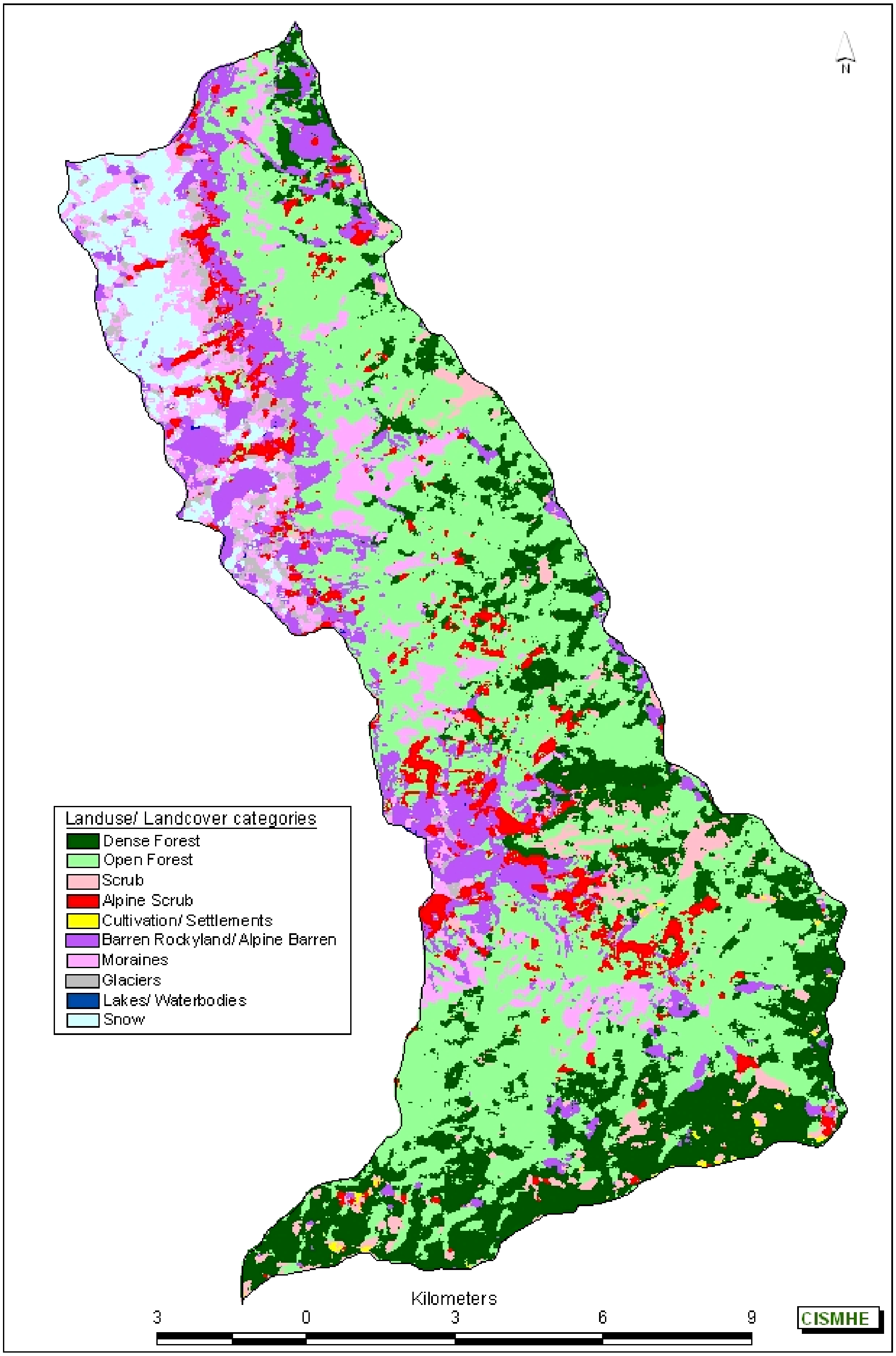


Fig. 7.15 Landuse/ landcover map of Lachen Chhu watershed of Teesta river basin in Sikkim

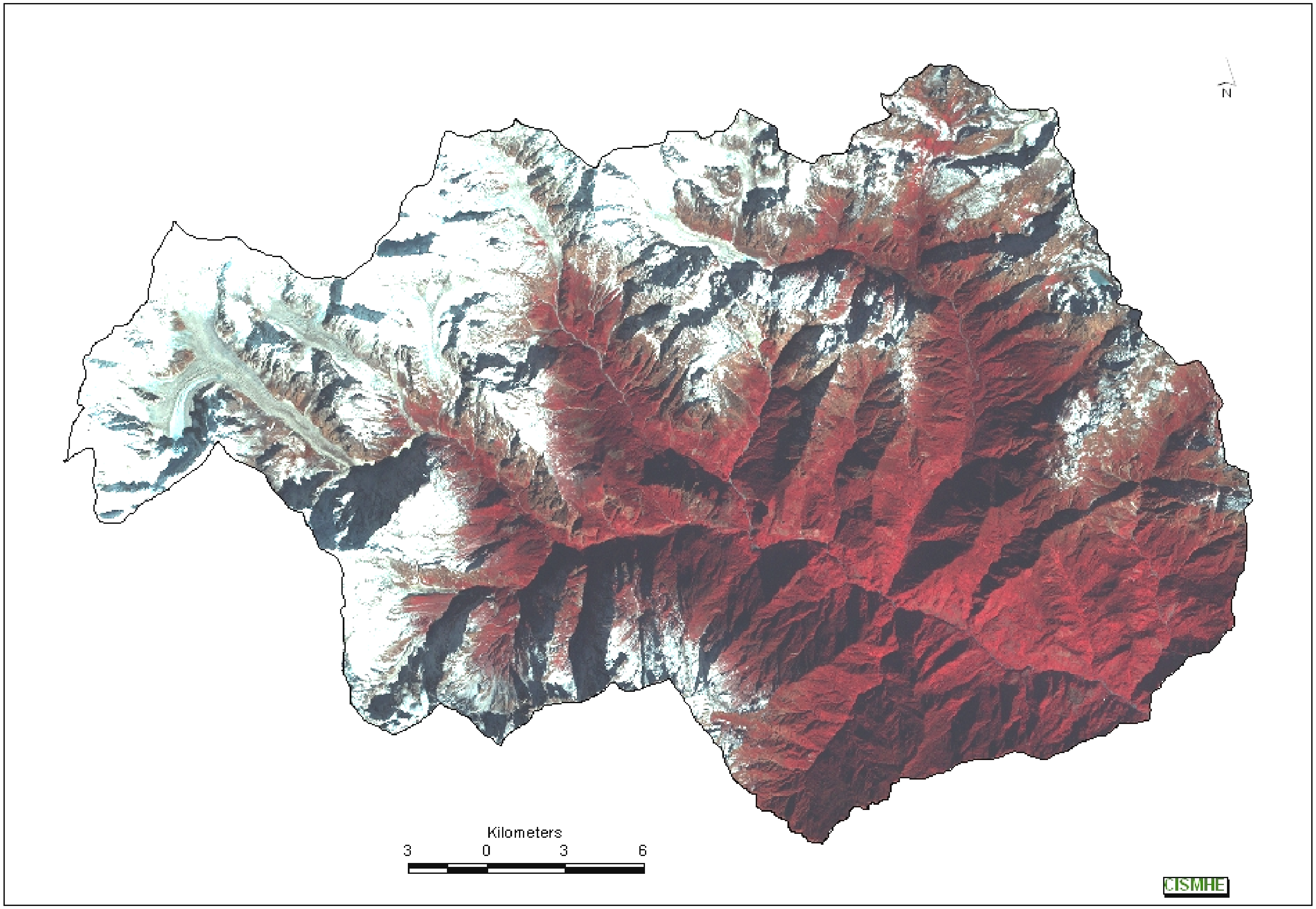


Fig. 7.16 False Color Composite (FCC) of Rangyong Chhu watershed of Teesta river basin in Sikkim

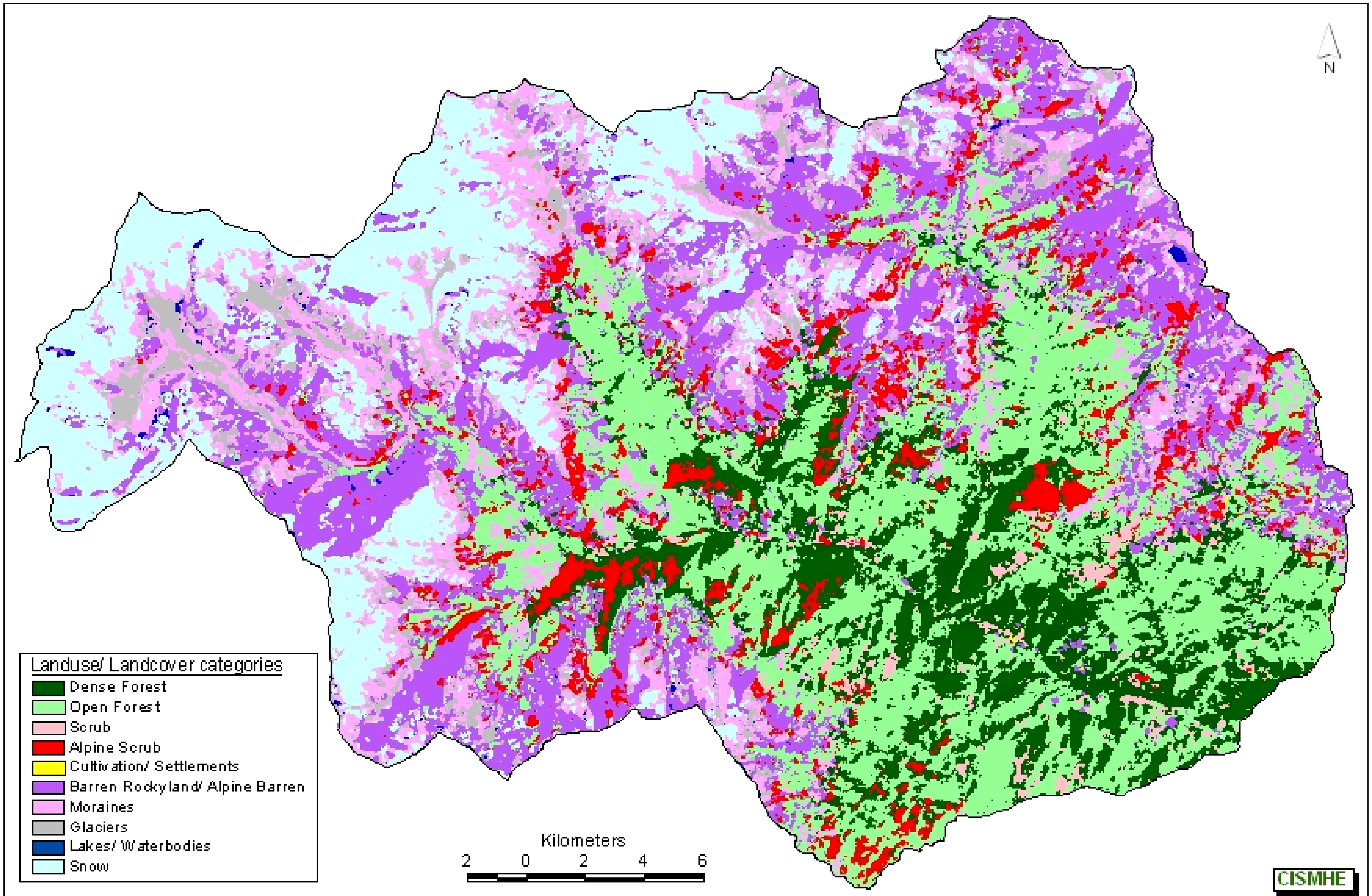


Fig. 7.17 Landuse/ landcover map of Rangyong Chhu watershed of Teesta river basin in Sikkim

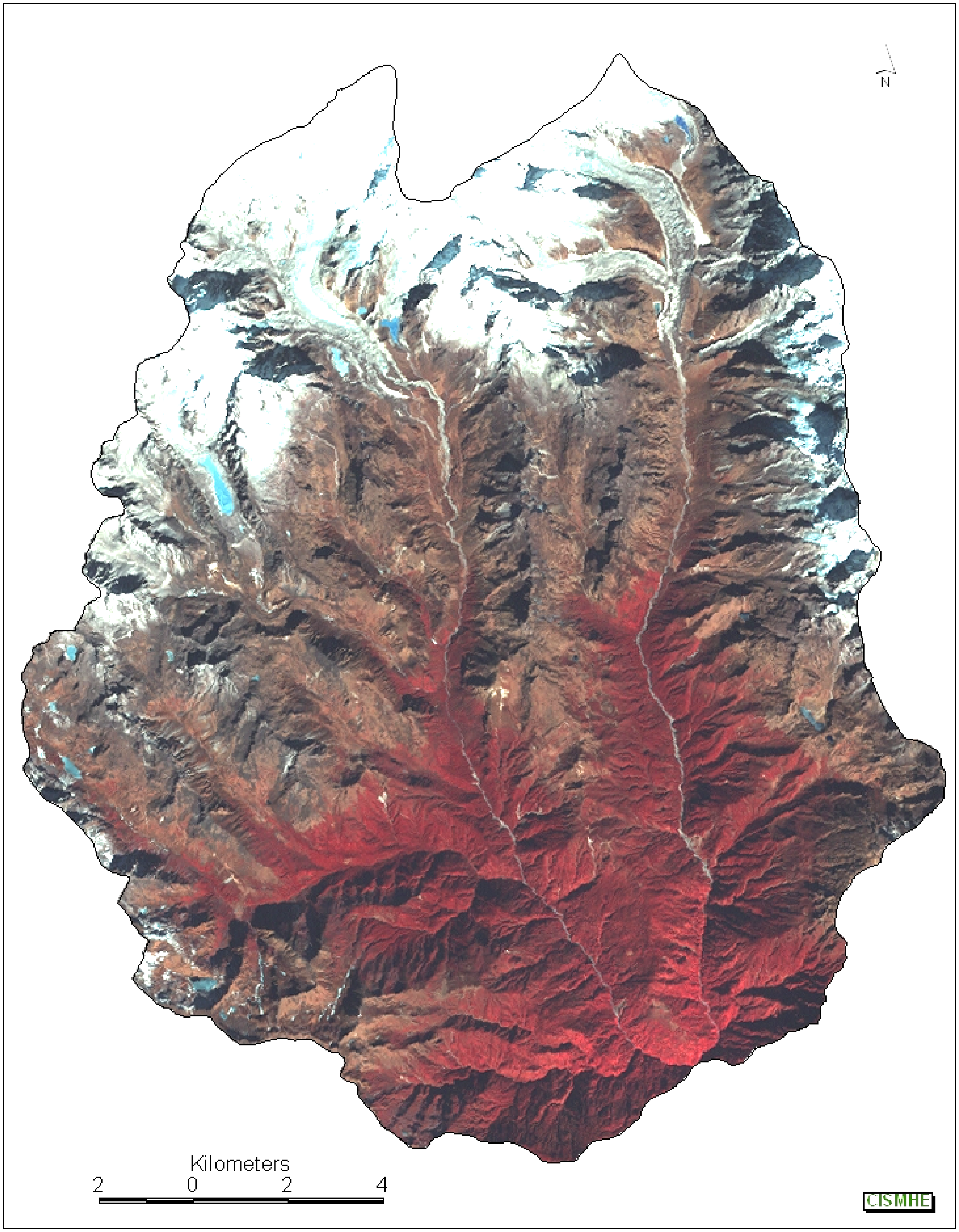


Fig. 7.18 False Color Composite (FCC) of Prek Chhu watershed of Teesta river basin in Sikkim

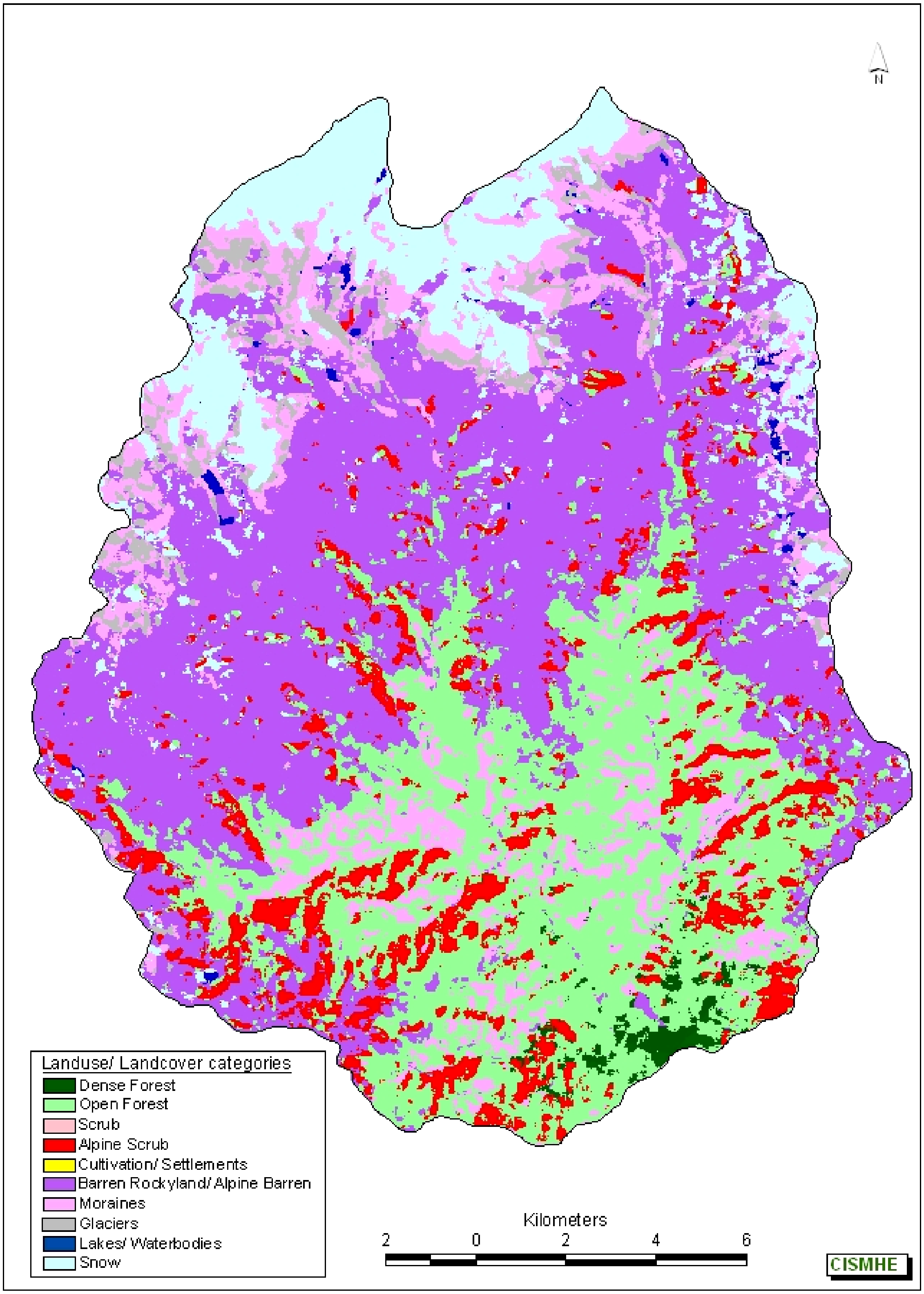


Fig. 7.19 Landuse/ landcover map of Prek Chhu watershed of Teesta river basin in Sikkim

7.6.8 Rel Chhu

Rel Chhu watershed is densely forest (66.67%) with about 18% of dense forest cover and 48.67% of open forest cover (see Fig.7.15 and Figs 7.20 - 7.21). Barren and rockyland landcover constitute about 14-28% of area. Glaciers and snow cover only 3% of watershed area.

7.6.9 Rathong Chhu

Rathong Chhu watershed also is under good forest cover. Dense forests constitute 18% of its area whereas open forests cover 44.6% of area (Figs 7.22 - 7.24). Further 14.39% of watershed area is under temperate scrub and 6.4% under alpine scrub. A small percentage of area is barren or rocky (7.2%). Moraines also cover very little area (about 3%).

7.6.10 Dik Chhu

Dik Chhu watershed is densely forested (67.7%) of which 23.3% area is under dense category and rest is under open forest category (Figs 7.24 - 7.26). Sub-tropical and temperate scrub constitute 8.3% of area whereas alpine scrub covers more than 8.4% of watershed area. About 2% of its area under habitation or cultivation and more than 11.4% of its area is under barren/rockyland landcover.

7.6.11 Rangpo Chhu

Rangpo Chhu watershed has more than 60% of its area under forest cover (see Fig.7.24 and Figs 7.27 - 7.28). Dense and open forests cover 24.3% and 35.9% of land area, respectively. Alpine meadows and alpine scrub constitute about 6.5% of watershed area. Sub-tropical scrub also cover 11.6% of the area at the lower altitudes. About 3.5% of watershed is under habitation or cultivation. Nearly 18% of area is either barren or covered with moraines. Upper catchment of Rangpo Chhu is covered with fir and rhododendron forests.

7.6.12 Rangit River

Rangit river watershed has dense forest cover of 30.7% whereas open forests cover 35.6% of area (see Fig.7.24 and Figs 7.29 - 7.30). About 15.5% of area is covered with sub-tropical and temperate scrub while 4.5% area is covered with alpine scrub. Only 9.1% of watershed is barren and rocky in nature. The habitation and cultivation areas constitute about 9.0% of watershed area.

7.6.13 Kalej Khola

Percent area under forest is maximum in this watershed i.e. 73.21% of this forest cover, 24.5% under dense forest category and 48.71% is under open forest category (Figs 7.31 - 7.33). Sub-tropical scrub also constitute 12.52% of area. About 3.6% watershed is under

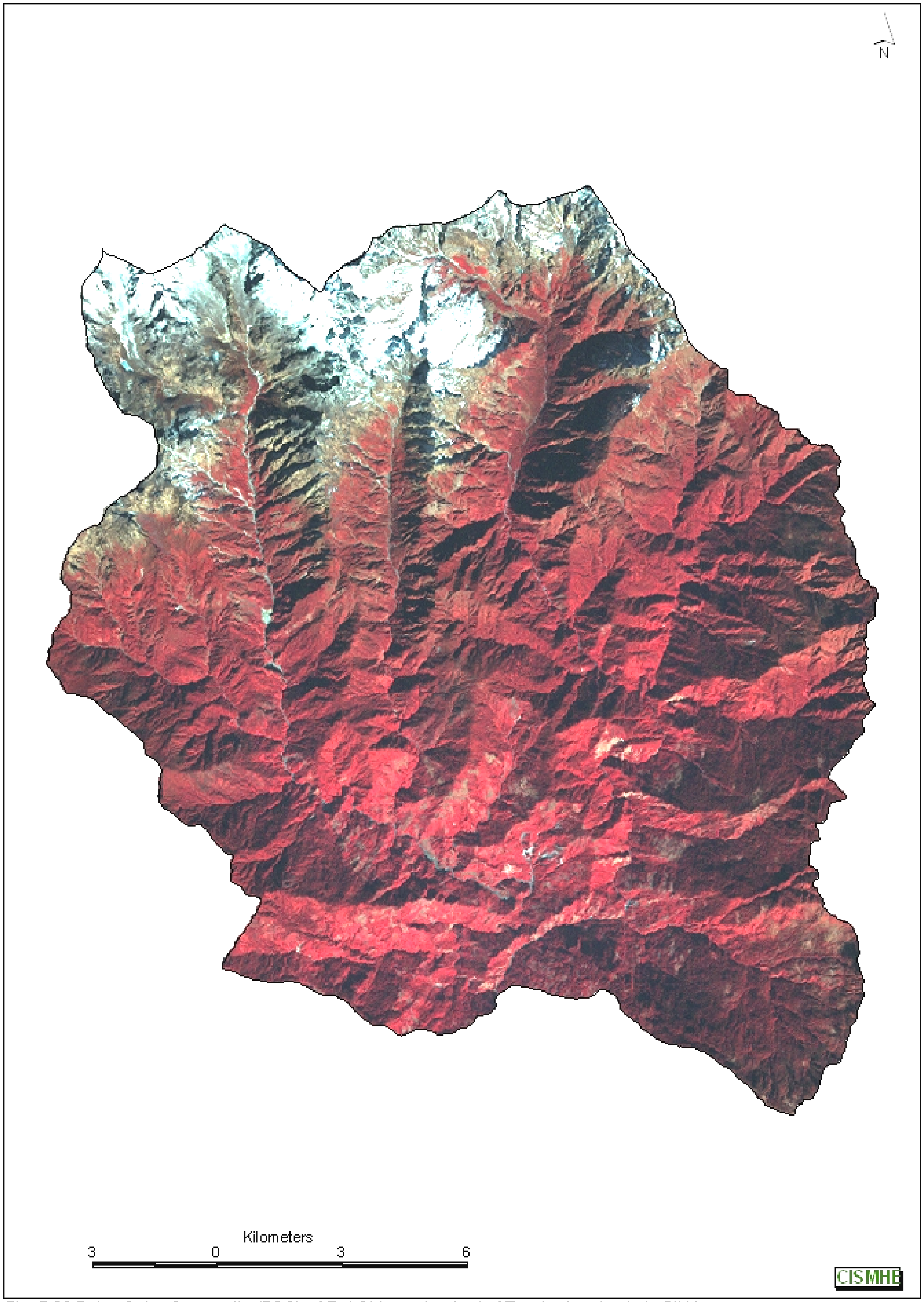


Fig. 7.20 False Color Composite (FCC) of Rel Chhu watershed of Teesta river basin in Sikkim

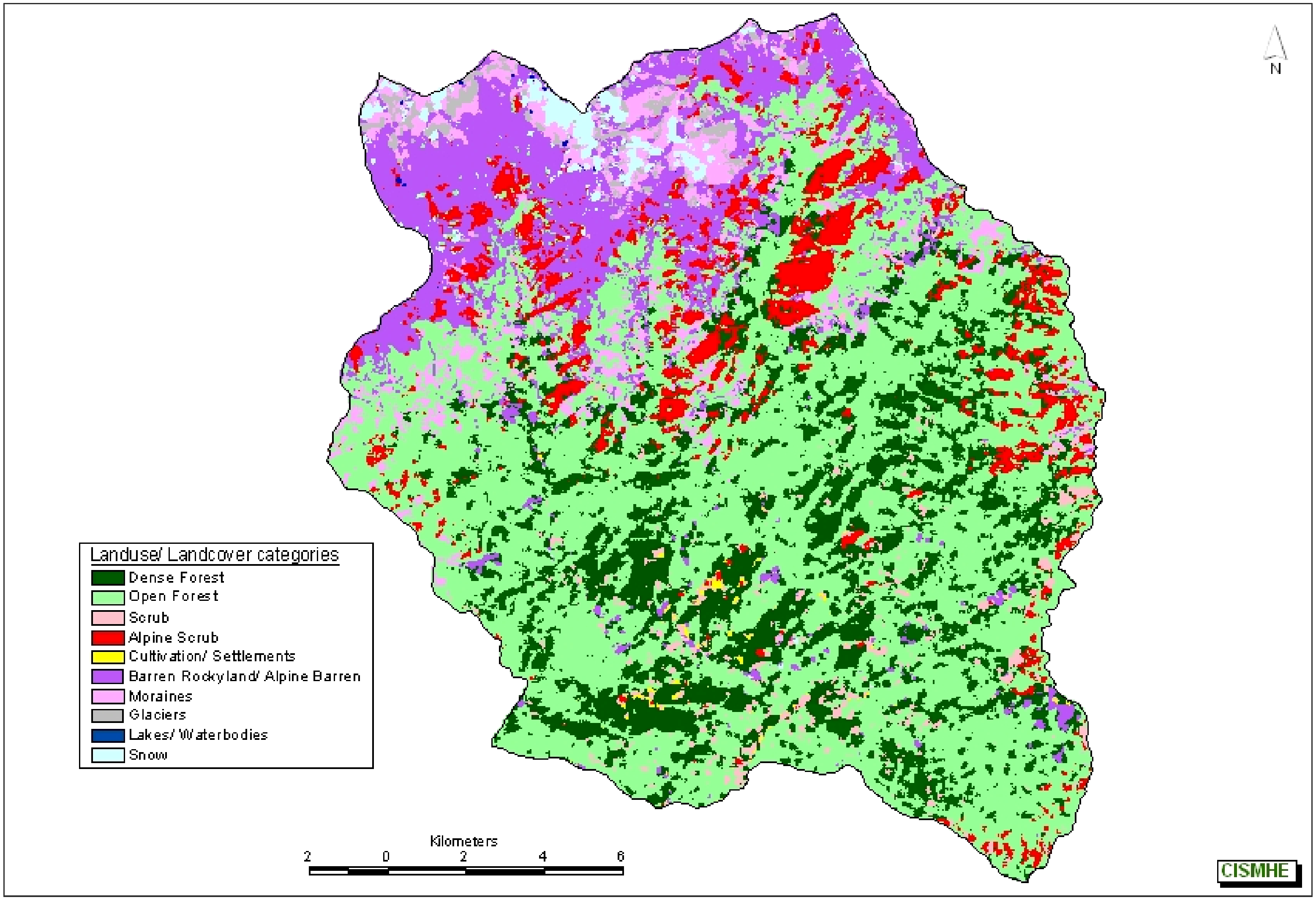


Fig. 7.21 Landuse/ landcover map of Rel Chhu watershed of Teesta river basin in Sikkim

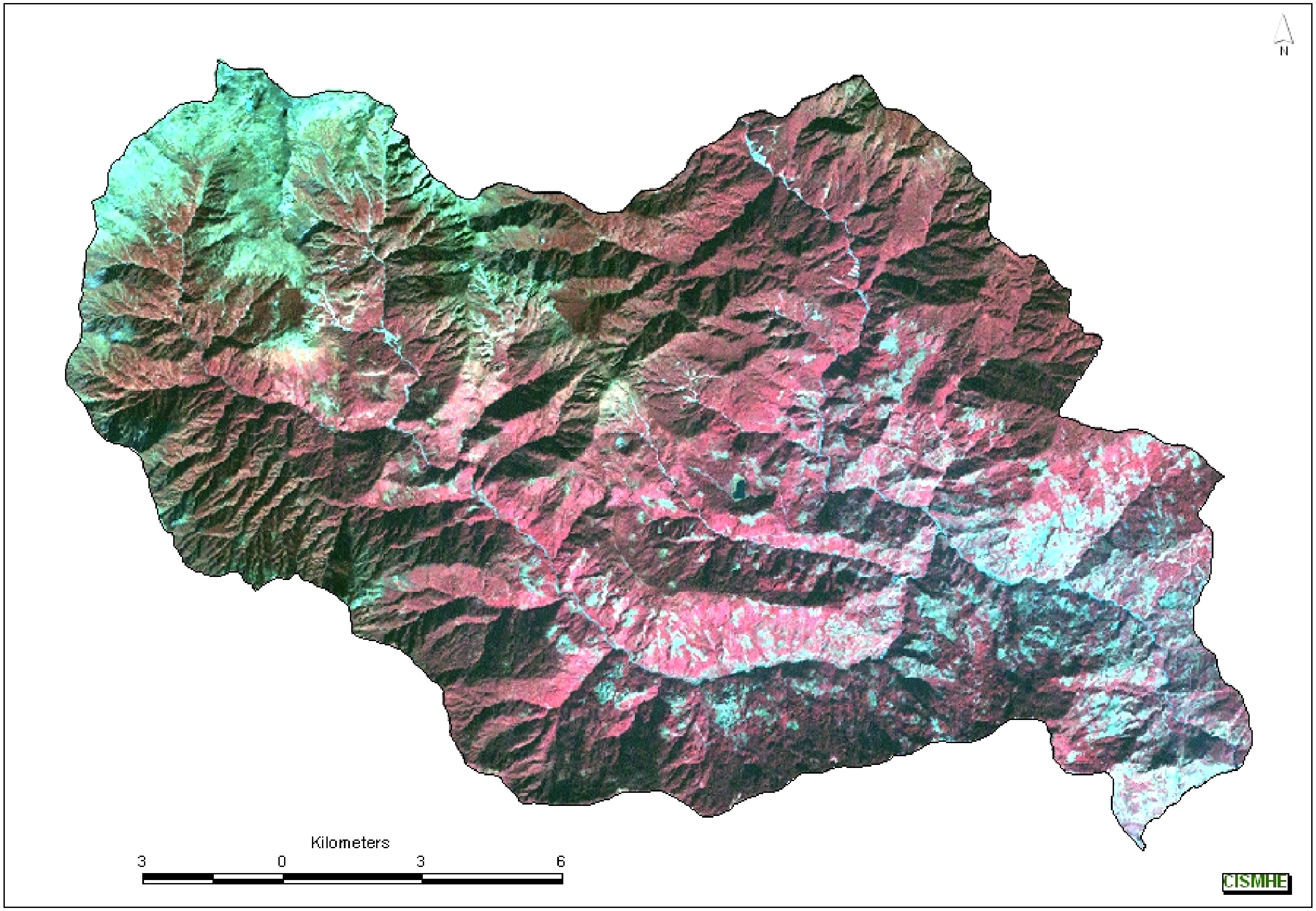


Fig. 7.22 False Color Composite (FCC) of Rathong Chhu watershed of Teesta river basin in Sikkim

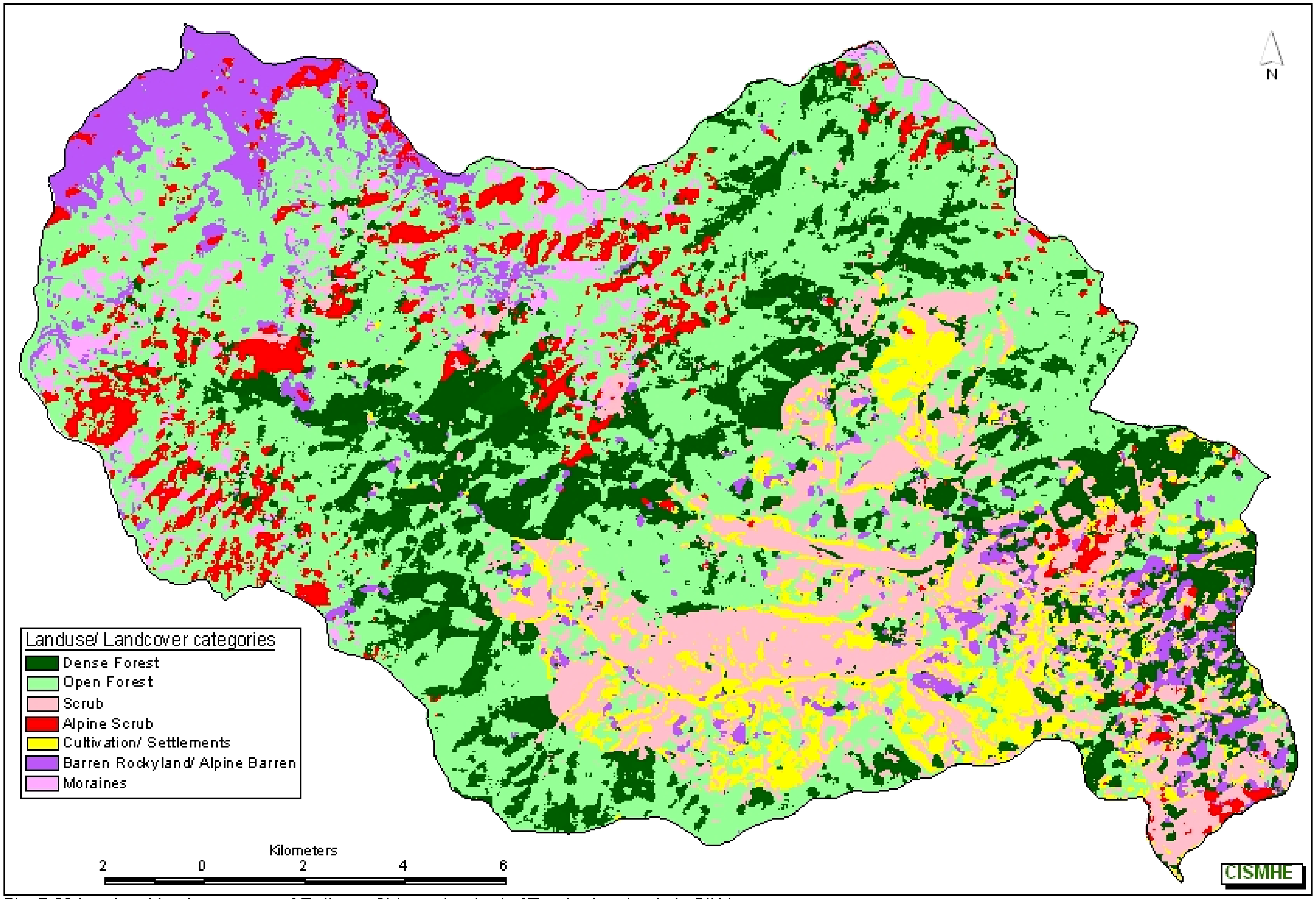


Fig. 7.23 Landuse/ landcover map of Rathong Chhu watershed of Teesta river basin in Sikkim

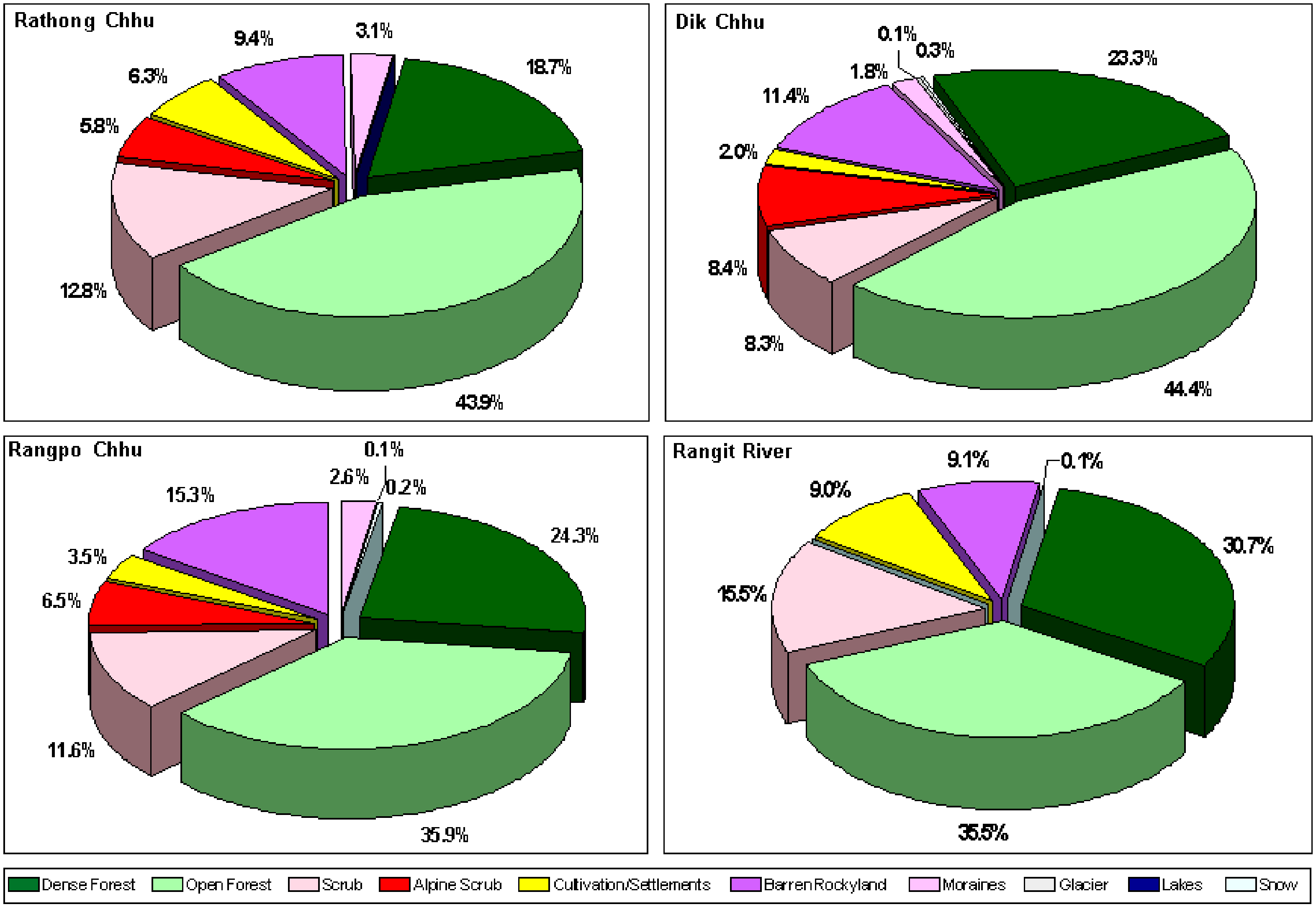


Fig. 7.24 Area (per cent) under various Landuse\Landcover categories of watersheds Rathong Chhu, Dik Chhu, Rangpo Chhu and Rangit River of Teesta river basin in Sikkim

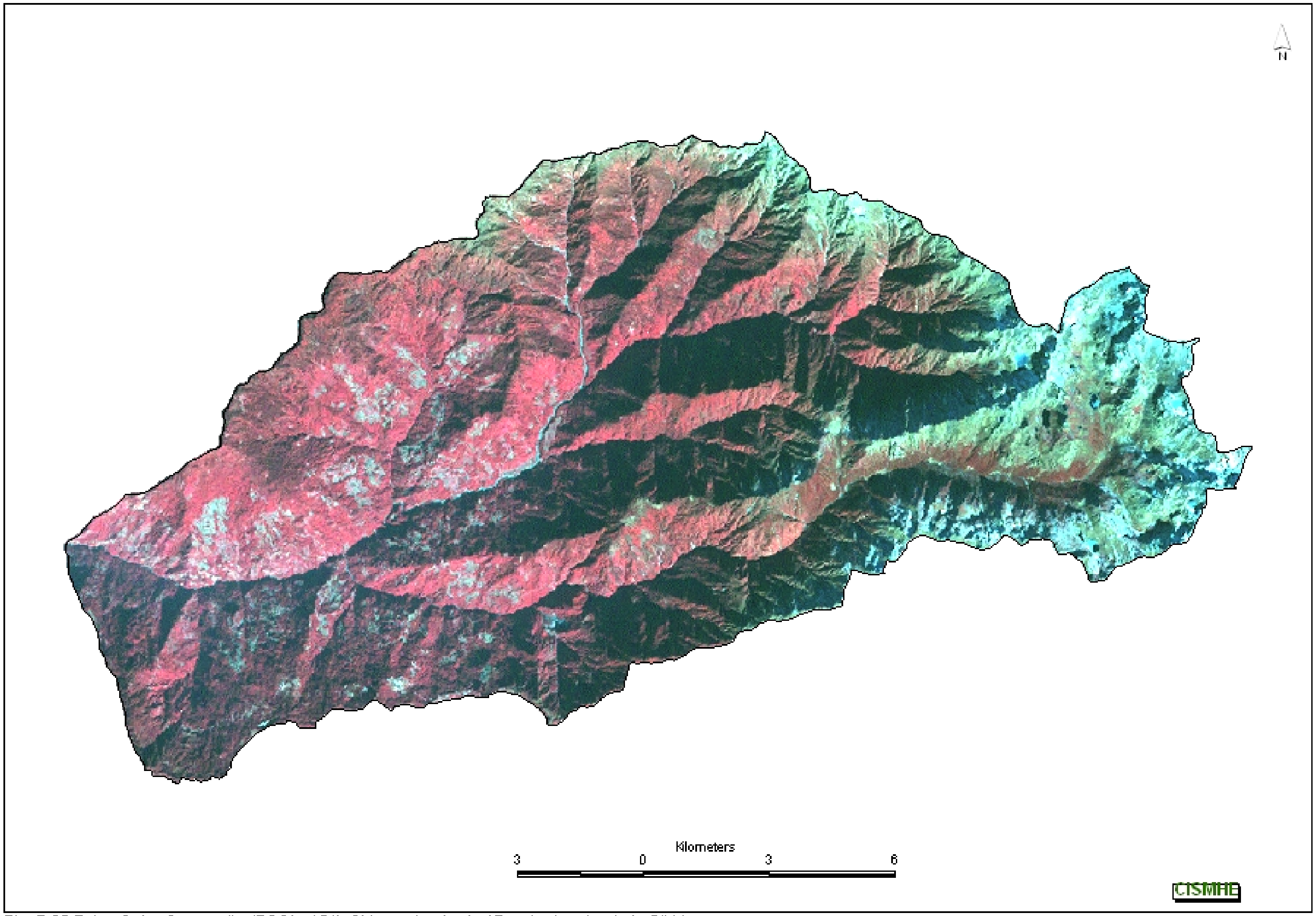


Fig. 7.25 False Color Composite (FCC) of Dik Chhu watershed of Teesta river basin in Sikkim

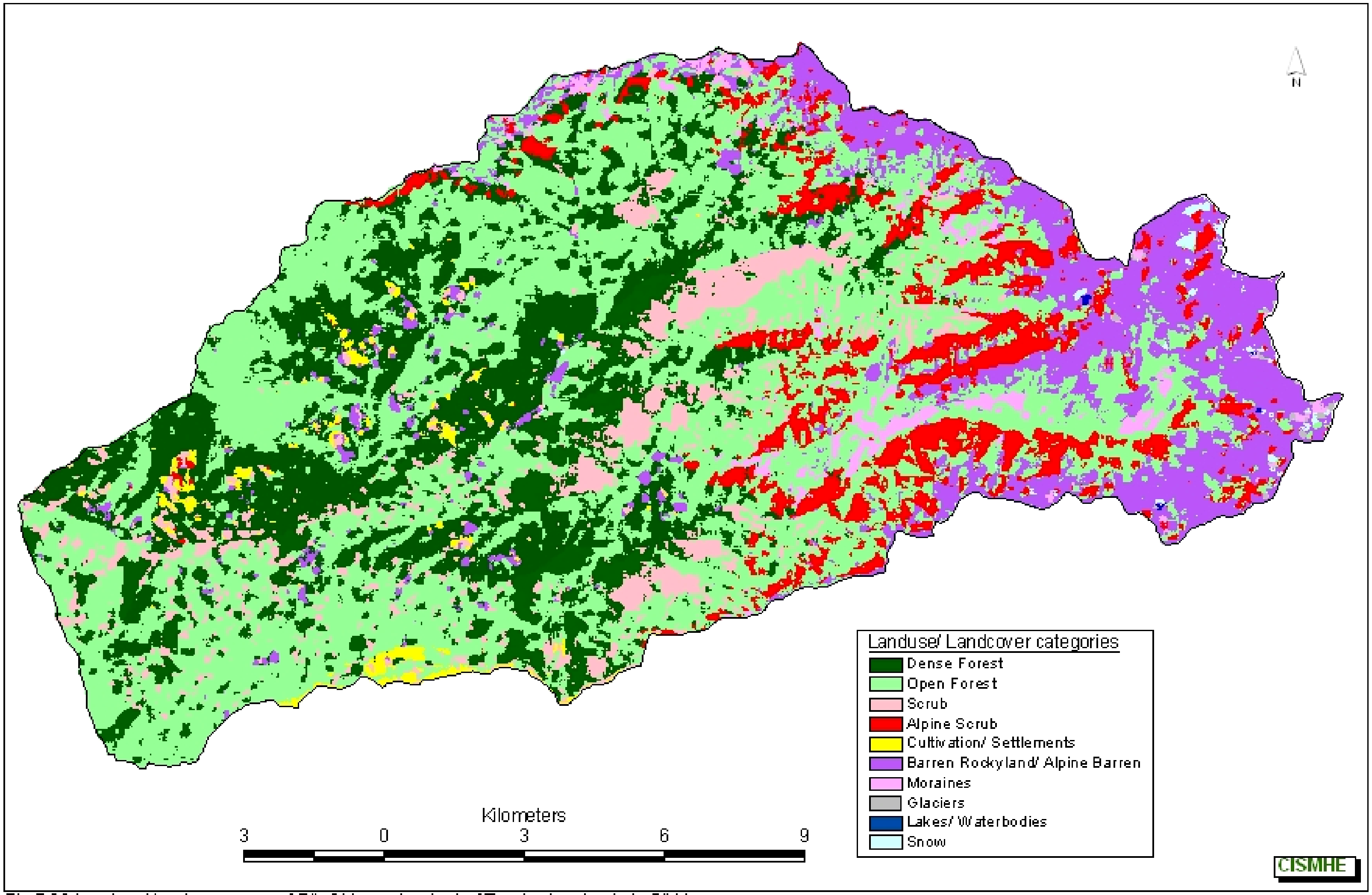


Fig.7.26 Landuse/ landcover map of Dik Chhu watershed of Teesta river basin in Sikkim

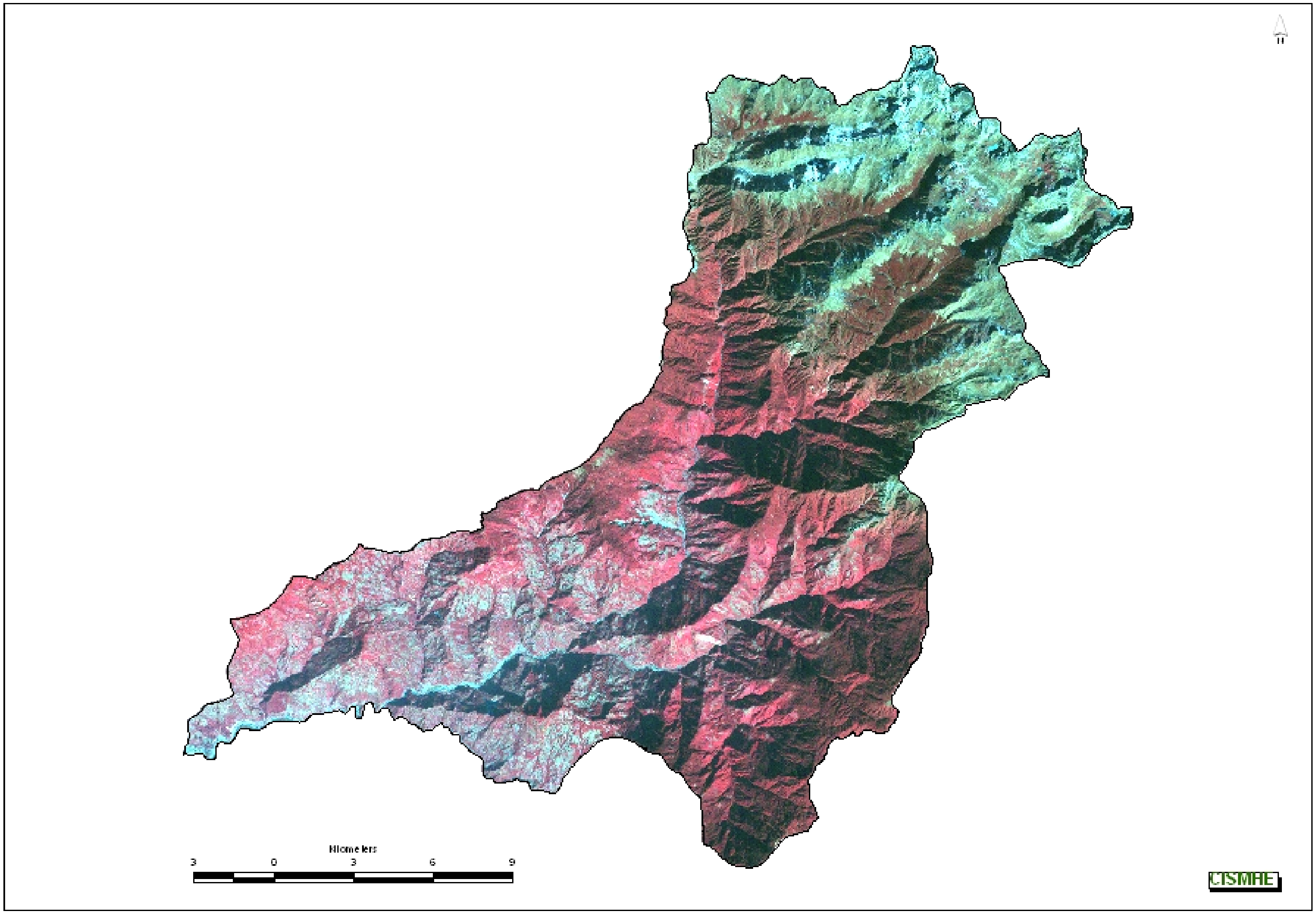


Fig. 7.27 False Color Composite (FCC) of Rangpo Chhu watershed of Teesta river basin in Sikkim

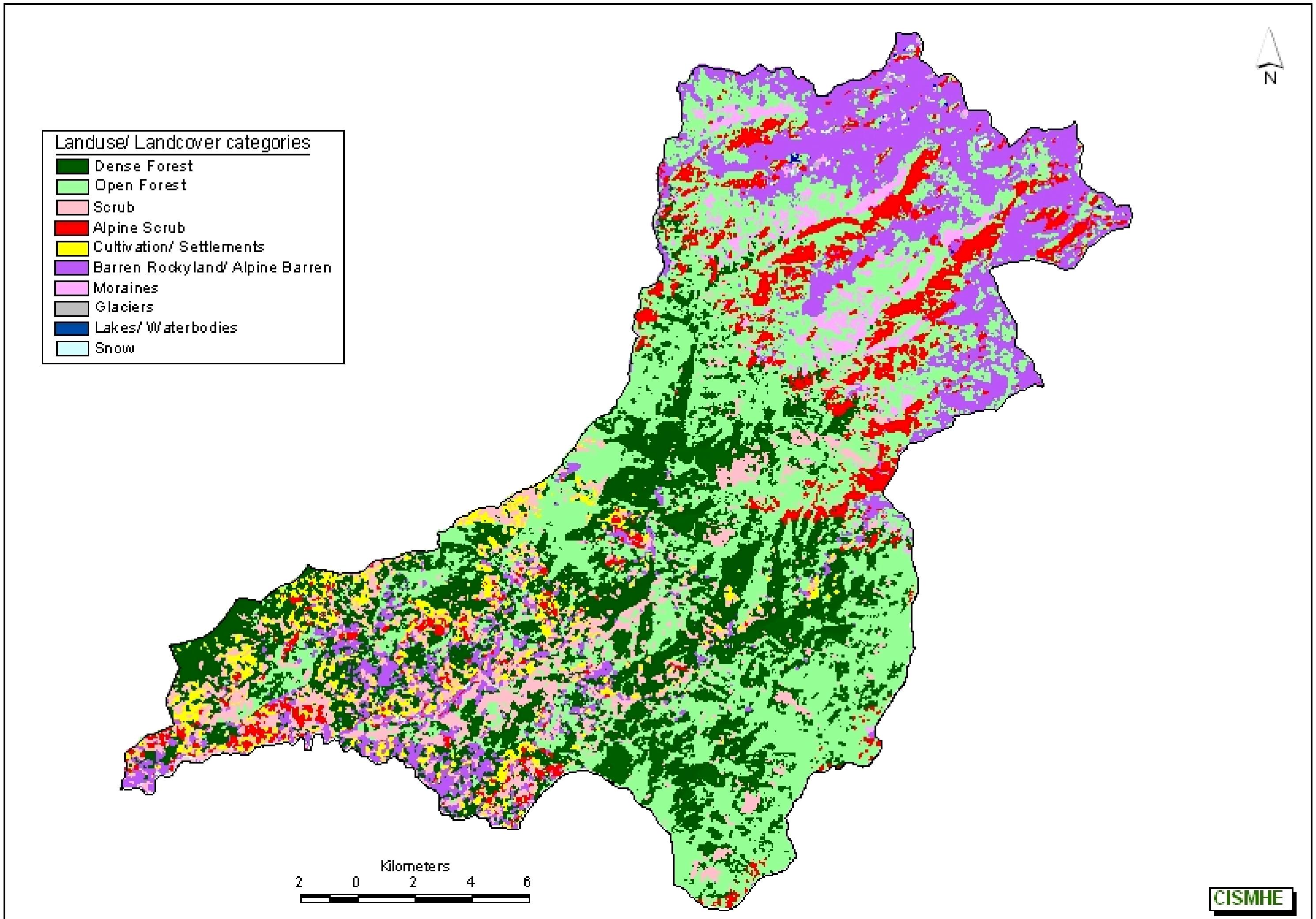


Fig. 7.28 Landuse/ landcover map of Rangpo Chhu watershed of Teesta river basin in Sikkim

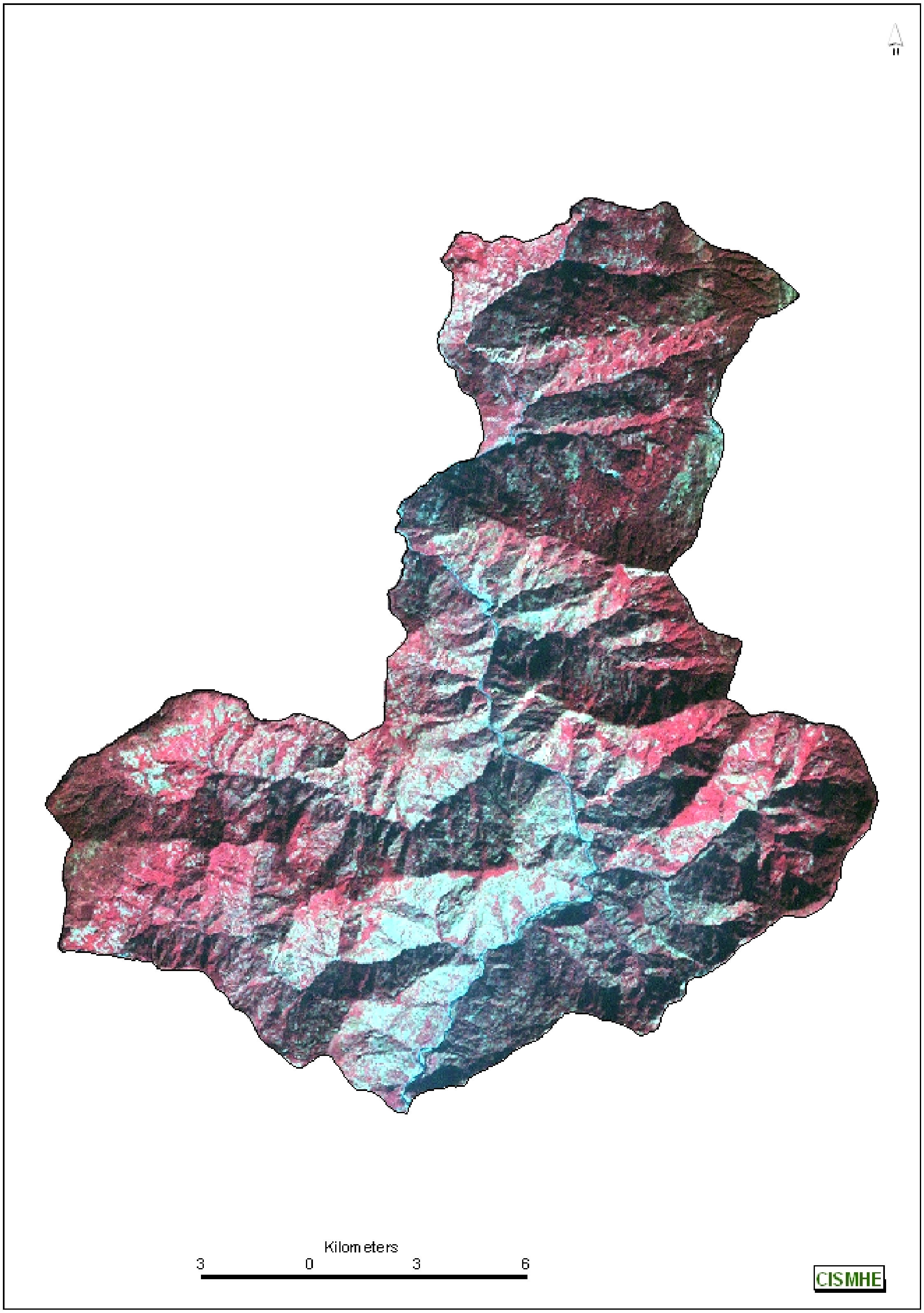


Fig. 7.29 False Color Composite (FCC) of Rangit River watershed of Teesta river basin in Sikkim

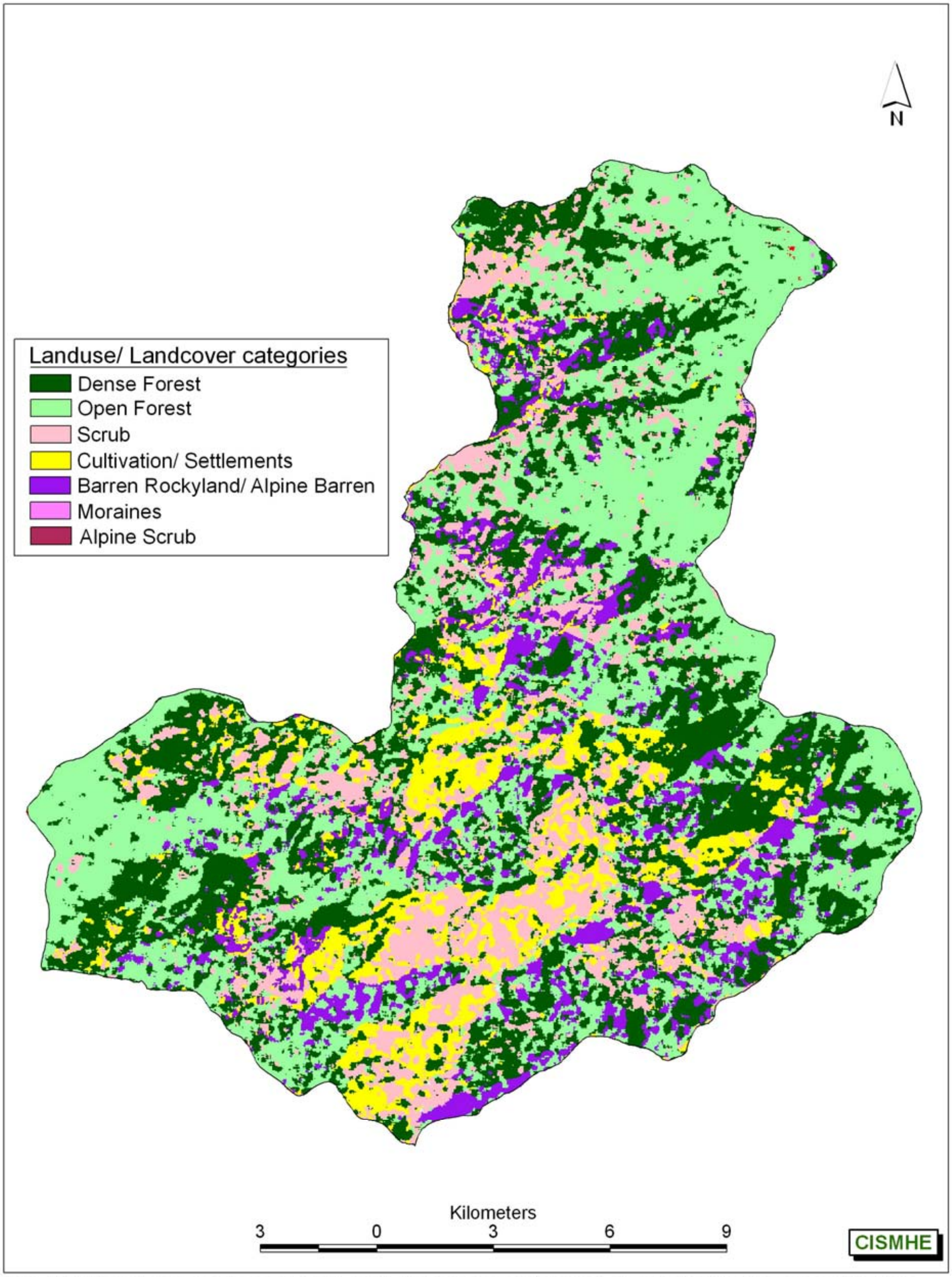


Fig. 7.30 Landuse/ landcover map of Rangit river watershed of Teesta river basin in Sikkim

habitation or cultivation landuse. Only 7.2% of the watershed is under barren/ rockyland landcover.

7.6.14 Ramam Khola

Forests cover 62% of this watershed comprised of 26.6% of dense forests and 35.4% of open forests (Figs 7.33 - 7.35). About 1/5th of watershed has scrub landuse. Habitation and cultivation areas constitute 7.9% of watershed.

7.6.15 Manpur Khola

This is the smallest watershed and has 45% of its area under forests comprised mainly of dense sal forests comprising 32.9% of total area (see Fig.7.33 and Figs 7.36 - 7.37). Scrub also cover 23.8% of watershed area.

7.6.16 Teesta (Lower Part) – Right Bank

This watershed is covered with more than 71% of forests, with dense forests comprising 33% and open forests covering 38% of area (see Fig.7.33 and Figs 7.38 - 7.39). More than 13% of watershed is under scrub landuse category. Area under habitation and cultivation landuse/ landcover category is about 9.4%. Barren and rocky landcover also cover 6.3% of watershed.

7.6.17 Rani Khola

This is one of the most disturbed watershed in Teesta basin, with Gangtok, the capital of Sikkim situated in this. Therefore, more than 19.3% area of the watershed is under habitation or cultivation landuse (Figs 7.40 - 7.42). The forests are either found in the upper catchment or in the vicinity of Rumtek monastery in Fabong Lho sanctuary and constitute about 49% of total watershed area. Further, scrub landuse also constitute 23.9% of watershed.

7.6.18 Jaldhaka

This is the only watershed in Sikkim which does not form the part of Teesta basin and drains directly into Brahmaputra in West Bengal. It has a forest cover of 52% and open forest constitute 49% (Figs 7.42 - 7.44). Alpine scrub cover about 14% of watershed area. More than 34% of Jaldhaka river watershed is under barren rockyland and moraines landcover category.

7.7 FOREST TYPE MAPPING

Forest type map of Teesta basin shows that Sub-tropical forest and Temperate forest are the two predominant forest types in the basin (Figs 7.45 and 7.46). Sub-tropical forest covers 12.88% of the entire basin of which 6.92% of dense canopy and 5.96% are of open canopy and are distributed mainly in Manpur Khola, Rangpo Chhu, Rani Khola, Ramam Khola and Teesta (Lower Part) watersheds (see

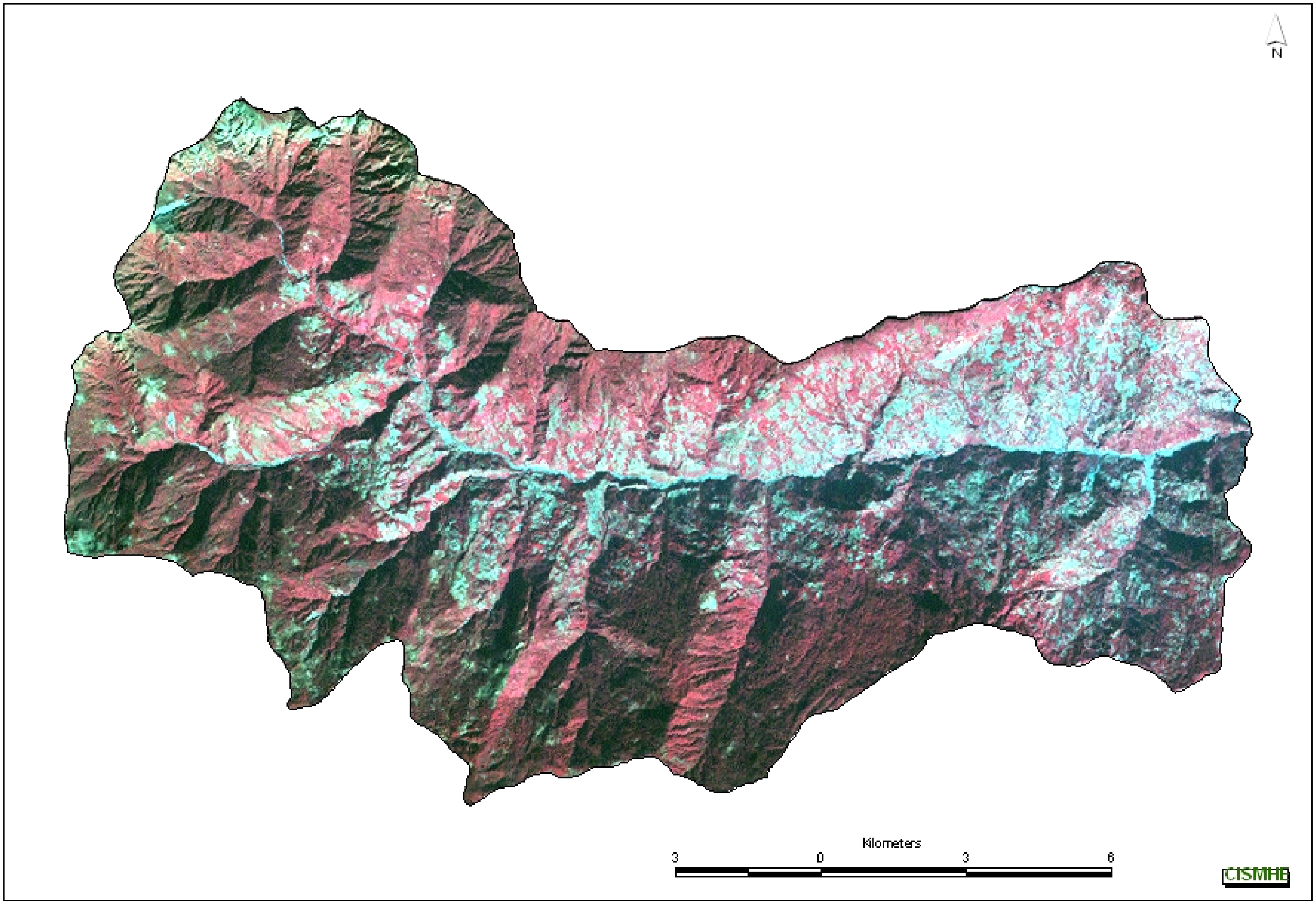


Fig. 7.31 False Color Composite (FCC) of Kalej Khola watershed of Teesta river basin in Sikkim

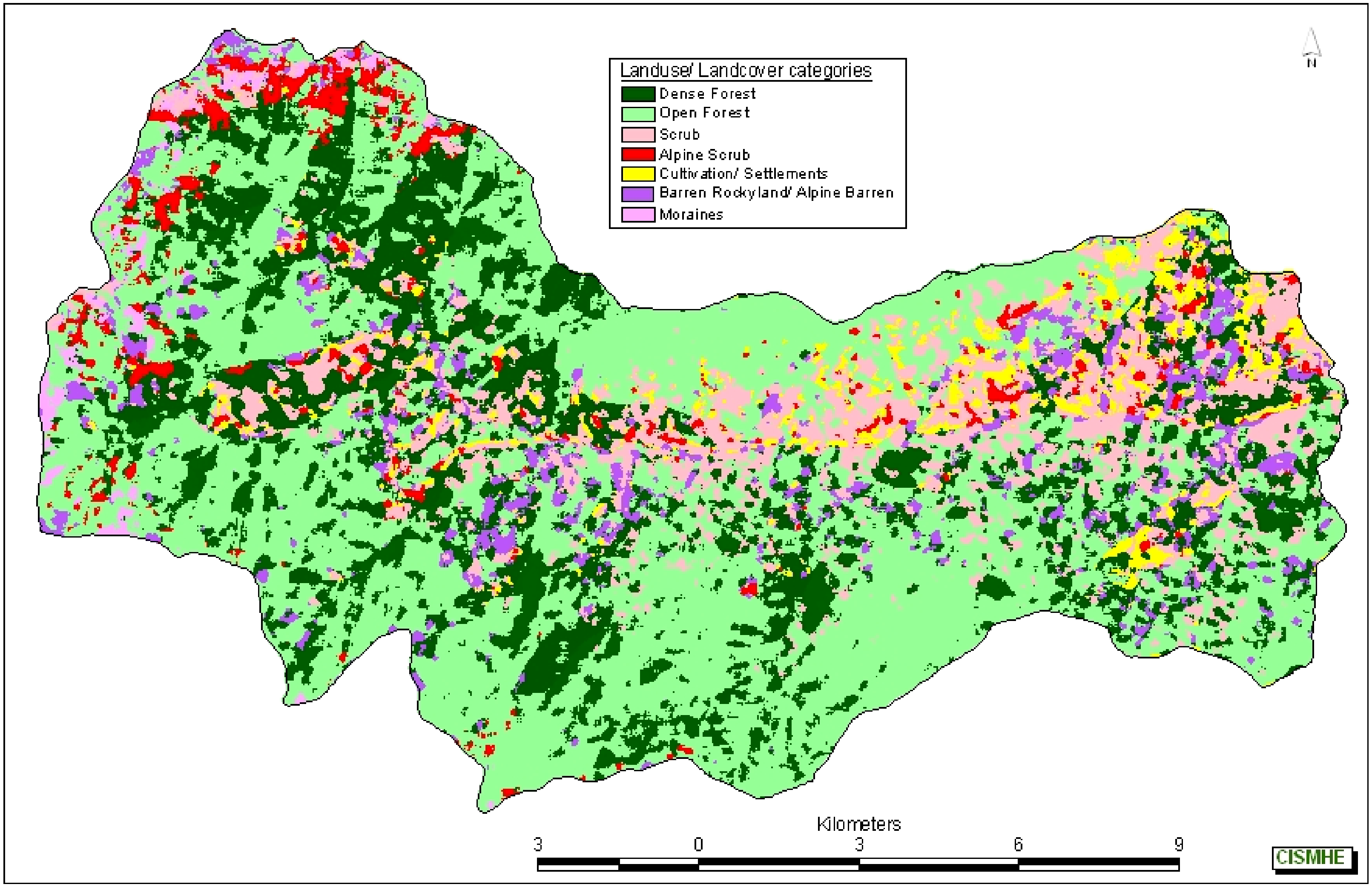


Fig. 7.32 Landuse/ landcover map of Kalej khola watershed of Teesta river basin in Sikkim

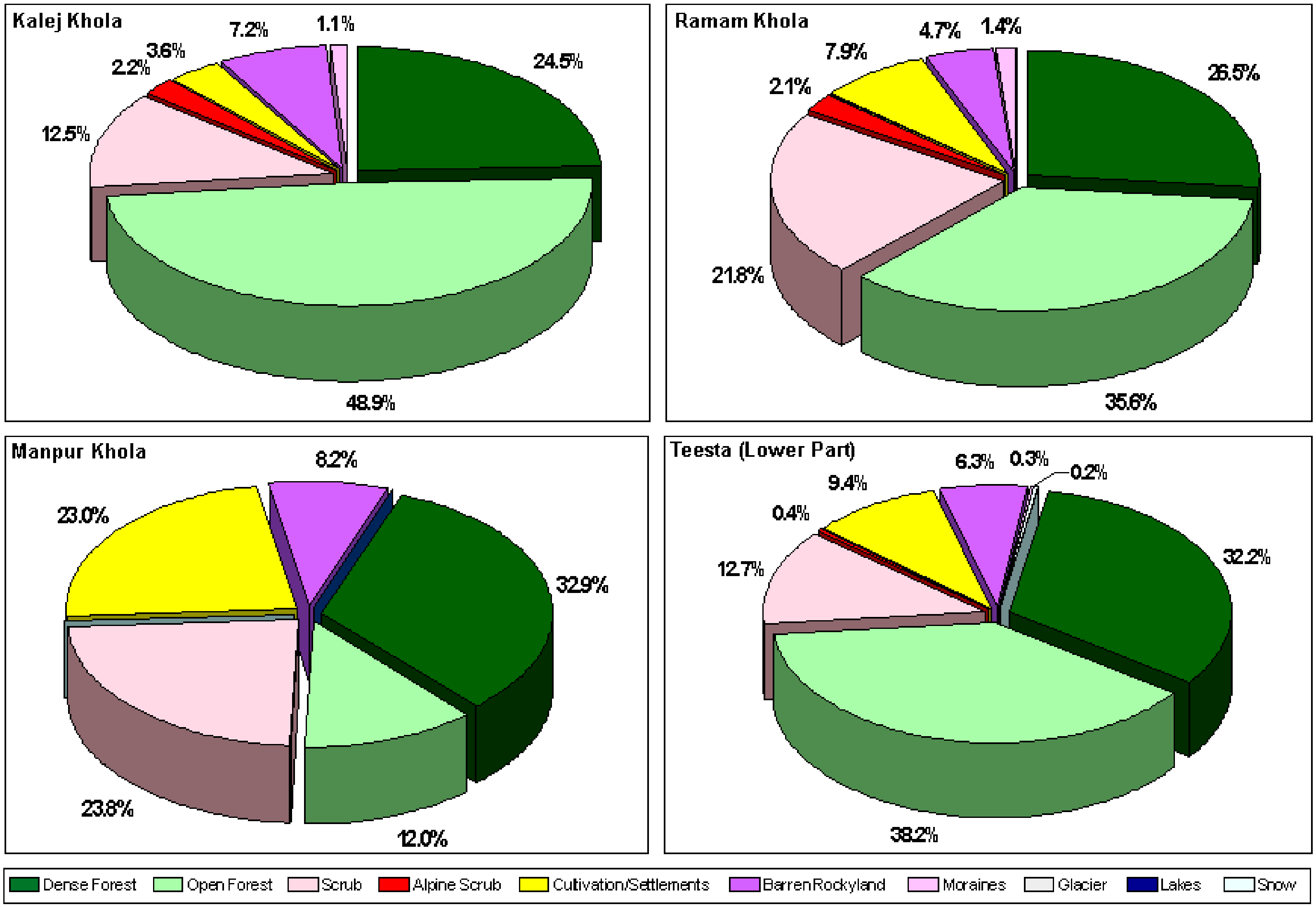


Fig. 7.33 Area (per cent) under various Landuse\Landcover categories of watersheds Kalej Khola, Ramam Khola, Manpur Khola and Teesta (Lower Part) of Teesta river basin in Sikkim

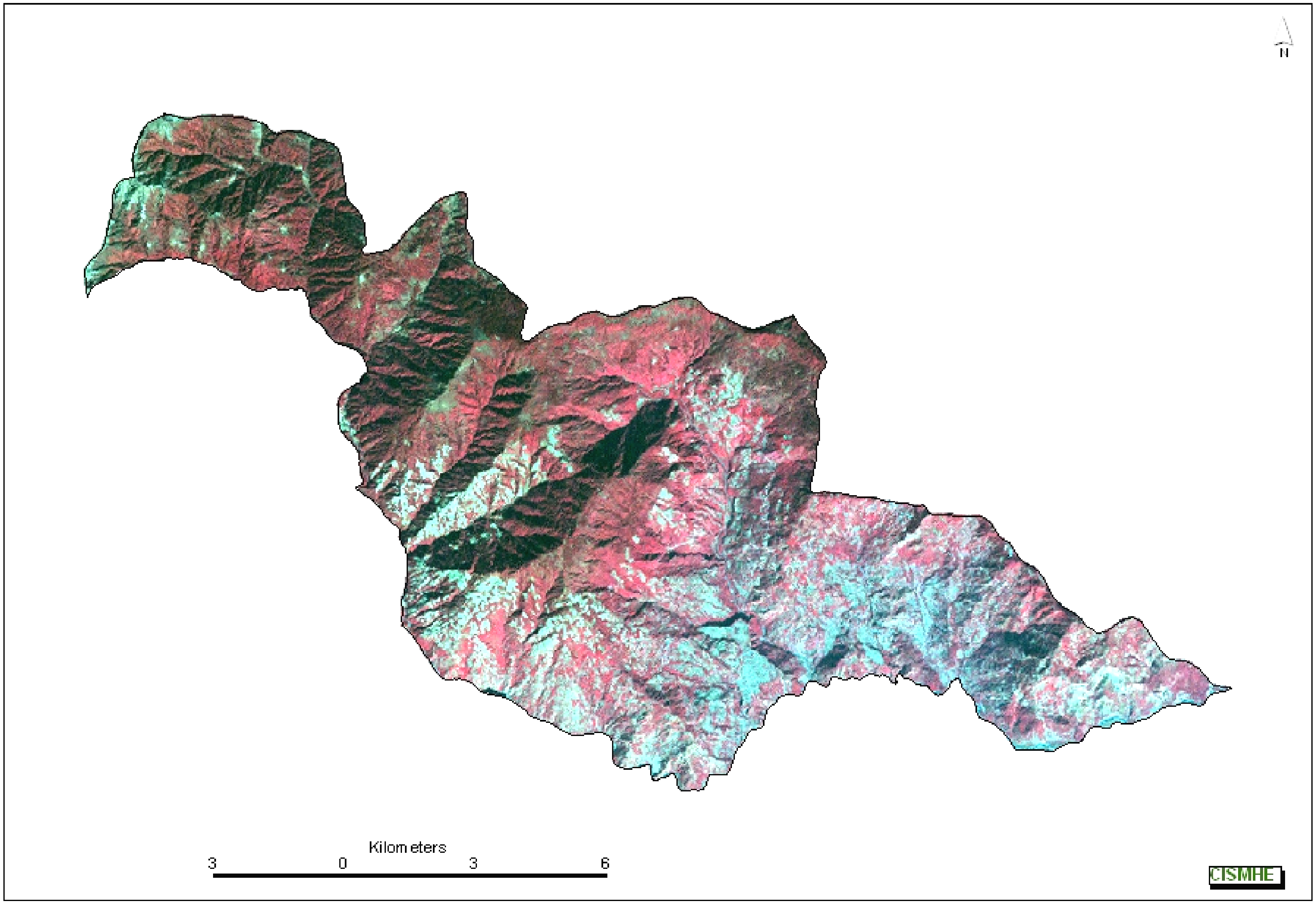


Fig. 7.34 False Color Composite (FCC) of Ramam Khola watershed of Teesta river basin in Sikkim

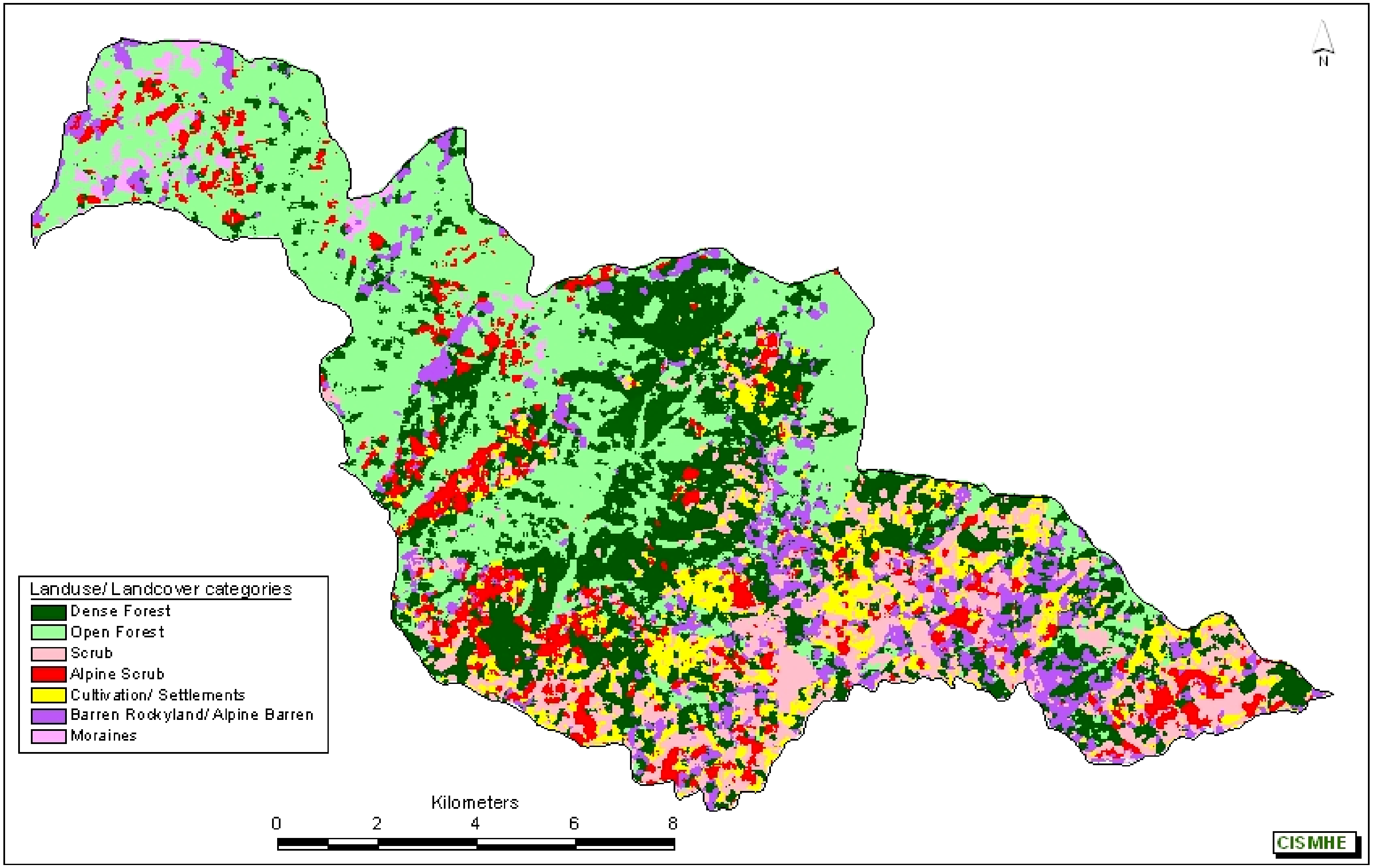


Fig. 7.35 Landuse/ landcover map of Ramam khola watershed of Teesta river basin in Sikkim

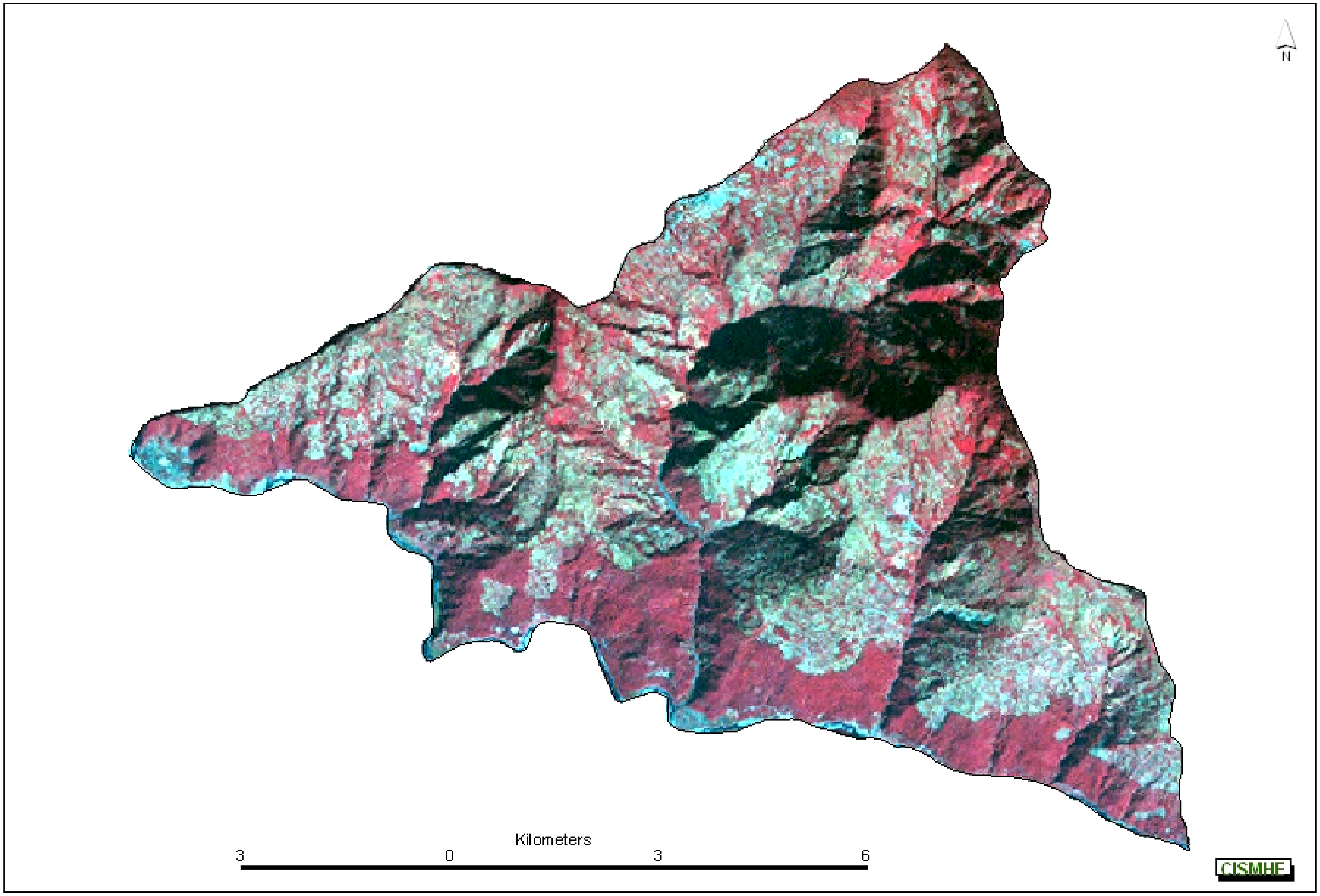


Fig.7.36 False Color Composite (FCC) of Manpur Khola watershed of Teesta river basin in Sikkim

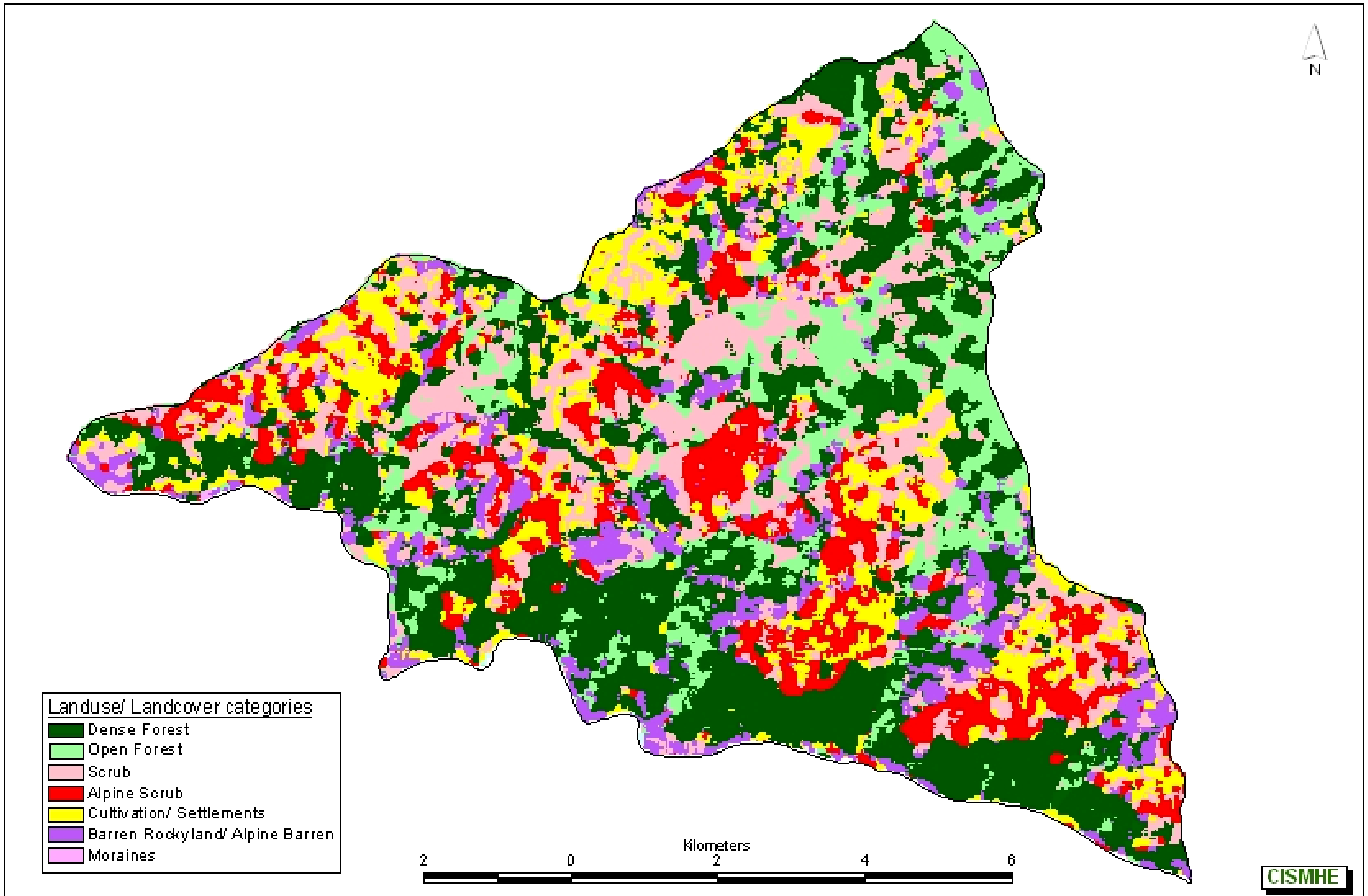


Fig.7.37 Landuse/ landcover map of Manpur khola watershed of Teesta river basin in Sikkim

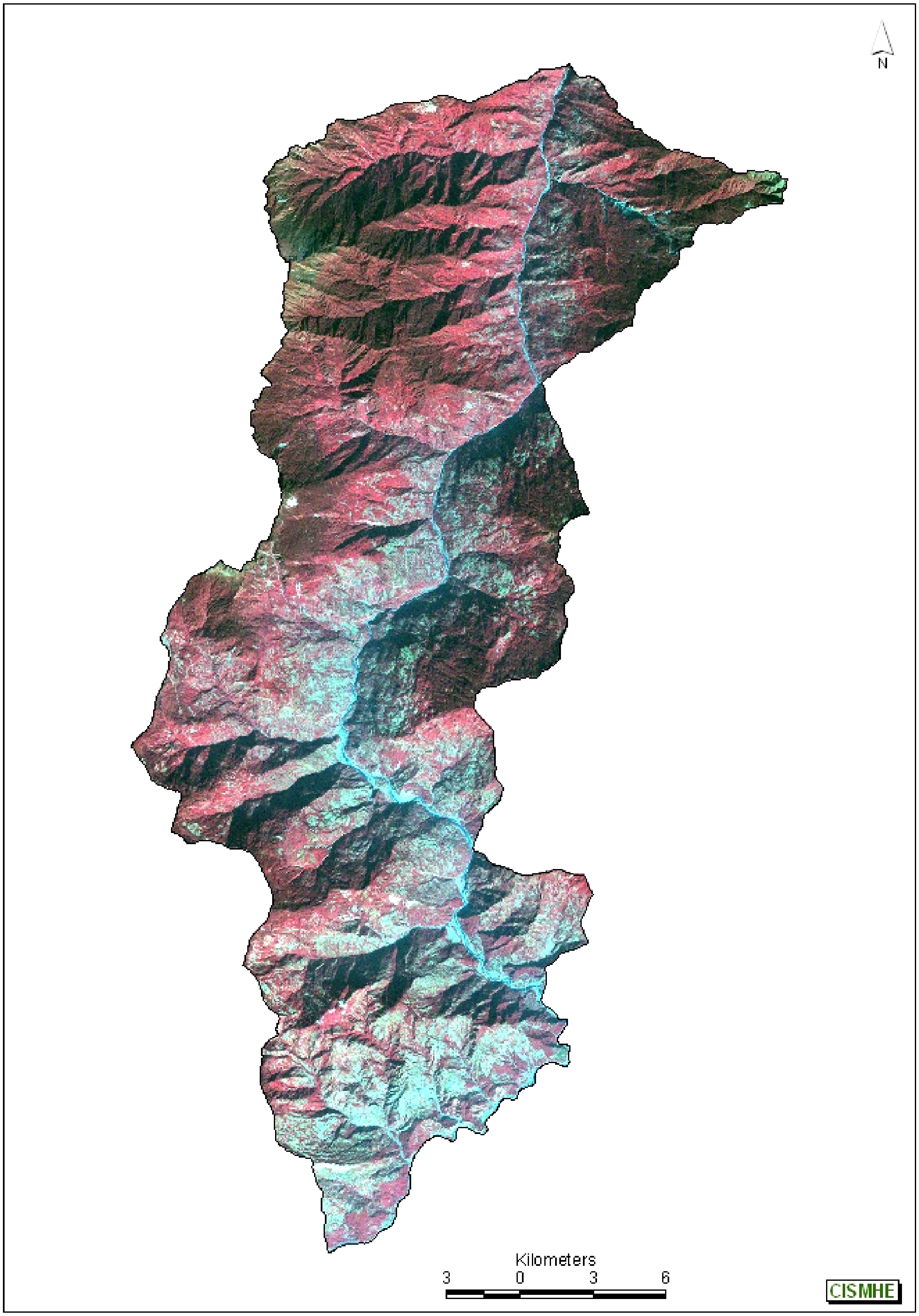


Fig. 7.38 False Color Composite (FCC) of Teesta (Lower Part) watershed of Teesta river basin in Sikkim

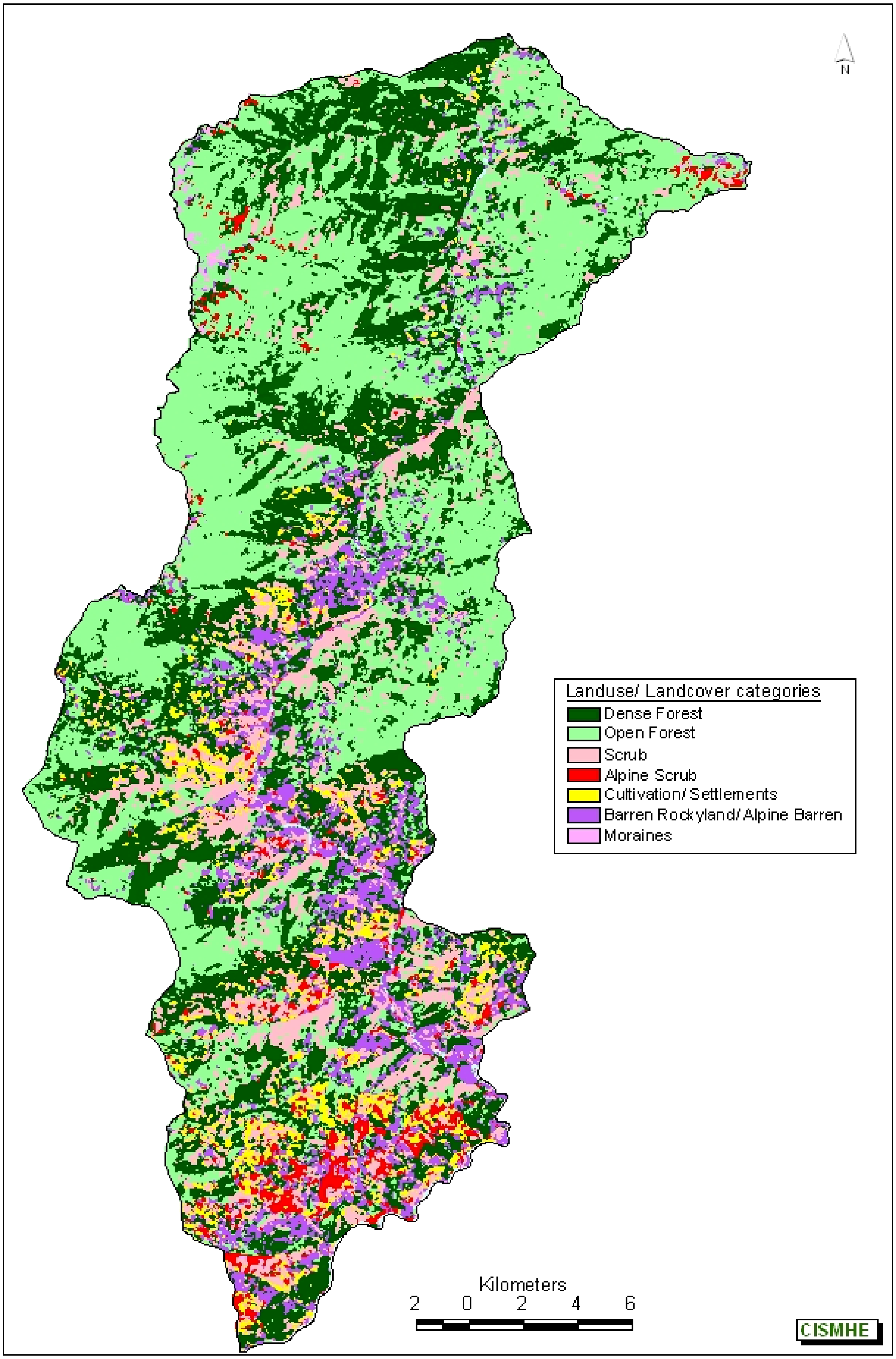


Fig. 7.39 Landuse/ landcover map of Teesta (Lower Part) watershed of Teesta river basin in Sikkim

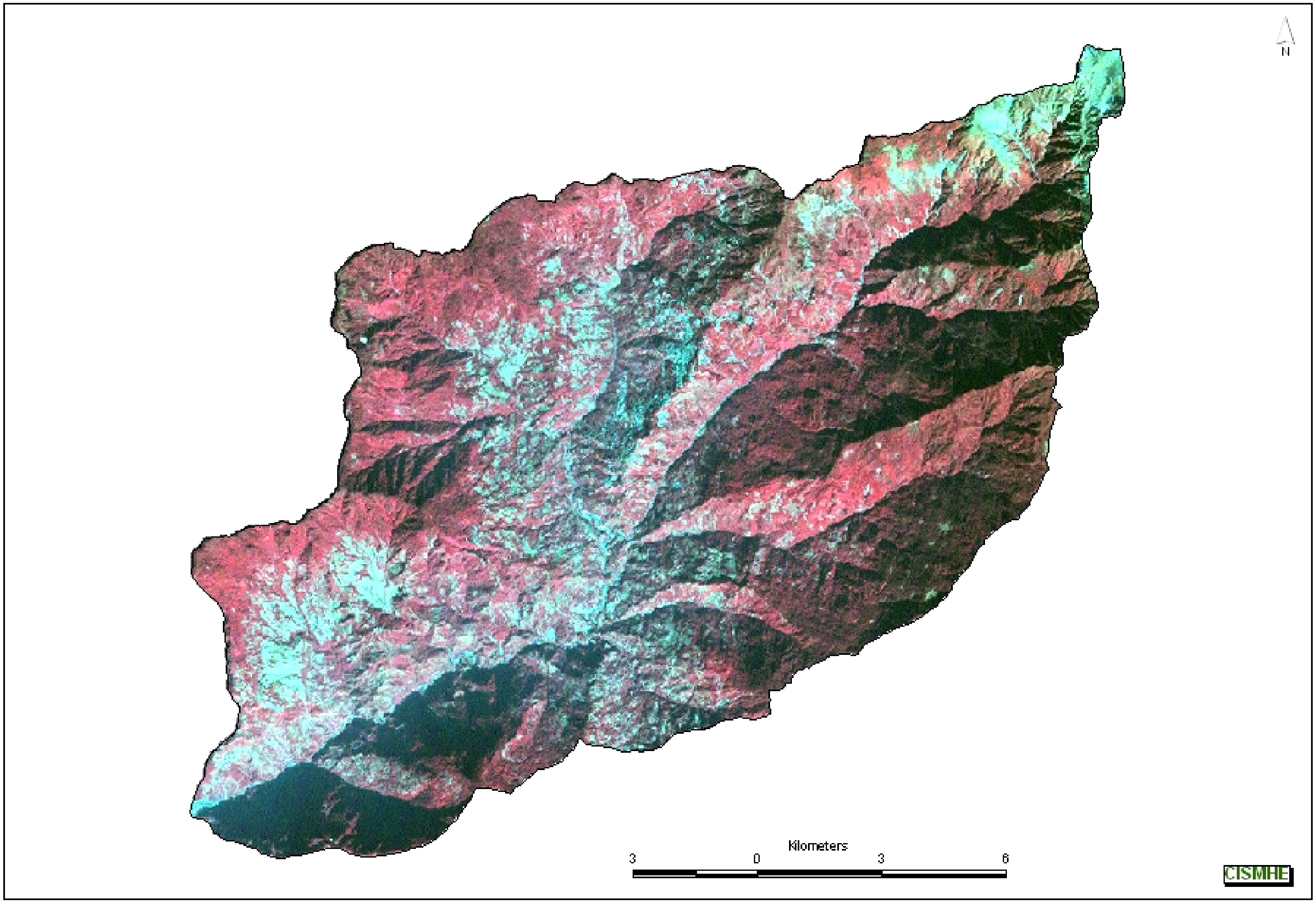


Fig. 7.40 False Color Composite (FCC) of Rani Khola watershed of Teesta river basin in Sikkim

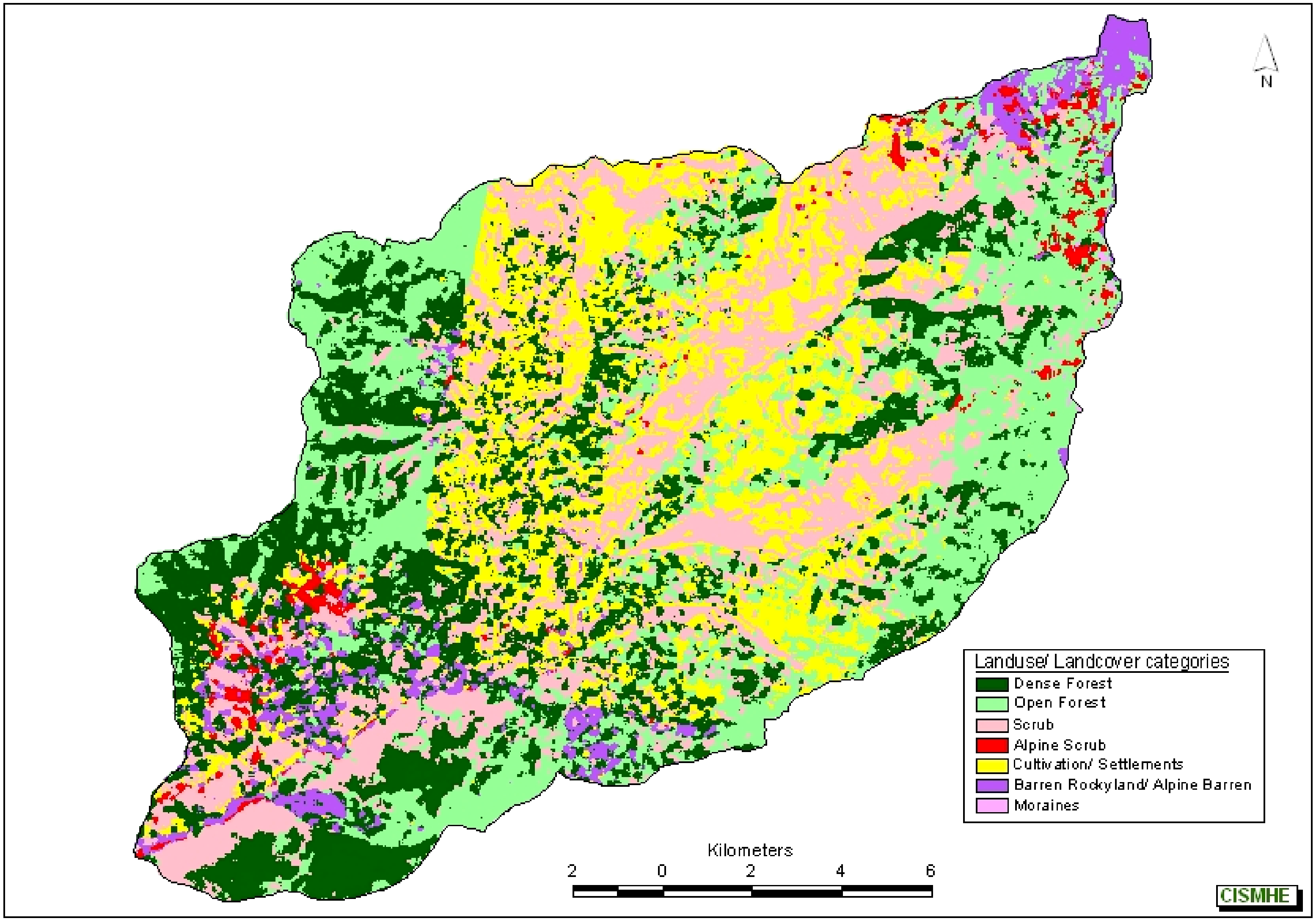


Fig. 7.41 Landuse/ landcover map of Rani khola watershed of Teesta river basin in Sikkim

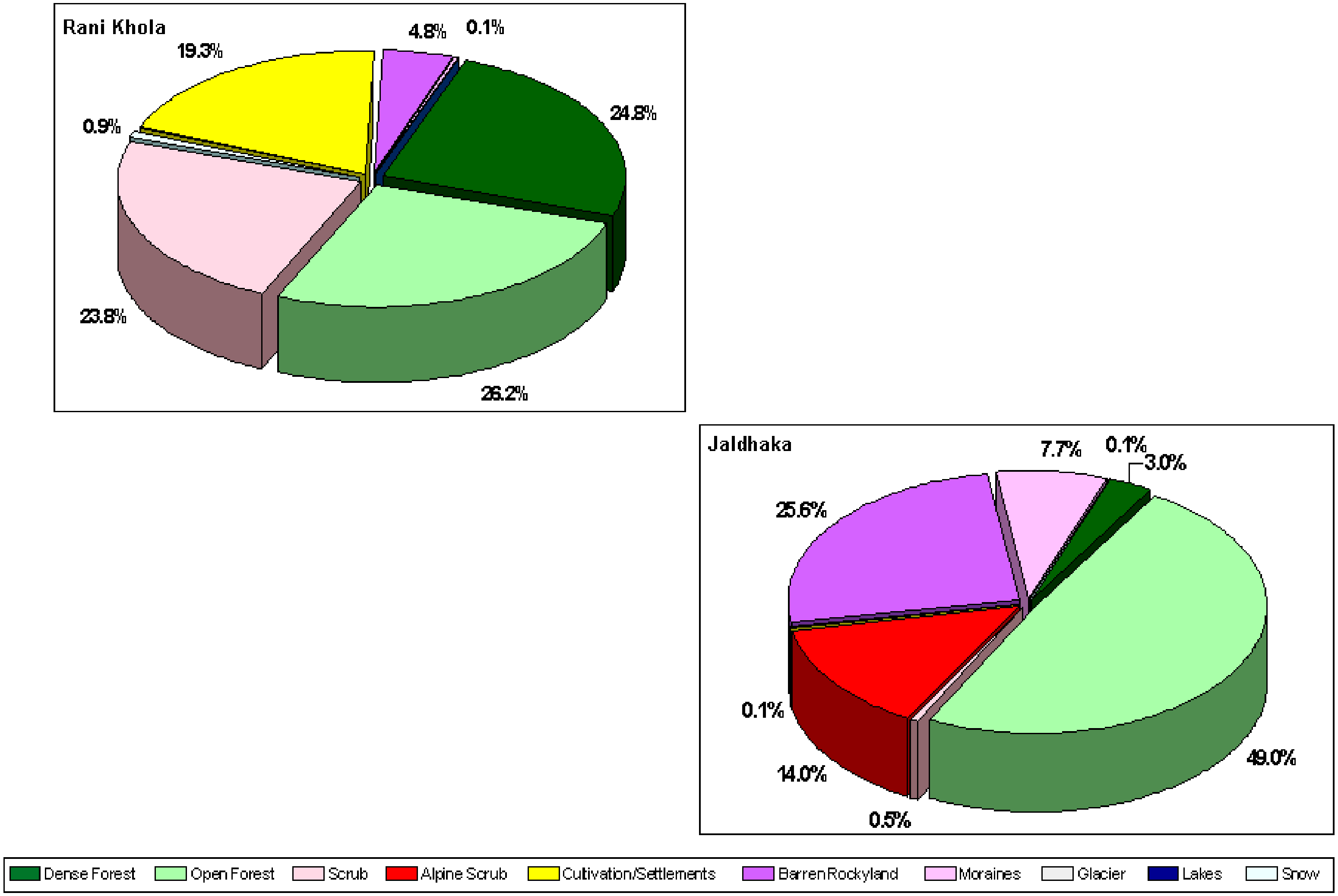


Fig. 7.42 Area (per cent) under various Landuse\Landcover categories of watersheds Rani Khola and Jaldhaka river of Teesta river basin in Sikkim

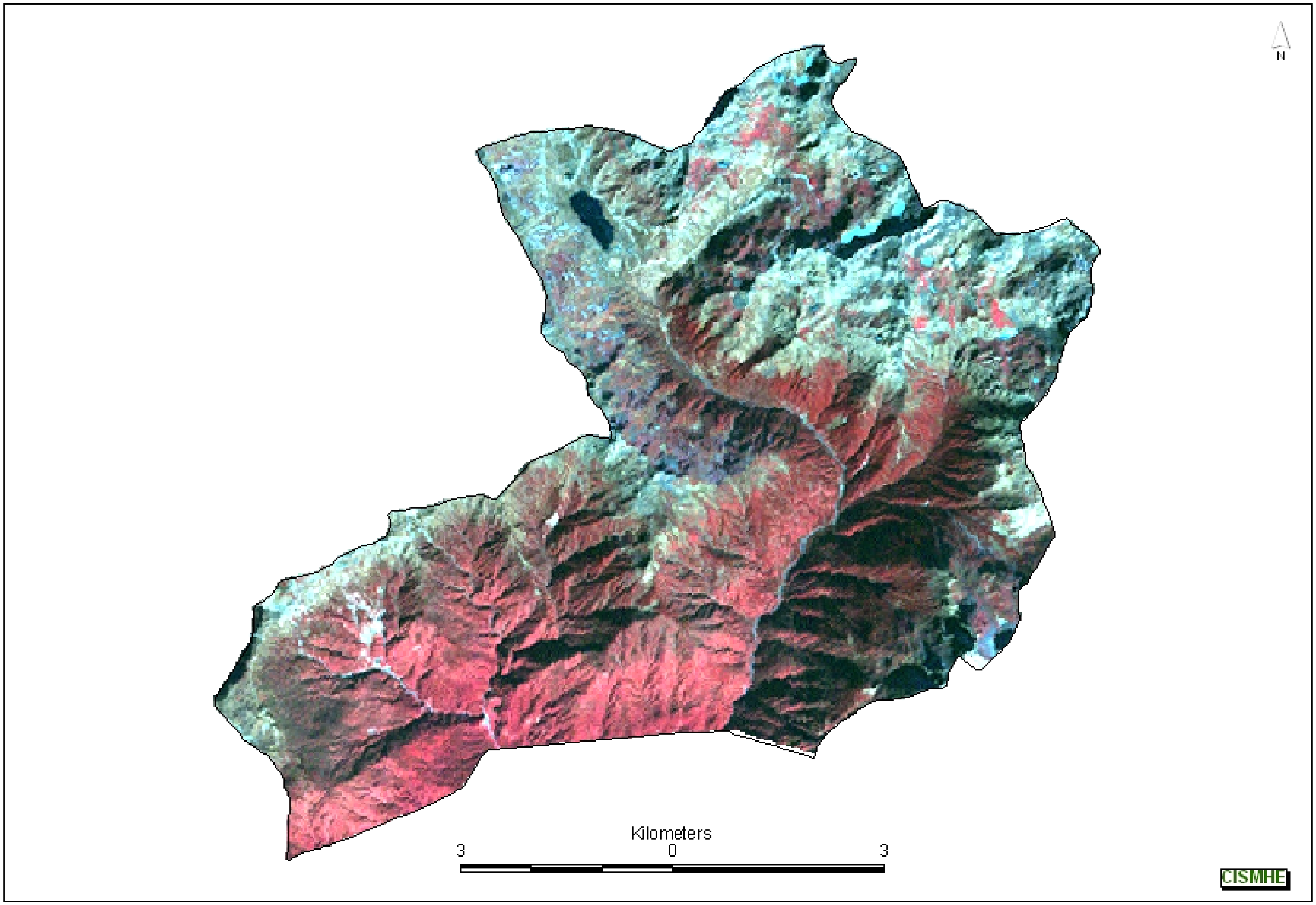


Fig. 7.43 False Color Composite (FCC) of Jaldhaka watershed of Teesta river basin in Sikkim

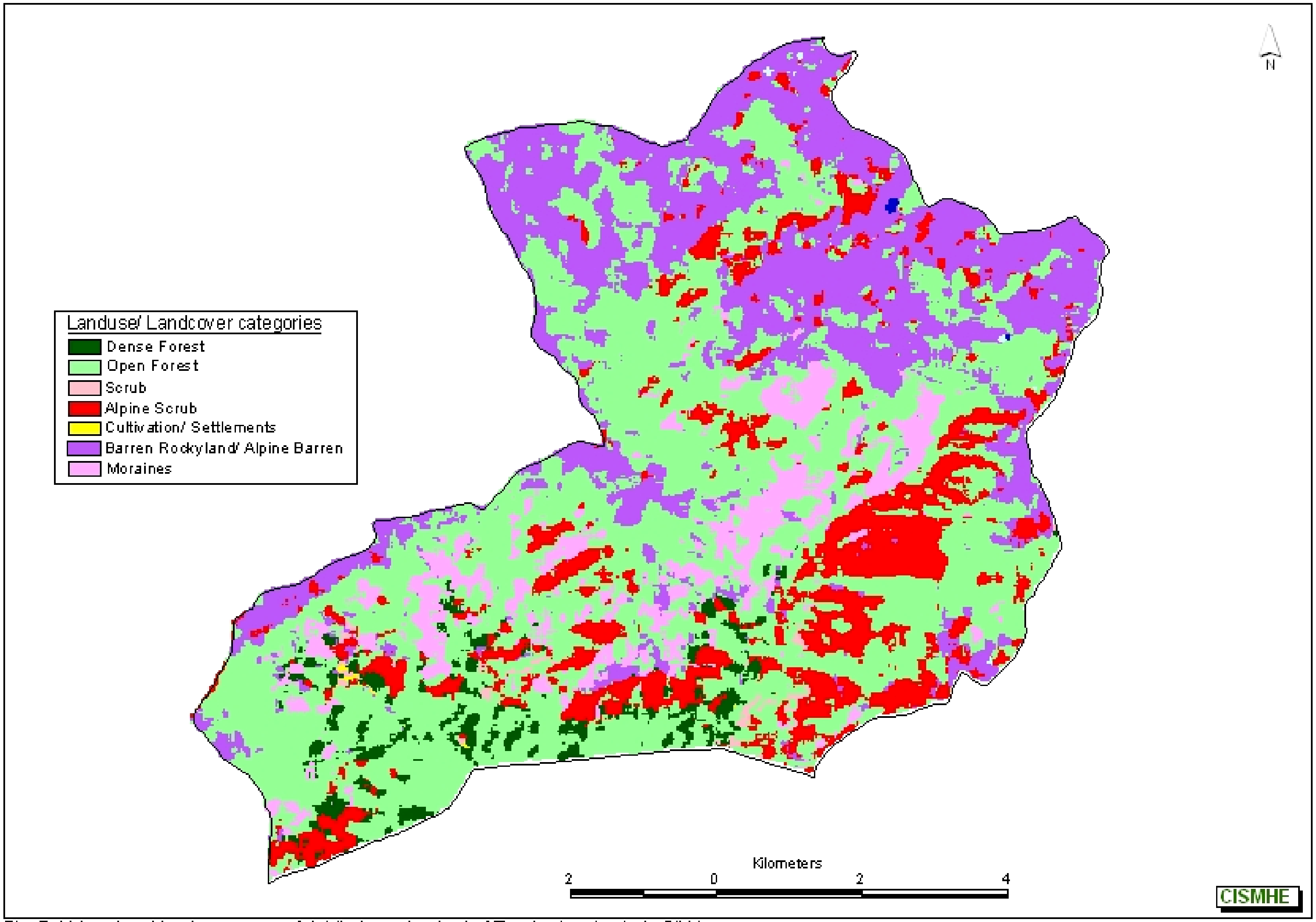


Fig. 7.44 Landuse/ landcover map of Jaldhaka watershed of Teesta river basin in Sikkim

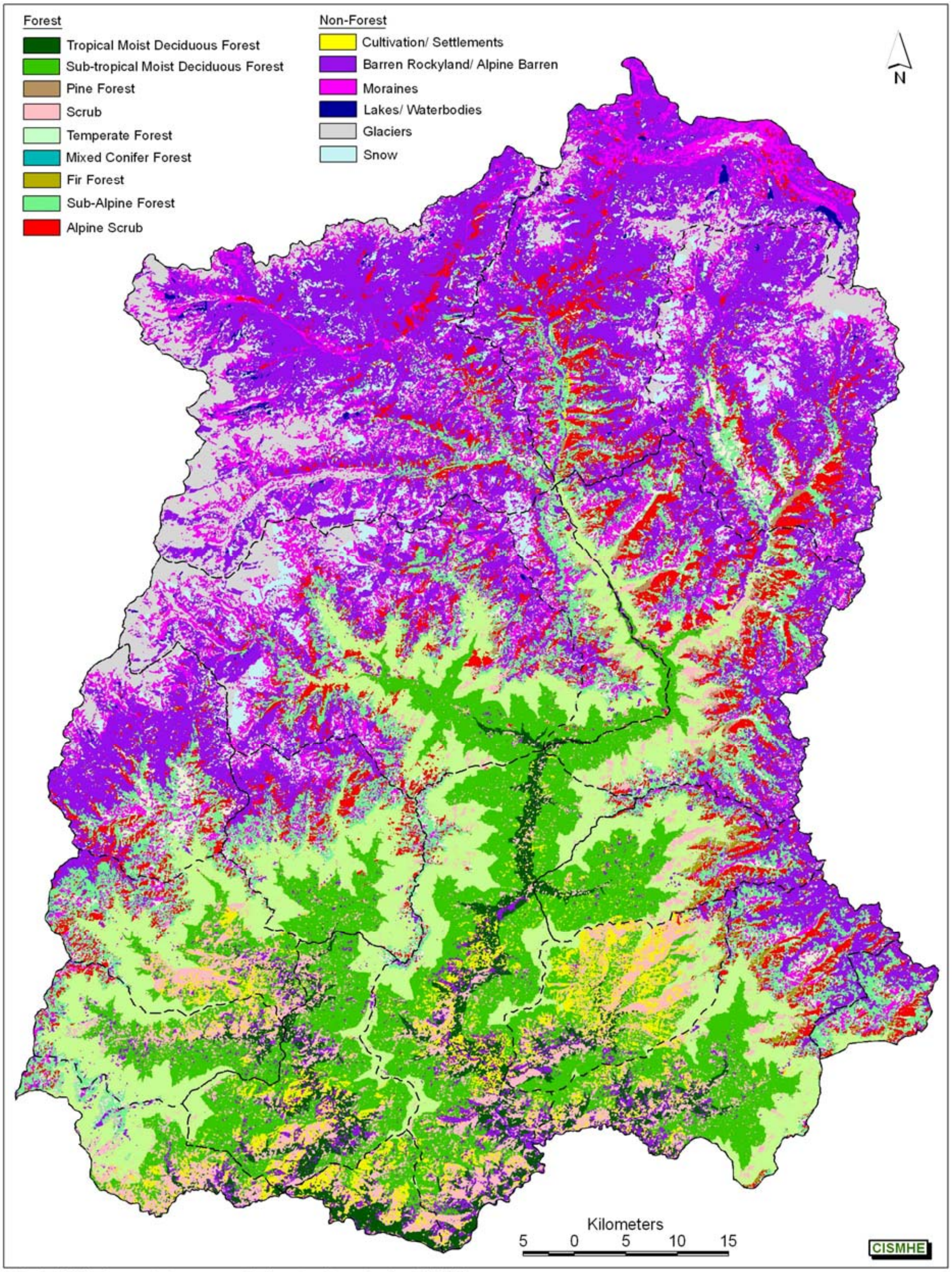


Fig.7.45 Forest types of Teesta basin in Sikkim

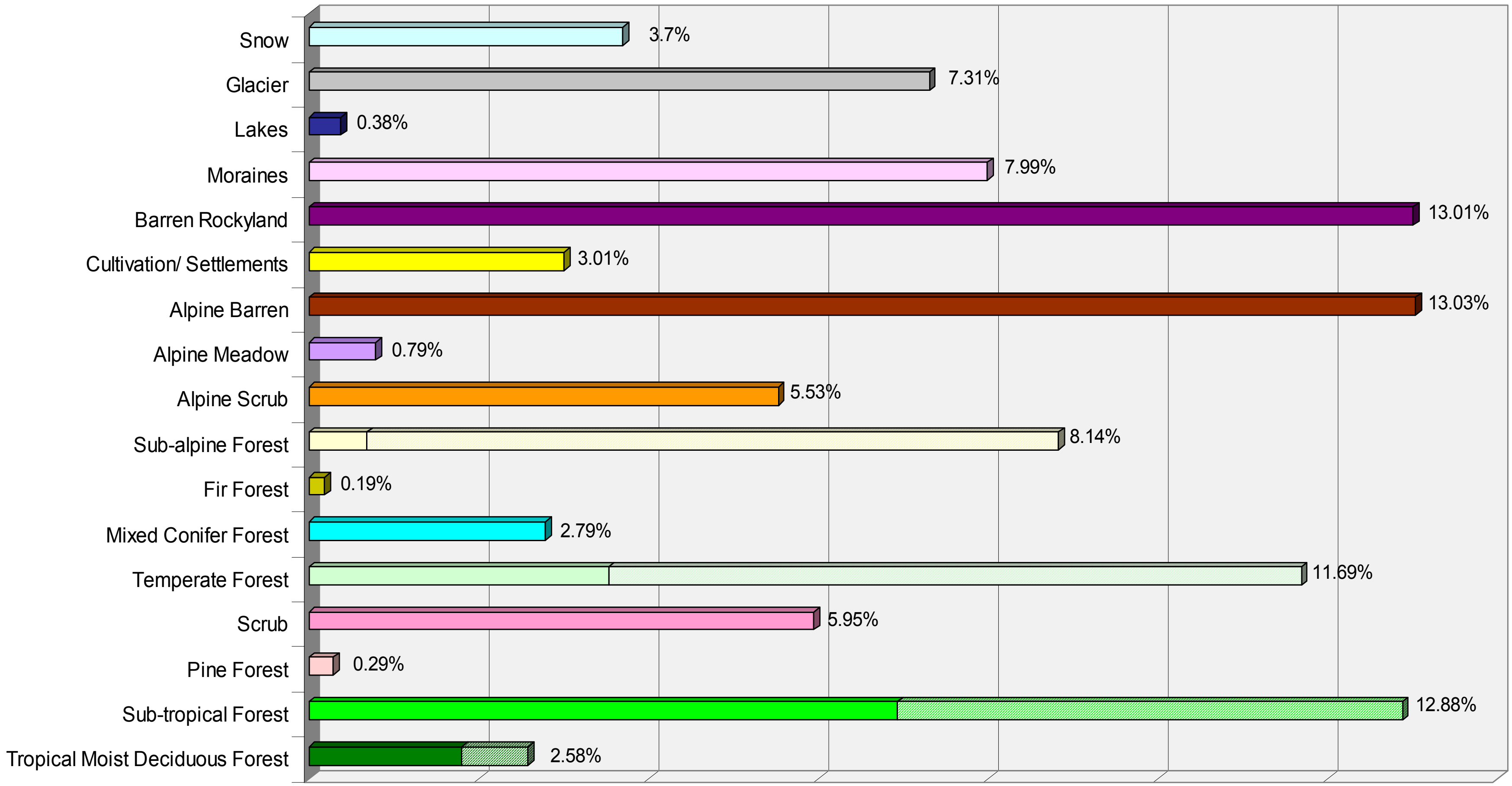


Fig.7.46 Per cent area under different forest types in Teesta basin in Sikkim

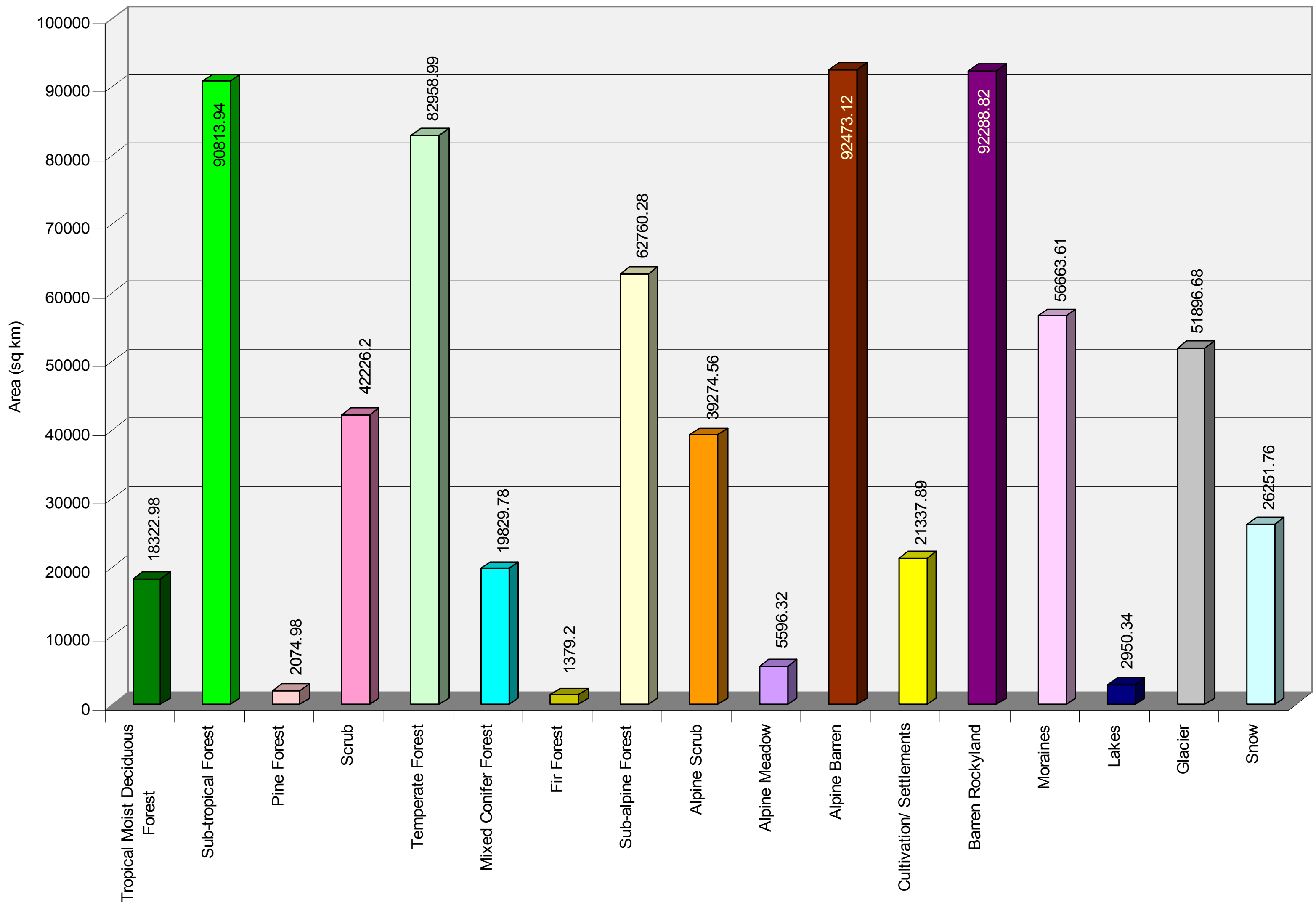


Fig.7.47 Area (sq km) under different forest types in Teesta basin in Sikkim

Fig. 7.46). Temperate forest types are spread over an area of 829.56 sq km (11.69% of Teesta basin), out of which 579 sq km is open canopy forest (Fig. 7.47). Tropical moist deciduous forests are found mainly in lower altitudes mainly in Manpur Khola, Rangpo Chhu watersheds. Mixed conifer forest, comprised of about 2.81% of Teesta basin, is found mainly in Rangyong Chhu, Lachung Chhu, Lachen Chhu and Yumthang Chhu watersheds. Sub-alpine forest constitute 8.83% of Teesta basin lying above 2,700 m in watersheds of Rangyong Chhu, Lachen Chhu, Lachung Chhu, Chhombo Chhu, Yumthang Chhu, Rel Chhu and Prek Chhu. Sub-alpine forests are comprised predominantly of different species of *Rhododendron* mixed with species of *Viburnum*, *Rubus*, *Gaultheria*, *Euonymus*, etc. Alpine scrub and meadow cover about 7.2% of Teesta basin in higher reaches with milder slopes. Alpine scrub is comprised of bushes and clumps of *Juniparus, Salix, Berberis, Rosa,* etc.

BIBLIOGRAPHY

Baret, F. and Guyot, G. (1991). Potentials and limits of vegetation indices of LAI and APAR assessment, Proceedings, International Geoscience and Remote Sensing Symposium (IGARSS'89)/ 12th Canadian Symposium on Remote Sensing, July 10 - 14. IGARSS' 89, Vancouver, BC : 1355 – 1358.

Blackburn, G.A. and Steele, C.M. (1999). Towards the Remote sensing of matorral vegetation physiology: relationships between spectral reflectance, pigment, and biophysical characteristics of semiarid bushland canopies. *Remote Sensing of Environment*. **70**: 278 -292.

Boegh, E., Broge, H.S.N., Hasager, C.B., Jensen, N.O., Schelde, K. and Thomsen, A. (2002). Airborne multispectral data for quantifying leaf area index, nitrogen concentration, and photosynthetic efficiency in agriculture. *Remote Sensing of Environment*. **81**: 179 -193.

Clevers, J.G. (1988). The derivation of a simplified reflectance model for the estimation of leaf area index. *Remote Sensing of Environment*. **35**: 53-70.

Elvidge, C.D. and Chen, Z. (1995). Comparison of broad-band and narrow band red and near infrared vegetation indices. *Remote Sensing of Environment.* **54**: 38-48.

Gao, X., Huete, A.R., Ni, W. and Miura, T. (2000). Optical - Biophysical relationships of vegetation spectra without background contamination. *Remote Sensing of Environment*. **74**: 609-620.

Hack, J.T. (1973a). Stream-profile analysis and stream gradient index, *U.S. Geol. Surv. Jour. Res.* **I.4**: 421-429.

Hack, J.T. (1973b). Drainage adjustment in the Appalachians, In: M. Morisawa (ed.) *Fluvial Geomorphology*, Binghamton, N.Y., 51-69.

Hoffer, R.M. (1978). Biological and physical considerations in applying computer-aided analysis techniques to remote sensor data. In: P.H. Swain & S.M. Davis (eds), *Remote Sensing*: *The quantitative approach*. McGraw-Hill International Book Company, New York. 227-289.

Huete, A.R. (1988). A soil adjusted vegetation index (SAVI). *International Journal of Remote Sensing*. **9**: 295-309.

Jensen, J.R. (1996). *Introductory Digital Image Processing: A Remote Sensing Perspective.* (2nd ed.) Englewood Cliffs, NJ: Prentice-Hall, 316.

Jordan, C.F. (1969). Derivation of leaf area index from quality of light on the forest floor. *Ecology*. **50**: 663-666.

Lillesand, T.M., and Kiefer, R.W. (1994). *Remote sensing and image interpretation*. John Wiley and Sons, New York.

Maxwell, E.L. (1976). Multivariate Systems Analysis of Multi spectral Imagery. *Photogrammetric Engineering and Remote Sensing*. **42**(**9**), 1173-1186.

Richardson, A.J. and Wiegand, C.L. (1977). Distinguishing Vegetation from Soil Background Information. *Photogrammetric Engineering and Remote Sensing*. **43**(**12**): 1541-1552.

Rouse, J.W., Haas, R.H., Schell, J.A. and Deering, D.W. (1973). *Monitoring vegetation systems in the great plains with ERTS*, Third ERTS Symposium. NASA, Washington, DC. 309-317.

Schowengerdt, R.A. (1983). *Techniques for Image Processing and Classification in Remote Sensing*. Academic Press, Inc, New York.

Seeber, L. and Gorintz, V. (1983). River profiles along the Himalayan arc as indicators of active tectonics. *Tectonophysics.* **92**: 335-367.

Sellers, P.J. (1985). Canopy reflectance, photosynthesis and transpiration. *International Journal of Remote Sensing*. **6**(**8**): 1335-1372.

Thenkabail, P.S., Smith, R.B. and De Pauw, E. (2000). Hyperspectral vegetation indices and their relationships with agricultural crop characteristics. *Remote Sensing of Environment*. **71**: 158-182.

Todd, S.W., Hoffer, R.M. and Milchunas, D.G. (1998). Biomass estimation on grazed and ungrazed rangelands using spectral indices. *International Journal of Remote Sensing*. **19**(**3**): 427-438.

Treitz, P.M., and Howarth, P.J. (1999). Hyperspectral remote sensing for estimating biophysical parameters of forest ecosystems. *Progress in Physical Geography*. **23**(**3**): 359-390.

Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*. **8**: 127-150.

Wiegand, C.L., Richardson, A.J., Escobar, A.J. and Gerbermann, A.H. (1991). Vegetation indices in crop assessments. *Remote Sensing of Environment*. **35**: 105-119.

ANNEXURES

OBJECTIVES OF THE WORKSHOP

1. To share the knowledge of Medicinal Plant, its cultivation, utility, value and marketing.
2. To look for the possibility of Interdisciplinary collaboration on promotion of Community Health & Development through Medicinal Plants.
3. To understand the future avenues for marketti8ng of medicinal plants for revenue generation
4. To look for the possibilities of Income Generation for the farmers of Sikkim State by selling selected medicinal plant as cash crop.

Participants' Profile

Participants were invited from all the four districts of the State. They included mainly the NGOs functionaries promoting or willing to promote cultivation of medicinal plants, prospective medicinal plant farmers/growers most of them being registered with the Sikkim State Medicinal Plant Board, Traditional System of medicine Practitioner, staff of State Medicinal Plant Board, traders/firms from Siliguri and Kolkatta.

Resource Persons' Profile

Resource Persons were invited from the Panchavati Greentake Research Society, an NGO working in Medicinal Plant in Darjeeling (West Bengal), State Forest Department, State Medicinal Plant Board (Sikkim), Medicinal Plant Firm/Trades (Siligur & Kolkatta) and the West Bengal Directorate of Medicinal Plant.

Day One (7th January 2005)

Arrival & Registration of the Participants at the Venue

The participants reached at KEEP Office, Pastanga, E. Sikkim, the venue of the workshop on 7th January 2005. The workshop was organized with the local traditional and cultural flavors and hospitality at Pastanga with the cooperation of KEEP, an Organization promoting village ecotourism. Praticipats were registerd followed by the informal business discussions where parciapnts were welcomed by offerbnig traditional rosary by the members of KEEP. KEEP members also highlighted about the KEEP Organization and its activities to the delegates, followed by the self introductions of the participants. They were t
hen offered the refreshment and accompanied by KEEP members for their home stay arrangement.

Day Two (8th January 2005)

Inaugural Sessions

Before the formal inauguration of the workshop, the gathering mourned for a minute for the tasnami victims.

Then, the workshop began with the warm welcome address delivered by Dr. P.C. Rai, Sr. Program Officer of VHAS followed by the ceremonial Scarf offering to the Chief Guest Mr. Kunga Zongpo, Area MLA cum Chairman of SNT, Govt. of Sikkim by Dr. H. Lepcha, President of VHAS and to Dr. J.P. Tamang, Regional Coordinator of Carrying Capacity of Teesta Basin Project by Mr. C. D. Rai, Village Pancahayat and the Treasure of KEP.

BACKGROUND

State of Sikkim is rich in flora and fauna, culture and religions apart from being an attractive tourist's destination for all. The three ethnic communities viz., Lepcha, Bhutia and Nepali live in harmony and maintain a distinction by virtue of unique language, ethnicity, cultural-heritage, costumes, and of course the religion. As it is often emphasized that the biodiversity is a heritage of the country, land-locked State of Sikkim with a total area of 7096 sqkm, does contribute a lot to the nation's rich gene pool, particularly the medicinal plant resources. In the alarming situation of rapidly degrading environmental conditions, the ethnic mosaic of the Sikkim is very much in favor of the conservation of natural entities, precisely the flora & faunal species.

The richness of medicinal plants resources in the State is evident from the plant-based rich practices/systems of management of common ailments being inherited from time immemorial generation after generation, these being the only source and resource for complete medicinal health care services of the people until few decades ago. One more such valuable health care system is institutionally set up due to the migration of Tibetan refugee into Sikkim called Swarikpa which have also found recognition in the Govt. modern health facility set-up. For all these prevailing practices in the State, medicinal plants are the basis as everyone agrees that plants are the remedy of hunger and health and the research on it are as old as human civilization. The famous Ayurvedic, Unani, Chinese and Tibetan systems of medicine are mostly prepared from herbal plants along with some animal parts/products and minerals. As a matter of fact, herbalism is returning to public favor.

Sikkim harbours 400+ species of medicinal plants (Srivastava & Kapahi 1990), many of them having high value in trade. Thus, the State has a great potentiality in mobilizing the people towards farming and cultivation of such valued medicinal plants through planned and organized agro-technology and assured markets which will give boosting to the economic activity of the State. However, it has not been possible to utilize this potentiality due to various reasons, despite interest and willingness of the farmers to undertake medicinal plant cultivation.

Realizing the fact, Voluntary Health Association of Sikkim, a State Level non-profit making Organization initiated activity in the State with the theme of educating people on the importance and value of local health practices and herbal resources. Survey and documentation of such practices and resources, establishment of a small Herbarium, creating awareness about this, application of cost effective natural elements at the local level for the management of common ailments and raising a community nursery/herbal garden of medicinal plants for exhibition, public awareness, demonstration and need-based application etc have been some of the activities of VHAS in this direction. In the meantime, VHAS was supported for a micro project entitled *Medicinal Plants with reference to Awareness, Community Garden and Cultivation under the Carrying capacity Project of Teesta Basin in Sikkim, by the Center for Interdisciplinary Studies for Mountains & Hill Environments, University of Delhi South Campus.*

To strengthen the ongoing activities, a *Proposal for a State Level Workshop on An Approcah to Promotion of Community Health & Development Through Medicinal Plants was approved by the Center for Interdisciplinary Studies of Mountain & Hill Environment, University of Delhi South Campus*, under *Carrying Capacity Study of Teesta Basin Project,* to be held at Gangtok, with the main objective of sharing knowledge on Medicinal Plants cultivation, its value and marketing and to gain an alternative of economic activity boosting community health through medicinal plants.

Key Note Address was given Dr. J.P. Tamang, Regional Coordinator of Carrying Capacity of Teesta Basin Project where he gave an insight into the activities carried out under the project in Sikkim and also highlighted the objectives of the ongoing workshop. He also explained about the need of developing the local medicinal plant product in processed and value added form which will fetch good price than simply selling raw resources, and further cited the common example of Crocin Tablets and Titepaati (*Artemicium vulgaris*) to substantiate his address. Dr. Tamang also attracted the attention of the Chief Guest, the MLA and Chairman of the Govt. of Sikkim and the various delegates towards the need of setting Research & Development Institutes by the Government in the State to extract, investigate and analyze the active principles from our natural resources which can be utilized and exploited in much profitable way than in crude form.

The delegates then introduced themselves in the workshop. Following this, the Chief Guest f the Workshop Mr. Kunga Zongpo, Area MLA cum Chairman of SNT, Govt. of Sikkim lighted the ceremonial lamp to mark the tradiitonal opening of the event. Mr. Bhutia then delivered inaugural address declaring the workshop open. He expressed happiness for this kind of workshop was held in his constituency and suggested to conduct similar workshops in others places of the State so as to benefit the common people at large. Highlighting the importance of age-old healing traditional and available medicinal plants, he said that it is now time to look forward towards sustainable exploiting these resources for the economic upliftment of the poor peoples through proper and scientific cultivation and marketing perspectives. Mr. Bhuita also opined this type of activity in future will open up avenues for employment to our youths and should help to strengthen the economic fabric of the society. He declared the workshop open and wished all participants for the success of the workshop.

The Inaugural Session of the workshop concluded with the Vote of Thanks that was proposed by Dr. (Miss) H. Lepcha, President of VHAS Executive Board. The participants with the Chief Guest then visited an exhibition put up by Sikkim State Medicinal Plant Board, Gangtok, and the SAIMAA Agrotech, Kolkatta.

The House then reassembled for technical session after high tea session with the Chief Guest.

TECHNICAL SESSION

Medicinal Plants of Sikkim: Avenues & Perspectives

Mr. Bijoy Gurung, Additional Director, Dept. of Forest & Environment, Govt. of Sikkim shared his long experinecs in the filed of medicinal plants in the State and accordingly discussed about the medicinal plants of Sikkim Hills and the avenues and perspectives associated with this. He also screened the visuals of different potential medicinal plant resources available at different geographical regions of the State and disclosed that nothing concrete and meaningful has been achieved although nature has bestowed a rich resource of medicinal plants to the State of Sikkim. Mr. Gurung also discussed the basics of medicinal plant and herablism culture of the place. Mr. Gurung also responded to the queries of the participants in the discussion. The text of his presentation is given in annexure-I.

Processing, value addition and marketing perspectives of medicinal plants of sikkim & Darjeeling Himalayas

Dr. G.C. Subba, Chief Chemist, Directorate of Meidical Plants, Govt. of West Bengal dealt with the issue of processing, value addition and marketing perspectives of medicinal plants of Sikkim & Darjeeling Himalayas in which Dr. Subba emphasized on processing and value addition for the better perspectives of marketing and economic returns.He also informed that although processing and value addition activity requires high expertise and sophisticated technology demanding much higher investemt, it is time for all the stakeholders to start a point in this line. Otherwise, sending and selling raw materials in the market doesn't fetch much benefit to us, he reiterated. Dr. Subba, in this respect, elucidated various examples of the final product prepared from the active principla of the medicinal plant with value aditon and the range of price in the national and intenational market that it fetches to the trader/firms.He cited an example of ***Dicocorea*** & ***Cinchona*** and elaborated the process & technological aspects to sell the final products in an international markets. The abstract of the deliberation is as follows.
The acceptance of plant based therapeutics is increasing day by day both in developing and the developed countries due to the fact that natural products are recognized as free from side effects, easily available at affordable prices and at times the only source of remedies available to the poor.

In view of the international market of medicinal plants touching US $ 65 billion per year (contribution from India being below US $ 1 billion per year) and growing at the rate of 7% per year, it is justified for any Govt. and/ or private agencies taking up commercial activities in this increasingly popular area.

Since the demand for raw materials is increasing the pressure on natural resource is multiplying rapidly. In order to secure a sustainable supply of raw materials the only option available is to embark on systematic cultivation of these plants in suitable and sufficient areas. The National Medicinal Plants Board, N. Delhi has framed a lot of blue prints to help and support interested groups taking part in medicinal plants endeavors.

Even though many of the plantations may attain viability simply by selling the raw produce as such but the financial return shall improve to a great extent if proper value addition is done wherever and whoever can afford it.

Large cardamom can be processed to yield volatile oil, oleoresins which are more valuable than the raw produce. Similarly Taxus baccata, Podophyllum hexandrum, Rose, Bacopa, Tagetes, Eucalyptus, Silybum marianum, Valerian, Dioscorea, Rye, Swertia, Artemisia annua, Lemon grass, Citronella, Patchouli, Geranium etc. can be processed to yield a number of value added products. Setting up of production units of herbal shampoo, mosquito repellants, solid and semi solid fragrances based on raw materials produced locally should be encouraged.

It may be noted here that the cultivation of the above mentioned medicinal and aromatic plants should not be encouraged for marginal farmers to take as primary crops. These may be cultivated as additional crops with usual items to start with. This activity demands a Govt. support for at least five years in building necessary infrastructure including sales outlets. It is also expected that the relevant Govt. department shall be able to bring bigger commercial houses of India and abroad to the state to set up their units. Success of medicinal plants sector in a sustainable way also depends heavily on proper Research and Development on plants and processes in question.

It may further be added that projects on medicinal and aromatic plants should preferably be taken of as a component of a composite programme on modern agricultural system comprising of high value vegetables, fruits, floriculture, and even bio-diesel plants and bamboo. Hence it can be concluded that medicinal plants sector has a bright future provided the necessary technical and administrative inputs are properly planned and made available.

Other aspects of medicinal plant discussed during the session are presented in Annexure-II.

Cultivation of hig-value medicinal plant –Chirata as an additional income generation in the hill areas of Sikkim & Darjeeling

The session on this topic was dealt with by the resource person Dr.Prajwal.C.Lama, Secretary, Panchavati Greentech Research Society (PGRS), Darjeeling, West Bengal.The abstract of his presentation states Chirata plant is well known to the hill people of the Eastern Himalaya. Even in the oldest book "Ayurveda"also revealed that this kirat titya (Sanskrit) plant used for the skin diseases. Apart from the above medicinal uses, chirata has many potentialities for different diseases. The recent importance of the medicinal plant in the local, national as well as in the international scenario generated new dimension to the medicinal line. The opening of the National medicinal Plants Board at the union level with state level emphasized all the concerned people to rethink of the medicinal plants found in our locality.

Among the 32 enlisted medicinal plants, 16 plants are wildly available in the Sikkim and Darjeeling Hills. This suggested that if the new generation wants to run in the present globalization race, this sector plays an important and sustainable venture.

PGRS has developed a thorough agro technique for the cultivation of chirata plant in the Sikkim and Darjeeling Hills. This scientific based technology will definitely boost the cultivation method of the chirata plant at the village level. The success story of PGRS model at Darjeeling district under Jorebunglow Sukhia Pokhari Block expressed that the wildly grown plant can be domesticated and make a profit bearing plant too.

The participant put forward a host of question in relation to the cuktivation technique of chireto plant to which Dr. Lama replied encompassing varios factors associated with the germination of chireto seeds. The resource persons also assured to impart training to the interested farmers from Sikkim willing to grow chireot if they approach to PGRS.

Important text of the relevant deliberation is being given in Annexure-III.

Group Work & Discussion

Mr. Suman Rai, Regional Director of Ashoka Trust for Research on Environment Education (ATREE), Bagdogra then facilitated a group work where the participants were divided into various groups of 3-5 persons. They were asked to work on the issues that they need most to be discussed for commercial promotion of medicinal plant cultivations n Sikkim & Darjeeling.

The participants accordingly, worked in groups and presented before the house about the issues that they felt utmost to address medicinal plant cultivation as an alternative line economic/revenue generation.

Having partook in the discussion and thereby presentation sessions by the participants, following importnat point's vis-av-s medicinal plants were noted.

1. Marketting problems/difficulties
2. Lack of information vi-a-vis medicinal plants
3. Lack of technical know-how or agrotechnology

4. Less support from financial institutuions/Banks and/or procedural complexity in Bank even it is willing to lend money
5. Information not reaching them about the support for medicinal plant cultivation from SMPB
6. Lack of proper guidance
7. Unorganized farmers with small landholdings
8. Need for forming Cooperative of Mediicnal Plant growers
9. Absence of any R&D Institutes to explore other potentialities & possibilities out of rich medicinal plant resources available in the nature of State.
10. Lack of intersectoral collaborations in respect of medicinal plant activity
11. Absence of information flow & knowledge sharing, etc.
12. Need for formimg Farmers' Cooeprative
13. Need for active principle extraction, value addition & processing unit, development of product etc.

Mr. Saikat Bose of Everest Enterprise, Siliguri who ~~was~~ also present as a trader responeded as regards to the marketing of some of the medicinal plants available in hilly regions. However, the marketing of chireto plant was a focus of discussion where Mr. Bose explained about the parameters for ascertaining prices for chireto while buying/selling chireto. Dr. Prajwal C. Lama, a resource person from Darjeeling showed two bundles of chireto samples that he had brought from Darjeeling and wanted to know the price of the same from Mr. Bose for the interst of the chireto growers. In response to a query, Mr. Bose also highlighted about the sale of ***Aloe vera*** for which he emphasized the farmers to form a group and acquire a simple unit/technology for extraction of ***Aloe vera*** juice that has the demand in the market.

Mr. Sujit Biswas of SAIMAA Agrotech, Kolkatta then highlighted about the profitable economic return from the commercial cultivation of ***Stevia rebaudiana*** plant, a natural sweetener, and an altenative to diabetic patients. He also distributed the samples of Stevia plant for the calorie free sweet taste of the said plant.

With this, the technical sessions of the day came to an end, and having taken rest & refreshment, participants were taken for a village walk and local sight seesing trails, being guided by the volunteers and guides of KEEP Organizaton. They were also explained about the traditional significance of the village and its surrounding in relation of village ecotourism development activities.

In the evening, traditional Bhutia, Nepali and Rai cultural programs were organized by the KEEP for the entertainment and sharing of traditional experience with the delegates where the participants also did participated and shared their ideas and experiences. They were then offered traditional dinner with local ethnic dishes.

DAY 02 (Jan. 09, 2005)

Role & Status of State Medicinal Plant Board (SMPB), Sikkim

Mr. C. C. Lachungpa, Range Officer, State Medicinal Plant Board (SMPB), assisted by Ms. C.K. Rai, Research Assistant of the Board discussed about the status and the activities of SMPB in the Satet of Sikkim, the zist of which is given as under.

1. The State Medicinal Plants Board (SMPB) Sikkim a State Level Body has been set up by the Government vide Notification No. 100/FEWD dated 10-06-2002 under the guidance of National

Medicinal Plants Board (NMPB) to look after policy formulation & coordination with departments/organization ensuring sustained availability of medicinal plants and to coordinate all matters relating to their development and sustained use.

2. The National Medicinal Plants Board sanctioned 13 nos. of Herbal Garden Projects in different locations in the State .The 13 (thirteen) Herbal Gardens have been created for ex-situ cultivation covering in an area of 130 Ha and in-situ conservation of medicinal and aromatic plants in different region depending upon the agro-climatic zones.. Up-to date progress report in respect of all the projects have been enumerated are as follows.

3. Created and established 1(one) Ha area of each modern nurseries with poly and hothouse by providing maximum nursery inputs for production of quality planting materials. The total estimated planting materials produced in each nursery is 75000 to 2,50,000 seedlings depending upon the characteristic of species and agro-climatic zones which have been widely utilized for ex-situ cultivation and in-situ conservation areas in herbal garden, and some seedling have been distributed to the farmers and self-help groups.

4. The Action Plan of SMPB has been prepared with a view to have comprehensive study to asses the requirement for the development of the sector, commercial potential of various medicinal plants, to gather a reliable data on the existing demand & supply position and price mechanism duly involving existing growers, primary collectors, traders and user networks, thereby covering the entire conceivable value chain.
Besides, resource persons also enlightened about the following important points.

- Medicinal Plants prioritized by the SMPB
- Present state of their collection & utilization
- Status of their cultivation
- Trade status
- Extension activities, etc.

Resource Persons also replied to various qeries asked by the participants and further assured full cooperation to the farmers on their behalf.

The consoliodated text of the above discussions is presented in Annexure –IV.

VALEDICTORY SESSION

In the valedictory session, the participants and the resource persons gave their feedbacks about the workshop and expressed happiness on meticulous arrangement of workshop with the involvement of peoples' representative as well as village based organization like KEEP. They also expressed their thankfulness to VHAS & KEEP functionaries for the hearty welcome and local hospitality accorded to them. Some of them disclosed that they not only did get benefit about the medicinal plants issues but also about the village tourism promotional activities which they wish to initiate in their villages from this great learning.

VHAS & KEEP functionaries then offered the participants and resource persons with ceremonial scarf as a mark of traditional repect, love and gesture.

Dr. H. Lepcha, Preseident of VHAS, then finally wrapped up the two days workshop and delivered vote of thanks to everyone involved in making the workshop a success.

ANNEXURE-I

Herbalism:

The art of using plants as medicines

Medicinal Plants are one of the most important non- wood forest products

History-

Codified: Ayurveda
Samhita

Buddha Period: Swarikpa/ Amchi
Siddha

Yunani
Naturopathy
Homeopathy

Local Himalayan Herbal Healers:

1. Dhami
2. Jhakri
3. Phedangba
4. Bijua
5. Bumthing
6. Ojha

Herbal Wealth of Sikkim

Categorization of Medicinal & Aromatic Plants

Categorization on the basis of altitude-Zonation

a) Sub Tropical zone:150m-1200m
b) Upper and middle hills:1200m-3000m
c) Alpine and sub alpine zone: 3000m above

TRADE NETWORK

Village Collectors/Farmers
Village Traders
Road Head Traders
Terai whole sellers

Trade - General Context

Largest Economic natural resource

Present Trend

- Rs.460 crores per annum-Trade
- Expected to rise to Rs. 3000 crores by 2005
- Licensed Manufacturers-above 7000
- Herbal Practitioners- above 4,00,000
- Porous border advantageous- no exact quantification
- Opportunistic sourcing
- Lack of value addition and economic collection- depletion of natural raw material

Trade - Sikkim Context

Herbal collection from natural habitat and its trade is banned in Sikkim

Sources reveal that revenue from herbal collection has never exceeded Rs. 1,00,000

Important herbs on trade are- **Chiraito, Majitho, Kutki, Bikh/Bikhma, Jatamansi, Pipla**
Illegal Trade items include- **Yarcha Gombo, Panch- Aule**

Government Initiatives

- **Minor Forest Produce created in 1991 under Forest Department**
  - Nursery
  - Plantation of Medicinal Plants
  - Awareness programs
- **Establishment of State Medicinal Board under National Medicinal Plant Board**
  - Private cultivation encouraged apart from nursery
  - Herbal Garden created up to Panchayat level
  - Sustainable use of Medicinal Plants
- **Other Initiatives-ICAR, ICFRI, CSIR, Agriculture Department, Universities and NGOs**
  - Survey
  - Trainings and workshops
  - Small Projects
  - Researches

Prospects of Medicinal & Armatic Plants (MAP) in Sikkim

- Systematic Survey
- Ethno-botanical survey and documentation to study diverse nature of indigenous system of management and utility of our bio-resources.
- Training and education of farmers in MAP management
- Pre and post harvest technology development
- Research oriented agro technology and organic certification
- Phytochemical evaluation of local herbs
- Assessment of RET status
- Promotion of local herbal healer
- Herbal first aid package development and propagation through institutions such as schools and colleges
- Linking herbal art with ecotourism

- To check bio piracy across the porous borders an ecoregional approach should be initiated without considering any geographical and political boundaries
- Traders of MAP's and manufacturing units to be taken into confidence so that private cultivation of MAP's, value addition to our herbal products and proper marketing are ensured apart from in-situ conservation

Forestry approach-

- Dissemination of herbal idea and means
- Proper regulation for collection from wild
- Make room for private cultivation of MAP's in the high altitude blanks (farmer co-operatives)-encourage in-situ crude processing
- Tune forest act and policy to facilitate certification of herbal produces from private cultivation
- Time bound declaration of no harvest zone

Local Initiatives-

- Awareness of herbal reality and educate people-revitalisation of local health traditions
- Encourage culture of herbal habit and indigenous systems of living in society tuned with natural surrounding and the changing climatic environment

ANNEXURE –II

PROCESSING, VALUE ADDITION AND MARKETTING PERSPECTIVES OF MEDICINAL PLANTS OF SIKKIM & DARJEELING HIMALAYAS

PROGRAMME FOR STUDY OF MEDICINAL PLANTS

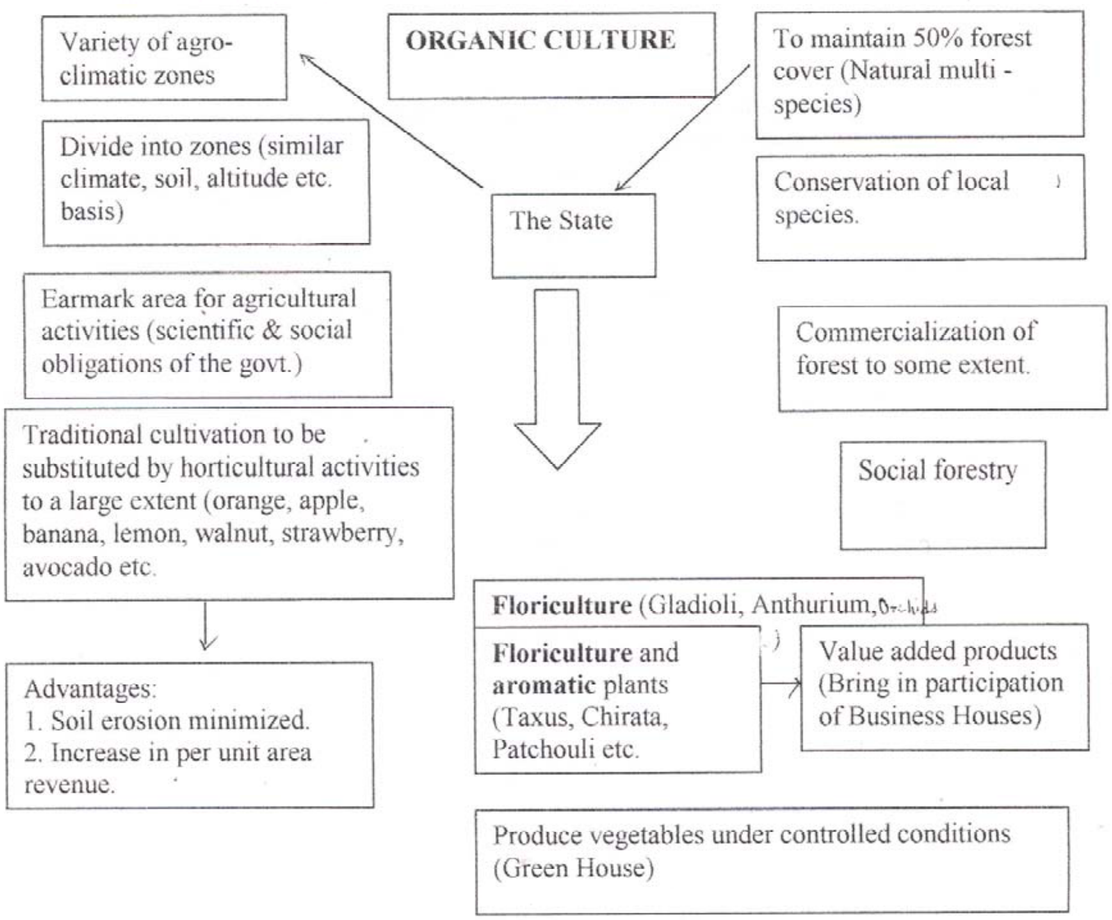
1. Collection of correct informations from village doctors etc.Regarding medicinal plants its uses, method of collection ands its appercation.
2. Identification of plants and literature survey.
3. Crude extraction by polar organic solvents and fractionation as shown in the next slide.
4. The extraction and fractionation and fractionation should be followed by biological activity test.
5. Identification of active compound (S)
6. Clinical trial- approval
7. Usually time required for the exercises – 10 to 15 years or may be more e.g. Taxol isolated – 1963, properly identified – 1971, FDA approval – 1992, December.
8. Commercial exploitation of the plant.

1. Commercially important species should be categorized after assment of their trade in the past and their future requirement.
2. Arrangement for mass multiplication of endangered species should be made
3. Massive affort be undertaken to cover a sizeable area (Government land and villages) to feed the commercial need.
4. Exotic medicinal plants may be introduced e. g. *Artamisie annua, Eucalyptus youmanii, E. macrorhyncha* after detailed study on their commercial requirement.
5. Sales outlets for the items be established in and outside the district with sufficient professional sales oromaotion drive to back up the entire exercises.
6. Finical and other assistance may be tapped from D. S. T., Govt. of India and even UNDIO during the initial stage.
7. Such Medicinal plants activities be carried out simultaneously by the entrepreneurs engaged in floricultures too.

Some of the major medicinal plants in international trade.

1 Atropa belladonna
2 Catharanthus roseus
3 I pacac
4 Cinchona
5 Catura
6 Aauvolfia
7 Papaya
8 Dagitalis
9 Dioscorea
10 Liquorice
11 Ginseng
12 Senna
13 Psvillium
14 Valaruian
15 Chammoile

Name of the plants	Active principle	Use
1 Taxax baccata	Taxol	Cancer
2 Rauvolfia sp	Reserpine	Hypertension
3 Podophylum sp	Podophyllotoxin	Cancer
4 Ammi majus	Xanthotoxin	Skin disorder
5 a) Eucalyptus macrorhynche	Rutin	Fragile blood Veins
b) E.youmani	Rutin	Fragile blood Veins
6 Artemasia annua	Artemisinin	Cerebral malaria
7 Catharantus sp	Vincristine, Vinblastin	Cancer
8 Panax sp	Triterpenoids	Tonic



Annexure-III

Cultivation of hig-value medicinal plant –Chirata as an additional income generation in the hill areas of Sikkim & Darjeeling

National Importnace of Mediicnal Plants

1. 70% Of the population depends on herbal medicine for health care
2. $ 1 billion domestic market
3. $ 30 to 60 global market
4. better acceptability and no side effect
5. medicinal plants are recorded in 386 families and 2200 genera

International Importance

a. Curing age related diseases
b. Curing life threatening diseases like cancer, AIDS etc
c. Checking migration to urban areas

Major Indian medicinal plants used in indigenous system of medicine

Botanical Name	Sanskrit Name
Abies webbiana	Taleespatra
Achyranthes aspera	Apamarga
Acorus calamus	Vacha
Aloe sp.	Kumari
Andrographis paniculata	Bhoonimoa (Kalmeg)
Asparagus adscendens	Mushali
Asparagus adacendens	Shatavari
Bauhinia variegate	Kachnar
Berginia ligulata	Pashan bheda
Boerhavia diffusa	Punarnava
Centella asiatica	Mandukparni
Clerodendrun serratun	Bharang
Convolvulus pluricaulis	Shankhapushpi
Crataeva nurvala	Varuna
Dioscorea bulbifera	Vidarikand
Embelia ribes	Vidanga
Gymnemma sylvestra	Madhunashni
Hedychium spicatum	Shathi
Holarrhena antidysenterica	Kutaja
Mesua ferrea	Nagkesar
Nardostachys jatamansi	Jatamansi
Ocimum sp.	Tulsi
Phyllanthus amarus	Bhumyamalika

Phyllanthus emblica	Amalika (amala)
Picrorhiza kurrooa	Kutki
Piper longum	Pippali
Pluchea lanceolata	Rasna
Psoralea corylifolia	Bakuchi
Rubia cordifolia	Mangistha
Saraca indica	Ashoks
Sausurea lappa	Kushtha
Sida sp.	Bala
Symplocos racemosa	Lodhra
Terminalia arjuna	Arjuna
Terminalia chebula	Hari taki (harad)
Tinospora	*Guduchi*
Tribulus	*Gokshura*
Valeriana jatamansi	*Tagar*
Vitex negundo	*Nirgundi*
Withania somnifera	*ashwagandha*

Market size of herbal medicines

Country	Drug sales in US $ (BILLION)
Europe (1991)	6.0
Germany	3.0
France	1.6
Italy	0.6
Others	0.8
Europe (1996)	10.0
USA (1996)	4.0
India (1996)	1.0
Other countries (1996)	5.0
All countries	30.0-60.0

FUTURE STRATEGIES

- Cultivating medicinal plants as crops to take the pressure off remaining wild stocks
- Conserving back up collections in botanic gardens and seed banks
- Developing local programmes for the sustainable use and conservation of important medicinal plants
- Regulating damaging trade in the medicinal plants by means of nationally and internationally agreed legislation
- Forming new government policies to recognize the vital importance of medicinal plants for health care and economy
- Conserving the knowledge of local peoples and indigenous cultures on the uses and value of plants for medicine
- Breeding and developing improved strains of medicinal plants to reduce the need for wild collecting
- Establishing units for the production of new drugs at the local level
- Establishing research units at the local level for scientific studies in the medicinal plants and to develop intellectual property

Medicinal plants selected for the 3 hill zones

1. **Higher zone (8000 ft. and above)**
   a. Orchis latifolia auct. Non L
   b. Podophyllum hexandrum royle
   c. Picrorhiza kurroa royle ex Benth
   d. Nadostacheys jatamansi (D. don) DC
   e. Aconitum spp
   f. Allium strachii, L

2. **Middle zone (5000-8000 ft.)**
   a. Swertia chirata (wall) clarke
   b. Selinum tenifolium Wall Ex. Clarke
   c. Potentilla Fulgens, Wall
   d. Digitalis Purpurea. L

3. **Lower Zone (1000-5000 ft)**
   a. Piper longum, L
   b. Mentha Piperita, L
   c. Rauvolfia Serpentina, (L) Benth. Ex Kurz

Technique for Chirata cultivation

SEED TREATMENT FOR GERMINATION

A. *PREPARATION OF NURSERY BED*

NURSERY BED
10'X4'

⇓

RAISED SOIL BED BY 6"

⇓

BURNT THE FOREST
LITTER ABOVE THE SOIL

⇓

WATERED WITH WEEDICIDE AND
PGRs

⇓

SPREAD THE STRILISED
SOIL ABOVE THE BURNT ASH

BED READY FOR SEED SOWING

B. TREATMENT OF CHIRATA SEED

↓

100g CLEANED AND HEALTHY CHIRAT SEEDS

↓

500g FRESH COW DUNG + 500lts TAP WATER
MIXED THOROUGHLY AND MAKE SLURRY,
DISCARD THE SOLID SUBSTANCES

↓

FILTERED THE SLURRY THROUGH
THE THIN CLOTH

↓

FILTERED + 100 g CHIRATA SEEDS
MIXED THOROUGHLY AND KEEP
THE MIXURE FOR 5 HOURS

↓

SPRAY THE MIXED SLURRY ON THE
NURSERY BED WITH THE HELP OF SPRAY
GUN OR WATER CAN UNIFORMLY

↓

COVER THE WHOLE BED WITH TRANSPARENT
POLYTHENE FOR A MONTH.

Annexure –IV.

MEDICINAL PLANTS PRIORITIZED BY THE SMPB, SIKKIM

Out of the 32 species of medicinal plants prioritized by NMPB, 14 species have already been identified and selected for cultivation in-situ conservation and ex-situ area under different Herbal Garden, Panchayat Herbal Garden and for cultivation in the farmland by the farmers under **Contractual Farming** in different Agro-Climatic Zones of Sikkim.

(Hindi - H, Nepali – N, Lepcha –L, Tibetan –T)

Sl No	Local Name	*Botanical Name*	Distribution	Types	Part used & Uses
1.	H - Amla N - Amla L -Amlokung T -Skyusura	*Emblica officinalis Gaertn* *Phyllantus emblica Linn.*	Tropical/ sub-tropical Lower Hill Upto 4000ft.	Small Tree	Fruits, leaves, flowers, roots, bark seeds Multi uses
2.	H - Ashwagandha	*Withania somnifera (Linn.)Dunal*	Sub-tropical/ Semi-Temperate Region up to 6000 ft.	Shrub-by bush	Whole plant/Roots/ Seeds Tonic, cough, dropsy, female disorder, ulcers, painful swelling
3.	H - Atees ,Atis N - Bikh, Atish T - Bonna dkarpo B - Ais	*Aconitum heterophyllum Wall.*	Sub-alpine to Alpine 8000-13000 ft.	An erect Herb	Roots, Ant fertility agent, tonic, stoma chic, ant periodic, hysteria, piles, throat diseases
4.	H - Vatsnabh (Vish) N - Bikh, Bish, Akphale, NiloBikh L- Nyine	*Aconitum ferox wall. (A.Chasmanthum)*	Temperate / Alpine 10000-14000 ft.	Perennial Herb	Tuberous roots Cough, asthma, leprosy, fever snakebite, skin diseases
5.	H- Chirata N- Chiraita L - Rungkyen T- Tagota	*Swertia chirayata Buch-Ham*	Upper Hill / Temperate 5000-10,000ft	Annual. Perennial herb	Whole plant Tonic, leucoderma, skin diseases, chronic fever.
6.	H-Giloe, Amrita, Gurach N -Garjo, Gurgau L – Kantherric	*Tinospora cordifolia Miers.*	Tropical / Sub-Tropical Upto 1000 ft.	A large climbing shrub	Leaves & stem Jaundice, vomiting, piles, skin diseases, elephantiasis
7.	H -Indian Berberry N - Chutro L - Sutung Kung T -Skyer ba	*Berberis aristata DC.*	Upper Hill 5500-11000 ft.	Erect & spinous shrub	Roots, bark, branch lets & fruits Skin diseases, diahorrea, jaundice, tonic

8.	H - Jatamansi N - Jatamansi, Hawsa, Naswa T -Spanspos	*Nardostachys jatamansi DC.*	11000-17000 ft.	Perennial herb	Whole plant & root stock Skin diseases, leprosy, ulcers, cough
9.	H -Kalihari N –Langarey Tarul, Bikhful L -Sunkri buk T-Lingali,Langla	*Gloriosa superba Linn.*	Sub-Tropical Lower hill up to 3500 ft.	Herbaceous & glabrous climber	Tubers, roots flowers Chronic ulcers, leprosy, piles, abdominal pains
10. *	H - Kutki N - Kutki T - Putse Sel	*Picrorhiza kurooa Aut.non.Royle.*	Alpine Himalayans 9000-15000 ft.	Herb	Roots Cardio tonic, asthma, leucoderma
11.	H - Long pepper (Pippali) N - Pipla L - Kautin T - Pipilin	*Piper longum Linn.*	Lower Hill Forest up to 3500 ft.	Creeping herb	Roots & fruits Tumors, liver, spleen, abdomen, gout, lumbago
12.	H-Makoy, Gurkamai, Kabaija N-Kalobehi, Kalodatura T - Smon Snwdmarpo	*Solanum nigrum Linn.*	Worldwide	Shrub Weed	Fruits, roots, leaves Leucoderma, dysentery, vomiting, asthma, bronchitis, fever, urinary discharge
13. *	H - Shatavari N - Kurilo T - Neusiri	*Asparagus racemosus Willd.*	Tropical/ sub-tropical / Lower/ middle hill forests	Woody climber under shrub	Tuberous root Diabetes, jaundice, urinary disorder
14. *	H - Tulsi N - Tulsi L - Satul T - Byen rug pa, Dharpo	*Ocimum sanctum Linn.*	Lower Hill Cultivated	Herb	Leaves, seeds, roots Malaria fever, skin diseases, bronchitis,

But amongst the 14 (fourteen) species cultivated in different location by different agencies, only 9(nine) species have been found successful. The species are 3, 4, 5, 8, 9, 10, 11, 13, and 14 and some more species like Fox glove (*Digitalis purpurea*), Safed Musli (*Cholorophytum borevilianum*), Ajambari (*Panax pseudo-ginseng*), Kukur tarul (*Dioscoria deltoides*), Achuk (*Hippoae salicifolia*), Bojho (*Acorus calamus*), Dhengresalla (*Taxus baccata*), Jeevan Buti (*Cordyceps sinensis*) etc are also finding their ways for cultivation trials.

In addition to the above, the following 12 (twelve) medicinal plants species found in Sikkim have also been identified and selected for inclusion in the prioritized list of National Medicinal Plants Board (NMPB) on all India basis in different Zones, altitudes and representatives areas.

Sl. No.	*Local Name*	Botanical Name	Distribution	Type	Part used & Uses
1.	H- N- Bojho L- Riklok T- Sudag	*Acorus calamus*	Middle hill 3000-6000ft.	Herbaceous plants	Root/Rhizome Vermifuge, Fever antispasmodic, Insect repellent
2.	H-Pakhanbeda N- Pakhanbed L - T-	*Berginia ciliata*	Temperate to sub-alpine 5000-13000 ft.	Herb	Root & rhizome Tonic, fever, boils, astringent
3.	H- N- Mangan (Ajambari) L- T-	Panax pseudo-ginseng	6000-12000ft.	Herb	Roots Cancer, tonic, Aphrodisiac, resistance & defense of body
4.	H-laghupatra N-Bankankari, Panchpatey L- T-	Podophyllum hexandrum	9000-14000ft.	An annual shrub	Whole plant, roots, fruits Torpid fever, diarrhea, mental disorder, plague
5.	H-Manjit N-Majito L-Vhyem1 T-Btsod	Rubia cordifolia	Middle & upper hill 4000-7000ft	Perennial herbaceous climber	Root & Fruit Anti-dysenteric, uteri an pains , voice , complexion
6.	H- N-Sunpati L-Paluchulu T-Palu	Rhododendron anthopogon	Alpine 11000-16000ft.	Dwarf evergreen shrub	Whole plant except root, incense, snuff to induce sneezing
7.	H- N- Laligurans L-Etok T- ka ra baka	Rhododendron arboreum	Temperate & upper hill 4000-10,000 ft.	Medium size evergreen tree	Flowers, young leaves, dysentery, diarrhea, headache
8.	H- N-Buriokahti L-Pango T-	*Astible rivularis*	Temperate 5000-9000 ft.	Herb	Leaves/roots/Rhizome, Diarrhea, dysentery, blood purifier
9.	H- N-Achuk L-Lhala T-Lhala	*Hippophae salicifolia*	Temperate 5000-10,000 ft.	Shrub	Fruits/bark Lung diseases, skin Eruptions. Irritations
10.	H-Birmi N- Dhengresalla L-Cheongboo T- Mathui	*Taxus baccata*	Temperate & upper hill 6000-11000 ft.	Medium tree	Leaves Taxol cancer drug, Asthma, Bronchitis, epilepsy
11.	N-Jeevan Buti T-yarsgumpa	*Cordyceps sinensis*	Alpine 1100-	Fungi	It is anti aging medicine and it

			16000 ft		strengthens the immune system of body
12.	E- Foxglove	*Digitalis purpurea*	Middle to upper hills, 4000to 70000 ft	Herb	Effective heart tonic, and cardiac stimulant also stimulate urine production

PRSENT STATE OF THEIR COLLECTION AND UTILIZATION

Prior to establishment of State Medicinal Plants Board, (SMPB) collection and transit of medicinal and aromatic plants from the state was regulated by Forest Department. The forest department used to issue collection permit on payment of royalty to the government from areas rich in medicinal and aromatic plants. Two years before establishment of SMPB in the year 2002, the Government has banned the collection of medicinal and aromatic plants from the forest to rejuvenate the areas. After establishment of SMPB the main emphasis of the SMPB is to encourage progressive farmers to under take cultivation of medicinal plants such as Aconitum hetorophyllum, Aconitum ferox, Picrorhiza kurooa, Nardostachys jatamansi, Swertia Chirayita, Glorisa superba, Asparagus racemosus, Ocimum sanctum etc. After establishment of SMPB considerable quantity of Chirayita has been in the process of marketing by the SMPB collected from the Herbal Gardens and farmers engaged in cultivation of medicinal plants during the year 2004. it is expected that more and more farmers will start cultivation of medicinal plants and SMPB is expecting considerable volume of herbal products of *Chirayita, Atees, Vatsnabh, Kutki, Jatamansi, Kalihari, Sataravi etc.*

The medicinal plants products are expected to be marketed by the farmers through SMPB to the industries outside state. Besides, there is utilization of different herbs and shrubs by the local health practitioners. The quantity is being ascertained. The SMPB has registered **84 (eighty-four) Collectors, 112 (one hundred twelve), Traders, and 2 (two) Manufacturers** for those who have been actively involved for development of medicinal plants sector and marketing.

STATUS OF THEIR CULTIVATION

The cultivation of above said medicinal and aromatic plants mentioned is being undertaken by more than 210 (two hundred ten) registered farmers.

- 15 (Fifteen) projects of Contractual Farming to the tune of Rs. 1.39 cores (One cores thirty nine lakhs) have been sanctioned by the NMPB in which thirty percent direct incentives are given to farmers for promotion and cultivation of above mentioned species in different climatic zones and progress is satisfactory.

- 15 (fifteen) more Contractual Farming Projects are in the process of approval and sanction by the NMPB and some projects are under consideration in SISCO Bank, Government of Sikkim for Bank Appraisal Report.

- 166 (one hundred sixty six) Panchayat Herbal Garden have also been created in different Panchayat Units in all four districts of the State in which indigenous medicinal and aromatic plants have been raised. The SMPB is taking active role to provide technical assistance with improve technology and selection of commercially marketable species to grow in the Panchayat Herbal Garden to disseminate cultivation technology pre and post harvesting semi and full processing for value addition. Few proposals for semi processing unit of commercially marketable species of medicinal plants for value addition are under scrutiny and being established.

- The department and SMPB is providing technical assistance to these farmers. After seeing the performance of these farmers more farmers are expected to approach SMPB to undertake cultivation of medicinal plants. The beginning has been made to improve the economic condition of the marginal and small farmers.

TRADE STATUS

Prior to year 2000 the collectors from the state used to sale their herbal products collected from the wild to the traders located at Gangtok, Kalimpong, Siliguri and Kolkota. Since the Government has banned the collection of Medicinal plants products from the wild and encouraged cultivation of medicinal plants, the traders from different parts of the country have approached the SMPB for supply of raw drugs products namely *Aconitum hetorophyllum, Picrorhiza kurooa, Swertia Chirayita, Nardostachys jatamansi, Acorus calamus.*

EXTENTION ACTIVITIES

The development of medicinal plants sector with a view to utilize it on commercial lines on sustainable basis in a State like Sikkim is neither feasible nor viable without massive public involvement and willing support. This process also ensures protection of natural habitat by local communities and its accelerated coverage on their lands as alternative cash crops. In order to ensure this aspect including successful domestication and farming of medicinal plants on private land areas as alternative cash crops as a movement, the SMPB has organized and conducted extension and awareness pogramme at various places of Sikkim.

Workshop Recommendations

The Workshop deliberations had following important recommendations at the end of the technical sessions.

1. Wider sensitization and involvent of CBOs/NGOs for publicizing the significance of medicinal plant resources of the State
2. Govt. Departments and Agencies to play larger and significant role in supporting the prospective farmers for the the commercial cultivation of medicinal plants with assured and appropriate marketing provision
3. The persent bank loan procedures to obtain the subsidy for medicinal plant cultivation through State Medicinal Plant Baord (SMPB) to be reviewed as the procedure is complicated and the poor farmers of the villages cann't follow up the same to avail Govt.'s assistance.
4. Govt. Departments/Agencies to network with various firms/traders, companies/industries for the optimal prizing/cost of the local medicinal plant
5. Research Institutes to be set up for medicinal plant resources in the State
6. Govt. Departments and other Agencies must support the research and promotional activities to the NGOs of the State vis-à-vis medicinal plants of Sikkim State
7. Govt. Depaertnments and Agencies to provide suitable and cost effective agrotechnolgy with proper exposure, trainings, guidance and support systems to the farmers
8. Govt. & NGOs to tie up with institutes or companies to set up processing, distillation, value-adding, final product-processing units in the State for exploiting future economic avenues and potentialities through local medicinal plants
9. Government Departments and other Organizations/Agencies to involve NGOs/CBOs (which have easy access and credibility to the community) in every medicinal plant promotiomal activities
10. Concerned Departemnts/Agencies to ensure the flow of information about the activities, plans and programmes pertaing to medicinal plants, to reach even the people of the most remote villages
11. The Dept. of ISM &H, under the Ministry of Health & Family Welfare, Govt. of India, and/or other Agencies may support appropriate Projects for study and research about the therapeutic plants resources of Sikkim, to the NGOs of State.
12. Immediate but visionary plans and programs pertaing to the medicinal plants of the State must be drawn towards boosting local economy, conservation of the rich genepool (*ex-situ* and *in-situ*), sustainability and even the initiation of patenting process.

State Level Workshop on An Approach to Promotion of Community Health & Development Through Medicinal Plants.

Date: Jan. 08-09, 2005
Venue: KEEP, Gaucharan-Pastanga, E. Sikkim

Sl. No.	Name of Participants	Name of NGOs/CBOs/Village/ Govt. Agencies & Address	Grower/Farmer/ Trader/Collector/ Manufacturer/ Resource Person with Designation	Contact Tel. No.	Signature
1	K. Zangpo	Chairman S.N.T	M.L.A. Assam Lingzey	94341 86393	[illegible]
2	Dr. J.P. Tamang	Regional Coord.	—	98320 61073	[illegible]
3 ✓	Tilak Sing Subba	Temi, S. Sikkim	Farmer	280645. 9434183667	[illegible]
4	Mani Kumar Rai	Damthang S.Sk	Farmer	953595 267203	[illegible]
5 ✓	B. B. Gurung	Damthang S.Sikkim	farmer	953595 267252	[illegible]
6 ✓	Om prakash Bista	Tashiding [illegible]	Farmer	249233	[illegible]
7 ✓	Alikeshar Dahal	Tashiding [illegible]	farmers	94343 36054	[illegible]
8 ✓	Govind Gurung	Kaluk W/Sikkim	farmer	953592 245505	[illegible]
9 ✓	[illegible] Subba	Mainamla	NGO	300[illegible]	[illegible]
10 ✓	T. D. Bhutia	Meweping Youth Club	NGO	94341 64881	Bhutia
11 ✓	[illegible]	[illegible]	NGO	.	[illegible]
12 ✓	Chandrakala Rai	SMPB Forest		94343 57633	[illegible]
13 ✓	J. L. Limboo	S.S.K.S	N.G.O	255441	[illegible]

	Name of the Participants	Name of NGOs/CBOs/Village/Govt	Grower/Farmer/Trader/Collector/manufacturer	Cont Tel.No	Signature
14	Arjun Sedai	Turung S. Sikkim Farmer	98323?6848		[illegible]
15	Chandra Pd Adhikari	Sukrodaya Samaj (NGO)		245344	[illegible]
16	Ongcho Lepcha	Lingthem MCAS	M.C.A.S		[illegible]
17	Santosh Rai	N.G.O Budang	Farmer.	98320 85504	[illegible]
18	K. K. Rai	N.G.O	"	do	[illegible]
19	Dr. H. Lepcha.	VHAS President	-	202996 (R)	[illegible]
20	Dr. G.C. SUBBA	Govt. of W.B. Cinchona Directorate		9434166434	[illegible] 7/1/15
21	Sudip Biswas.	Siman Agrotech Calcutta-1	Fur	033 2437 1711	Sudip Biswas
22	P.C. Lama	Panchayati Greenbelt Res. Society, Dj	NGO	2256121	[illegible]
23	Manoj Pradhan	VHAS (Technician)		03592 226505	[illegible]
24	Benjamin Lepcha	VHAS PA		94343 56255	[illegible]
25	ASHOK KR. RAI	KEEP	NGO	98320 34033	[illegible]
26	Rajen Subba	VHAS	NGO	-	[illegible]
27	Dr. B. Gurung	Forest		94341 69603	[illegible]
28	Suman Rai	ATREE	Trust	93430 45422	[illegible]
29	Ugen D. Bhutia	SWYA W.SIKKIM	NGOs	98320 18874	[illegible]
30	Meera Thapa	Sanoney Ajambari Sangtha	NGOs	94342151?6	[illegible]

31	Basant Subba	KOPILA PARIWAR NGO	Tathangchen Assam Linzey	94343 38812	
32	Sanu Baldan	MLAS	Tadong		
33	C.C. Lachungpa	RO. KTAP	Gtk	943441 17501	
34	B. K. Rai	R.O. NTPP	Gtk	94341 52979	
35	P. Bhutia	FA	Rangpool	251566	
36	Saikat Bosu	Everest Enterprise	94, A.P. Sarani E.V. Pally Siliguri	94343 52588	Bosu.
37	Dr. P.C. Rai	VHAS / Facilitator	Nam Nang Gangtok	220961.	
38	Anita Rai	Pastanga	KEEP		
39	Mr. T. B. Rai	Pastanga	KEEP	98323 77054	
40	Rajeev Rai	Pastanga	KEEP		
41	Binita Rai	Pastanga	KEEP	9832046838.	Binita
42	Manita Rai	Pastanga	KEEP		
43.	C. D Rai	Pastanga	KEEP.	98320 46838	
44.	Hum Bdr. Rai	Pastanga	KEEP.	98320 34679	H. Rai
45.	Am Kumar Rai	Pastanga	KEEP	251085	
46	Arjun Rai	Khamthang	KEEP	251084	
47.	Girish Rai	Pastanga	'KEEP'		Girish Rai
48.	Dawa Tsh. Bhutia -	Pastanga	'KEEP'		Dawa Tsh. Bhu
49.	Meena Rai.	Pastanga	'KEEP'.		
50.	Hari Devi Rai -	Pastanga	'KEEP'		
51	N. Dhamu Bhutia	- Juksam	KCC		
52	Namgyal Chamu Sherpa	"	"		

Wednesday, 05 Jan, 2005 Vol. 3 No. 222 Gangtok ❑ Rs. 3

NOW! DAILY

FIRST WITH THE NEWS

VHAS set to promote community health through medicinal plants

a NOW REPORT

GANGTOK, 04 Jan: Volunteer Health Association of Sikkim [VHAS] has announced plans to hold a state-level workshop on "Approach to Promotion of Community Health Development through Medicinal Plants" at KEEP office, Pastanga, from 07 to 09 January.

The workshop will see the participation of prospective farmers and growers of medicinal plants from all four districts of the State, along with some farmers and traders from outside Sikkim.

The resource persons for the workshop are Dr. GC Subba, Chief Chemist, Directorate of Medicinal Plant, govt of West Bengal, Bijay Gurung, Additional Director, Department of Forest, Prajwal Lama, Panchawati Greentake Research Society, Darjeeling, Naveen Khanna, SAIMA, Agrotech, Kolkata, while CC Lachungpa, Range Officer, NTFT, and Chandrakala Rai, JRA, will also represent State Medicinal Plant Board [SMPB] as resource persons.

Ashoka Trust for Research on Environment Education [ATREE], Bagdogra, and FOSEP, Darjeeling, will also participate in the workshop to share their experiences.

The workshop will include an exhibition-cum-display by SAIMA, Agrotech, Kolkata, and State Medicinal Plant Board. A video presentation on medicinal plants will also be screened.

PC Rai, senior programme officer, VHAS, who will conduct this workshop, informs that this workshop comes under the "Carrying Capacity of Teesta Basin Project" under the sponsorship of Centre for Inter-disciplinary Studies of Mountain and Hill Environment [CISME], Delhi University.

He further informed that Dr. JP Tamang, regional director for Carrying Capacity of Teesta Basin Project, will deliver the key note address on the occasion.

VOLUME - WISE DETAILED INDEX

C O N T E N T S

VOLUME-I

INTRODUCTORY VOLUME

VOLUME-II

LAND ENVIRONMENT – GEOPHYSICAL ENVIRONMENT

VOLUME – III

LAND ENVIRONMENT - SOIL

VOLUME – IV

WATER ENVIRONMENT

VOLUME – V

AIR ENVIRONMENT

VOLUME – VI

BIOLOGICAL ENVIRONMENT

TERRESTRIAL AND AQUATIC RESOURCES

VOLUME – VII

BIOLOGICAL ENVIRONMENT

FAUNAL ELEMENTS

VOLUME – VIII

BIOLOGICAL ENVIRONMENT

FOOD RESOURCES

VOLUME – IX

SOCIO-ECONOMIC ENVIRONMENT

VOLUME – X

SOCIO-CULTURAL ENVIRONMENT

BIBLIOGRAPHY

ANNEXURES

EXECUTIVE SUMMARY AND RECOMMENDATIONS