2

Geomorphology and Climate

Geomorphology of a region is directly controlled by the climate, geology and the tectonic set up. This is especially significant in case of Teesta basin where the rock sequences have under gone complex polyphase deformation producing prominent tectonic features. Teesta River originates from Tista Khangchen glacier in North Sikkim and as it flows it cuts through all the lithotectonic units of Eastern Himalaya almost along the hinge zone of the north – south broad regional antiform, almost up to the southern fringe of the Trans- Axial Belt.

The state of Sikkim is unique in the sense that it is the only state in the country where its administrative boundaries coincide with the watershed defining the catchment of a major river basin. The state is 113 km long N-S and 64 km wide E-W approximately, with an area 7299 Sq. Km.. Teesta has maintained its course despite the tectonic uplift of Himalaya, as an antecedent river. Burrard et. al (1934) suggested that the head waters of Teesta river were part of the tributary of Tsangpo (Brahmaputra) in the geological past. Teesta and its tributaries have played a significant role in the development of complex geomorphic features of Sikkim (see Fig. 2.1). The elevation in the state varies from 200 m.a.s.l. to 8000 m.a.s.l. (Fig 2.2). Distribution of area in various height zones is given in Table 2.1.

Table 2. 1 (Based on Oxford University Atlas, 1990)

S. No.	Height Zone	Area	Percentage
1	200- 600 masl.	38.03 Sq. Km.	0.53 %
2	600- 900 masl.	299.75 Sq. Km.	04.2 %
3	900- 1350 masl.	785.85 Sq. Km.	11.00 %
4	1350- 1800 masl.	824.87 Sq. Km.	11.56 %
5	1800- 3000 masl.	1014.00 Sq. Km.	14.10 %
6	3000- 4500 masl.	1922.00 Sq. Km.	26.94 %
7	4500- 6000 masl.	2158.97 Sq. Km.	30.26 %

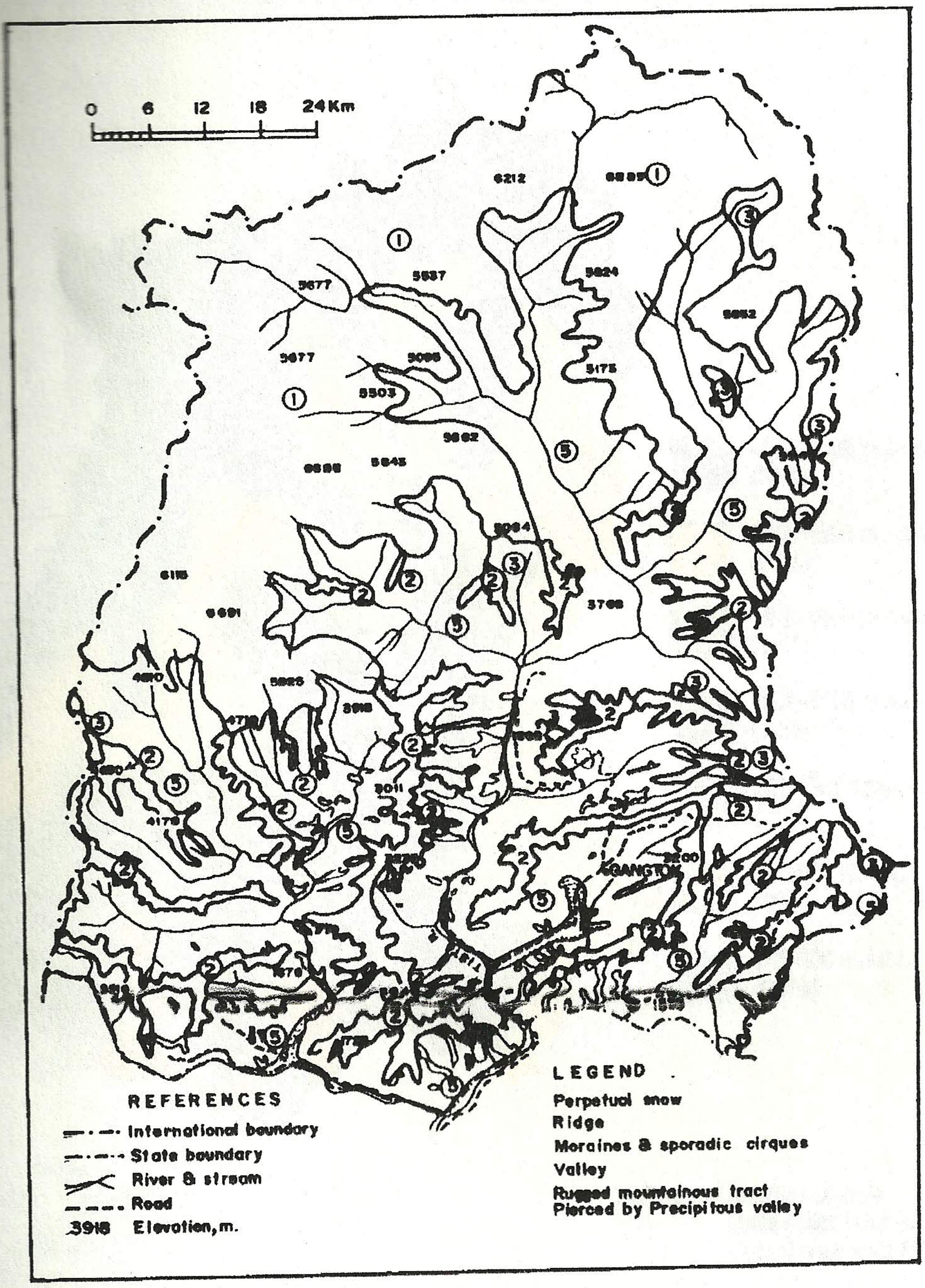

Fig. 2.1. Significant geomorphic features in Sikkim (after Tejwani 1981)

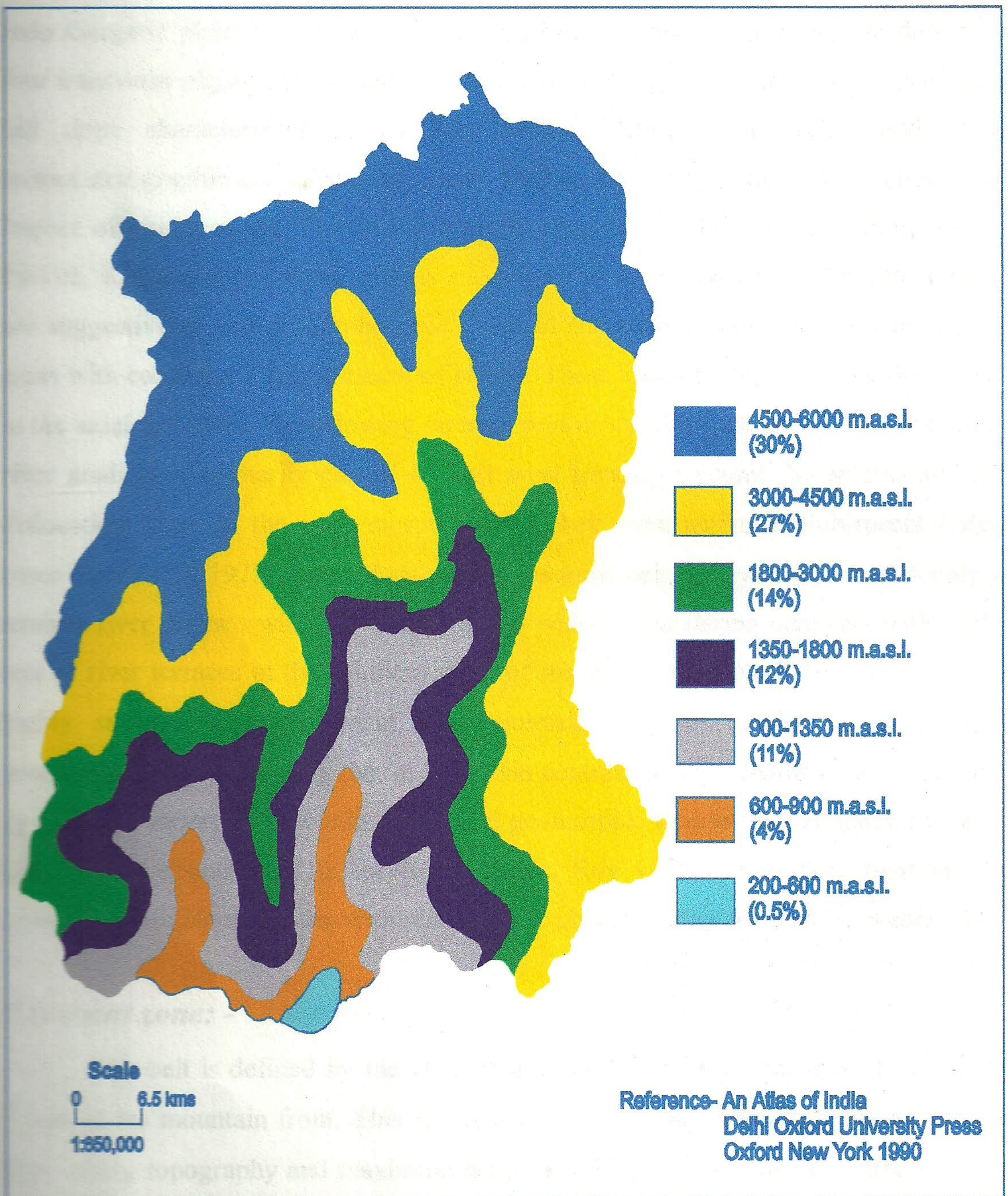

Fig. 2.2 Distribution of elevation zones of Sikkim (percentage of total area)

Sikkim's geomorphology and its relation with the adjoining plains can be better conceived when territories of Darjeeling district in West Bengal where Teesta joins the Indo Gangetic plain are considered simultaneously. Sikkim Himalaya is divided into four transverse physiographic zones with distinct geology, structure, geomorphology and hill slope characteristics (Sinha Roy 1975). They roughly correspond to four tectonostratigraphic domains: Sub, Lesser, Higher, and Tethys Himalaya (Gansser 1964). Impact of structure and tectonics is directly reflected in the landscape morphology of Sikkim. Knick-points, incised gorges and points of abrupt change in the course of river are suggestive of active morphogenic uplift of the central crystalline and its adjoining areas with consequent readjustment of slopes. These kink-points are essentially restricted in the axial belt. East-West flowing streams seldom exhibit kink-point. This break in the river gradient is primarily caused by east west trending tectonic lineaments and major dislocation zones in the axial morphotectonic belt were active in Sub-recent / Recent times (Sinha Roy 1975). In the Axial morphotectonic belt, valleys are incised deeply with straight river courses which is in contrast to widely meandering channels with multiple sets of river terraces in the southern parts of the inner and foothill belt. Teesta basin is highly suitable for establishing a relationship between erosion rates, slope and geomorphology, considering that in this basin contrasted slope characteristics, influenced by geology, variety of lithounits and varied geomorphic terrain- fluvial, glaciofluvial, and glacial - are encountered in the basin (Sinha, Roy 1975). Four morphotectonic belts having identifiable attributes, with related slope characteristics from north to south are:

Piedmont zone: -

This belt is defined by the Quaternary - Recent alluvial deposits at the southern flanks of the mountain front. This is a narrow belt ranging in width between 2 to 3 km with rolling topography and maximum height reaching 250-m a.m.s.l. Surface drainage frequency is low as compared to mountainous track in the north. This belt is characterized by very well- developed and well – preserved river terraces, with their long axes along the east- west trend of this belt. The terraces are normally tabular with a gentle southward surface slope. At least three terrace sets, in most cases paired, are present along the main rivers crossing the piedmont belt. Evidences of neo tectonic activities have been recorded in broad warps in the terrace material and in the terrace surface (Gansser 1964).

Inner and foothill zone: -

This belt is confined between the mountain front in the south and the Main Central thrust in the north, which roughly corresponds to Lesser Himalaya. The Siwalik sequence in the foothills contains gently northward dipping sequence of alternating sandstone, siltstone and pebble beds. These rocks are weakly deformed, only showing broad flexures and subsidiary shear planes near the Main Boundary Fault. The Gondwana rocks are well-foliated and intricately folded with shear planes. These rocks are overridden by the Daling cover sequence along the prominent thrusts. In Rangit and Rangpo Chu valleys, Gondwana rocks are exposed. This belt is characterized by important geomorphic features like river terraces along the major rivers and alluvial cones at the mouth of smaller streams.

Terraces: -

Terraces in the inner and foothill belt are not paired, they are developed on the concave side of broad meanders. By and large these terraces are developed at three topographic levels, high-level (T1), mid - level (T2) and low-level (T3) (Sinha Roy, 1972). Apart from this, at times a higher level terrace, nearly 200- 300 m above the thalweg, and nearly 30-40 m above T1 can be recognized, which might represent the vestiges of the proglacial terraces, formed during the advance of the Plesistocene ice front.

Alluvial cones: -

Alluvial cones are well developed at the confluence of tributaries with Major River. These cones result from accumulation of sediments at mouth of the low energy tributary channel. The cone developed on the gentle valley slopes particularly in the southern parts of the state, are larger in dimension than those formed at higher reaches with higher gradient. Cones can be classified into wedge and pyramid type, depending on the measure of toe-length and cone axis. The cones are strongly dissected by major stream or overlapped by the terraces. Toe erosion in some cases results in slope failure; this is further aggravated when they are disturbed by developmental activities like road building.

Axial zone: -

The axial belt represents the highest orographic tract of Sikkim. Lithological and structural setup of this belt is represented essentially by gneisses, granulites and granite.

The structural characteristics of these rocks have imparted a natural fissility along prominent planes of schistocity and joint planes. The slopes are essentially controlled by the orientation of these features, which on the other hand are dependent on the regional structural set up. This belt has numerous valley glaciers with evidence of past glaciation in the form of characteristic landscape and deposits. The mountain slopes are extremely rugged, covered with products of extensive mass wasting and debris supplied either by cirque glaciers or hill wash. The streams in this belt flow through old glacial valleys and have cut deep gorges and rock benches. Glacial lakes and signs of past glacial lakes form a significant part of the landscape of this belt. Many of the recessional glacial lakes have been the cause of flash floods in north Sikkim in the recent past.

Trans - Axial zone: -

In trans axial zone rocks of Tethyan sequence are essentially sedimentary sequence of limestone, sandstone and shale. They have a gentle homoclinal northerly dip. This has resulted in nearly flat to gently undulating topography, which further to the north merges with the Tibetan plateau. Wide U shaped valleys covered with glacial and outwash deposits are characteristic features of this zone.

Climate: -

Climate of a region has direct bearing on the factors, which are responsible for land mass movements of various types and description in a region. Mountainous character of Sikkim with extreme variation in height, from almost 200 m.a.s.l. to over 7000 m.a.s.l has resulted in variation of climate from subtropical, alpine to arctic condition in the state, depending on the elevation of a place. Climate of even a small watershed can vary from subtropical to alpine; for example in Rora Chu catchment at Ranipull it is sub tropical while in the vicinity of Changu Lake in it's head waters is alpine to arctic.

Rainfall is the most important climatic parameter, which has direct bearing on the landslide incidence. This is true for the state. Rainfall data from 18 stations in Sikkim (Table 2 II) shows that the mean annual rainfall is minimum at Thangu (821 mm) and maximum at Gangtok (3493 mm). In general the intensity of monsoons in the Himalaya decreases as we move from Pasighat in the East to Shimla in the west as shown in (Fig.2. 3). It is seen that in Gangtok, Sikkim, heavy rainfall is registered from May to September see (Fig 2.4) The average rainfall characteristics for Gangtok based on records 1982 – 1998 are tabulated in Table (2 III) (based on data made available by the Director CSMRS, New Delhi).

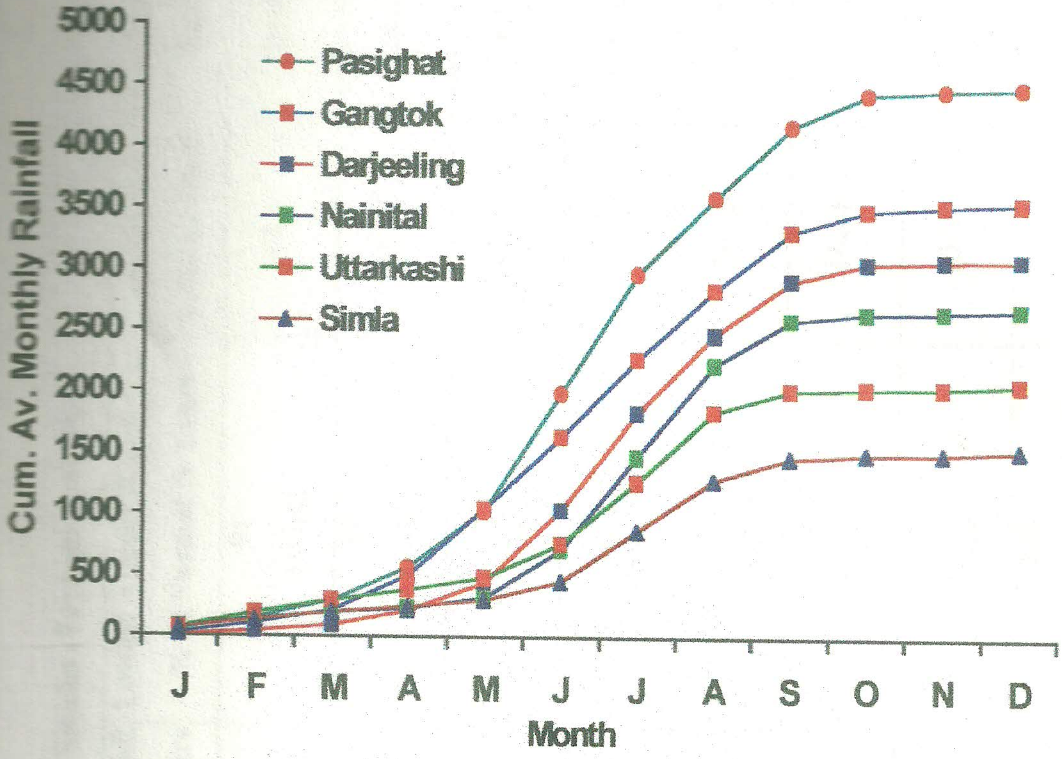

Fig. 2.3 Cumulative Average Monthly Rainfall (mm) in the Himalayas

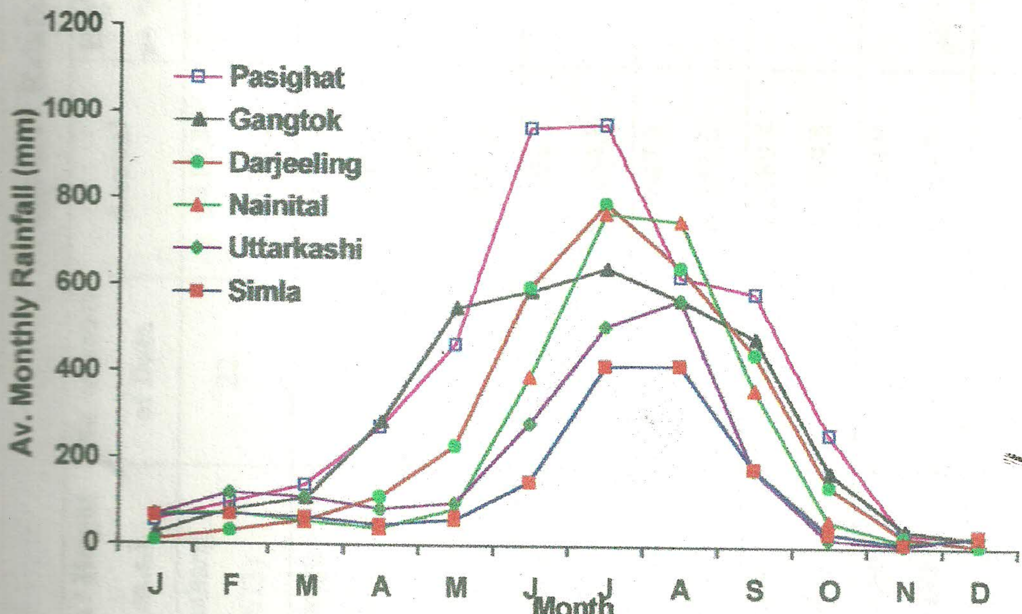

Fig. 2.4 Average Monthly Rainfall (mm) in the Himalayas

Table 2. II Rainfall characteristic of Sikkim (Tejwani et.al.1981)

Station / Height m.a.m.s.l.	No. of years of Data	Annual	Highest Annual Rainfall as % of Normal & Years	Lowest Annual Rainfall as % of Normal & Years	Heaviest Rainfall in 24 hours	
					Amount (mm)	Date
Yumthang (3673)	22	a 417.4 b 160.2	108 (1960)	91 (1964)	84.1	28.9.60
Thangu (3812)	16	a 821.1 b 100.0	182 (1961)	57 (1959)	101.6	18.5.54
Lachen (2697)	17	a 1652.4 b 161.3	115 (1963)	78 1962	116.0	26.5.66
Lachung (2633)	13	a 1703.5 b 154.8	130 (1974)	79 (1962)	216.0	13.10.73
Chungthang (1631)	20	a 2647.3 b 153.6	115 (1955	88 (1964)	261.6	22.7.54
Singhik (1402)	13	A 2989.4 B 169.5	136 (1958)	69 (1960)	162.3	22.6.57
Mangan (1310)	16	a 3238.9 b 160.5	111 (1961)	84 (1964)	233.0	4.6.67
Gnathang (3752)	9	a 3289.6 b 183.7	117 (1962)	108 (1963)	114.3	13.7.61

Chhangu (3840)	9	a 2900.7 b 173.3	121 (1958)	85 (1960)	143.5	26.5.58
Serrathang (4114)	7	a 2208.2 b 152.8	123 (1958)	35 (1963)	114.3	26.5.58
Rangli (832)	13	a 3220.6 b 147.8	142 (1971)	82 (1958)	216.0	13.10.73
Gangtok (1818)	14	a3494.5 b 163.7	111 (1963)	83 (1966)	192.5	3.10.73
Dikchu (869)	13	a 3235.2 b 152.0	123 (1971)	84 (1972)	232.2	13.10.73
Geyzing (1520)	16	a 2392.2 b 163.7	111 (1961)	86 (1966)	186.7	5.10.68
Yoksum (1780)	12	a 2619.6 b 146.4	131 (1959)	57 (1974)	151.8	30.7.81
Dentan (1372)	12	a 2338.5 b 134.7	146 (1964)	82 (1958)	152.1	9.7.59
Damthang (1981)	13	a 2197.0 b 134.8	187 (1959)	35 (1962)	341.4	4.8.64

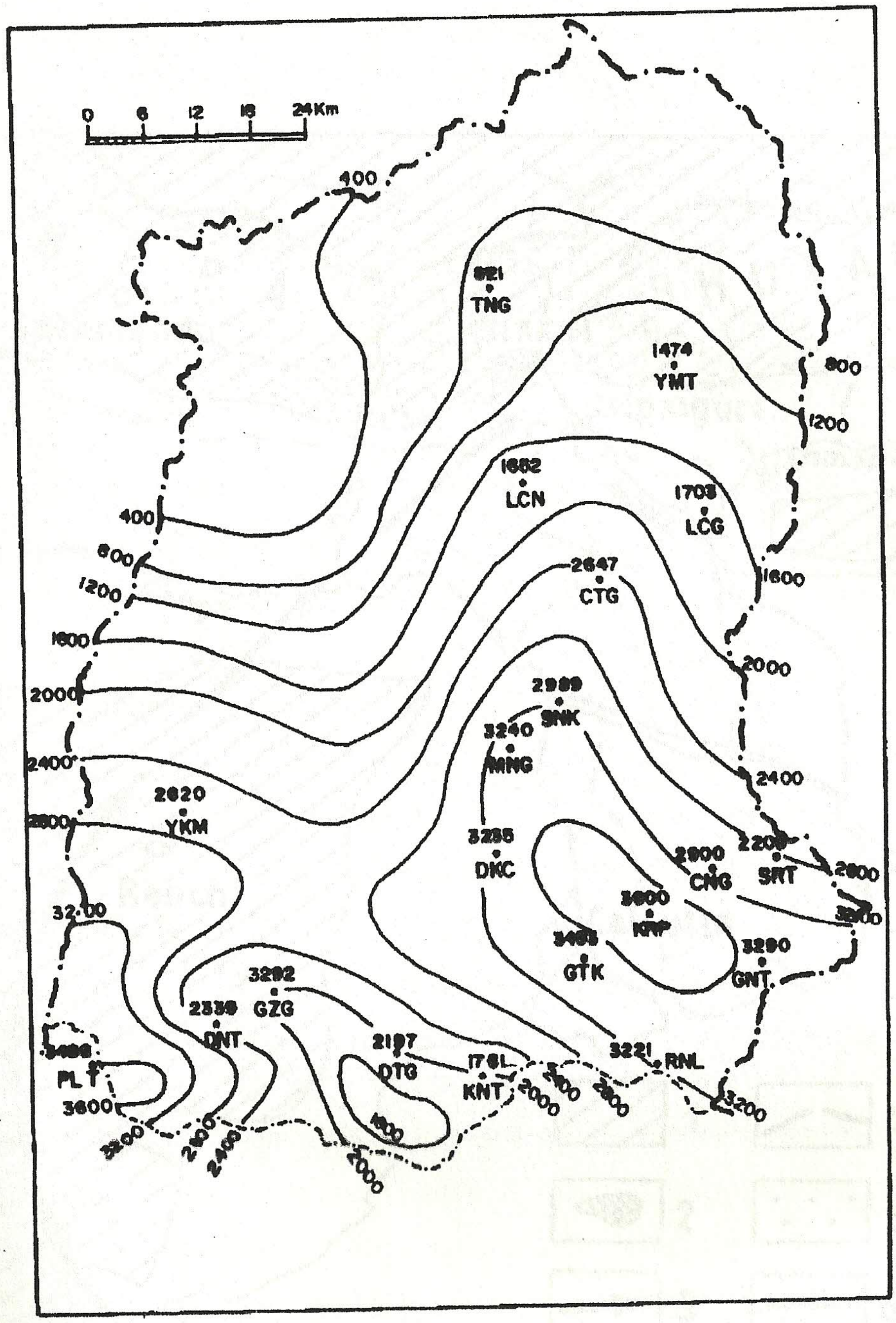

Fig. 2.5. Isohytal Map of Sikkim (after Tejwani 1981)

TNG-Thangu, LCN-Lachen, YMT-Yumthang, LCG-Lachung, CTG-Chungthang, SNK-Singhik, MNG-Mangan, DKC-Dickchu, GTK-Gangtok, KRP-Kyangnosa, CNG-Changu, SRT-Serrathang, RNL-Rangli, KNT-Kanamtek, DNT-Dentam, GZG-Geyzing, DTG-Damthang, YKM-Yoksum, PLT-Phalnt (West Bengal)

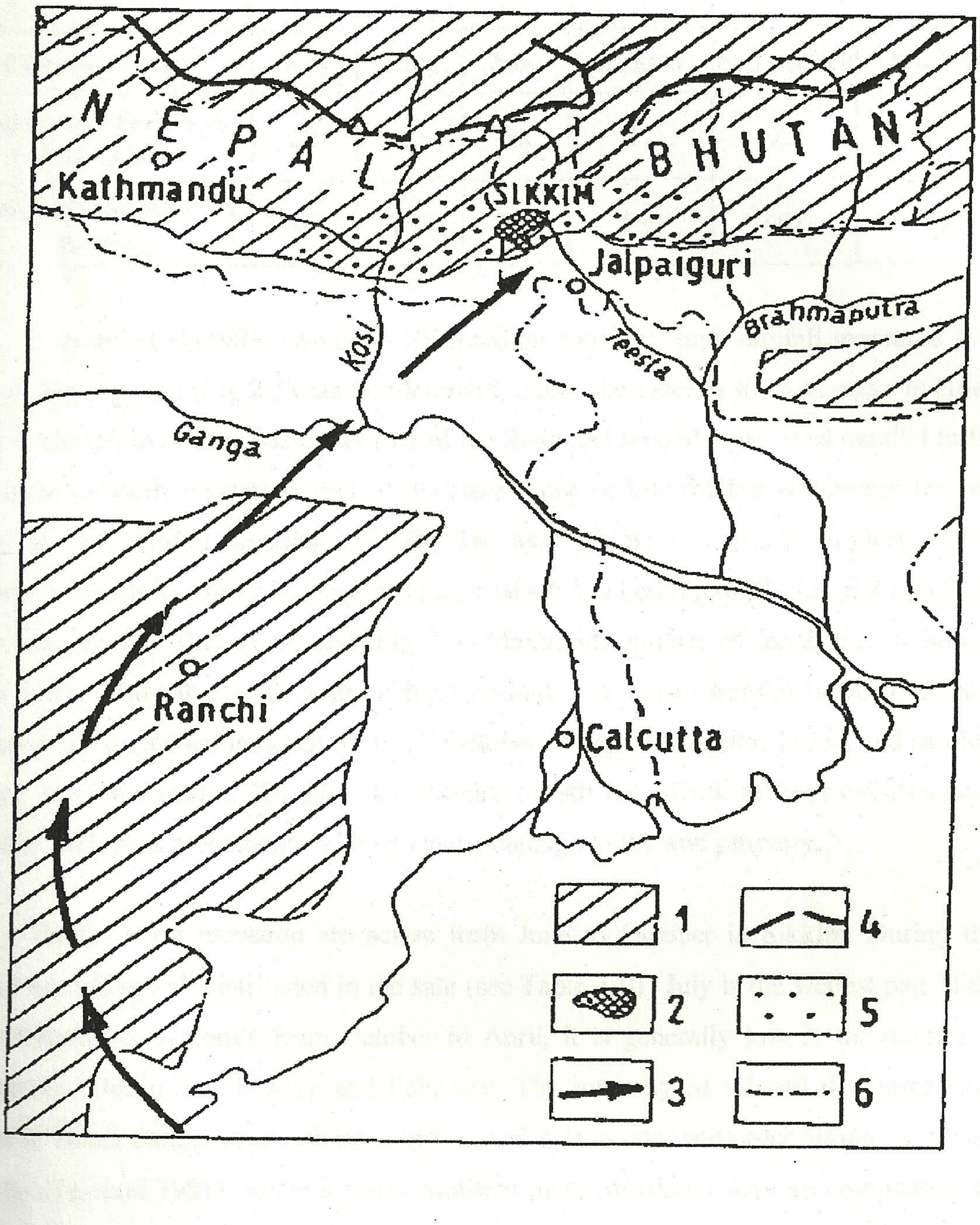

Fig. 2.6. Route of monsoon over Sikkim (Froehlich and Starkel 1972)

Table (2 III) Rainfall characteristics of Gangtok

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

Tejwani et.al.(1981) two NW- SE trending zones of high rainfall separated by a zone of low rain fall (Fig 2.5) can be identified. Zone one extends from Mangan in North West to Rongli in South- Eastern corner of the State and second zone runs parallel to the first zone in South Western corner of the state. Zone of low rainfall is between the two zones of high rainfall, trending NW-SE. The axis of this zone passes slightly SW of Namchi in South Sikkim. An important factor which has bearing on the rainfall in Sikkim is its proximity to Bay of Bengal (Fig 2.6) Maximum number of landslides in Sikkim occur in the Mangan Rongli zone of high rainfall. 158 cm of rainfall in 36 hours was recorded at Padamchen between 3rd to 5th October 1968(see Chandra, 1975), and recently in June 1997 at Gangtok 224 mm was recorded on 9th June. Both of these events caused massive land mass movements with extensive damage to life and property.

South- West monsoon are active from June to October in Sikkim. During this period rainfall is well distributed in the sate (see Table 2 III) July is the wettest part of the year. Rainfall is moderate from October to April, it is generally low in the months of November, December, January and February. The intensity of rainfall decreases from South to North during South- West monsoon and it is in opposite order during the winter months (Tejwani 1981). Many a times southern parts of Sikkim may go completely dry during winter months. A significant feature of rainfall distribution pattern of Sikkim is that at a particular place there may be intense rainfall, where as only a few kilometres away it may be completely dry or it may experience very little rainfall.

Major zone of high rainfall fall (Fig 2.3) covers larger parts of East Sikkim and southern part of North Sikkim North of Gangtok. The zone of low rain fall is largely in South Sikkim; it also covers parts of West Sikkim. Second zone of high rainfall covers the south western part of West Sikkim and northern most part of West Bengal. Maximum incidence of landslides in the state occurs in these two zones of high rainfall. Further analysis of rainfall data from 1960 onwards suggest that land slides incidence can be correlated in their severity to the multiple of average daily rainfall over the past 40years, during the months of June to October. The daily mean works to 20 mm over 40 years period.