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Rainfall variations along the Teesta valley in mountainous slope of Sikkim

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सार—दक्षिण-पश्चिम मानसून के आरंभ और समाप्ति की तिथियां निर्धारित करने के लिए टैडोंग व गंगतोक में माध्य साप्ताहिक वर्षा तथा उसके परिवर्तन की दर का विश्लेषण किया गया है। प्रस्तुत अध्ययन में चारों ऋतुओं के दौरान वर्षा/वर्षण वितरण के व्यापक पहलुओं के विश्लेषण का प्रयास किया गया है। इस पर्वतीय घाटी में वर्षा के लिए भौतिक लक्षणों के महत्व को प्रकट किया गया है। यह अध्ययन 12 केन्द्रों के आंकड़ों और 4-25 वर्ष की परिवर्ती अवधि के आंकड़ों पर आधारित है।

पर्वतीय ढलान वाले इस क्षेत्र में एकल मोड प्रकार की वर्षा होती है, जो जुलाई-अगस्त में अधिकतम होती है। इस घाटी में उच्चतर स्थानों में कम दूरी (4 किमी०) के अंतराल में भी वर्षा के प्रतिमानों में बहुत भिन्नता पाई गई है। घाटी में, समुद्र तल से 2000 मी० ऊपर स्थित केन्द्रों पर वर्षा में अधिकता और फिर काफी कमी पाई गई। समुद्र तल से 1500-2000 मी० की औसत ऊंचाई पर स्थित घाटी के मध्य भाग में दक्षिण-पश्चिम मानसून ऋतु के दौरान लगभग 250-300 सेंमी० वर्षा होती है।

ABSTRACT. The mean weekly rainfall and its rate of change at Tadong and Gangtok have been analysed to fix dates of onset and withdrawal of southwest monsoon. The study attempts to analyse broad aspects of rainfall/ precipitation distribution during the four seasons. The importance of orography for the rainfall in the mountainous valley has been brought out. The study is based on data of 12 stations and of varying period of 4-25 years.

Rainfall over this mountainous slope is found mono-modal with a maximum in July-August. Rainfall in the valley shows striking difference in patterns even at short distance (4 km) and situated at a higher altitude. Rainfall over stations in the valley increased up to 2000 m asl and then decrease sharply. The central part of the valley with an average altitude of 1500-2000 m asl receives about 250-300 cm of rainfall during southwest monsoon season.

Key words—Catchment, Onset, Withdrawal, Orography, Rainfall.

1. Introduction

Sikkim is a land of mountain crests. It consists of a tangled series of interlacing ridges, rising range above range to the foot of the wall of high peaks and passes which marks the "abode of snow" and its off-shoots (Risley 1989). Another more striking features of the State is the peculiar V-shaped valleys with steep and often precipitous slopes. In between the mountains on the east and west of Sikkim there is a succession of deep valleys with Teesta valley as the largest one (Fig. 1). The Teesta originating from the Zemu glacier snout, passes through the Himalayan ranges that bound the State on three sides forming a kind of horse shoe, from the sides of which dependent spurs project, serving as a lateral barriers to the Rangit and the Teesta's greater affluents, the Lachung, Lachen, Zemu, Talung, Rongni and Rangpo (Bose 1972). These basins have a southward slope.

Sikkim is the most humid place in the whole range of the Himalayans because of its proximity to the Bay of Bengal and direct exposure to the effects of the moisture laden southwest monsoon (Anonymous 1909). The great topographical variation along the Teesta valley give rise to extreme moist humid climate within its mountainous walls. The weather systems which cause variations of rainfall along the valley are largely dependent on conditions within its geographical limits. The amount of rainfall and its distribution in this valley are mostly dependent on various physical processes which are largely determined by the physiographical features of the region. In this mountainous state the most important single factor that determines the rainfall at a place is the altitude of the place.

The physiographical features force the monsoon current to rise when it comes across the ridges as barriers across the wind flow. As a result the moist air is forced to ascend up the hill slopes. In that process it is cooled sufficiently to reach the stage of cloud formation, and eventually the rains. But such generalised information does not give details about the variations of rainfall in relation to altitudinal variations along the Teesta valley which causes devastating flood from time to time. For the alround development of water resources of the country in the coming years, a large number of multi-purpose water resources projects are going to be undertaken in this region. It is, therefore, essential to have a fairly sound knowledge about the distribution of precipitation over this section of the Himalayas for the proper planning and design of these projects. An attempt has been made in this paper to study weekly rainfall distribution and onset of southwest monsoon at Tadong and Gangtok; monthly, seasonal and annual variation of rainfall with altitude and distance. Fig. 1 shows the catchment area of Teesta valley in Sikkim alongwith location of 12 rainfall stations situated in the valley.

2. Data

Except Gangtok (27° 20′ N and 88° 37′ E) and Tadong (27°20′ N and 88°38′ E) where fullfledged meteorological observatories are functioning since 1955 and 1978 respectively, other stations shown in Fig. 1 are mainly raingauge stations and rainfall data are available for approximately 4 to 25 years.

3. Mean weekly rainfall, onset and withdrawal of southwest monsoon

Onset dates of southwest monsoon over Gangtok and Tadong have been determined by using mean weekly rainfall values [Fig. 2(a)]. It is interesting to note that Gangtok had experienced higher rainfall compared to that of Tadong in almost all the weeks. The difference is more pronounced during the weeks in pre-monsoon and southwest monsoon seasons. Gangtok situated at an higher altitude of 443 m and at an aerial distance of only 4 km from that of Tadong received considerably higher amount of rainfall in almost all the weeks during the pre-monsoon and southwest monsoon seasons. The following method was adopted for determining the onset and withdrawal of southwest monsoon :

Let X_i $(i=1 \ldots. n)$ be the mean weekly rainfall of a station for n $(n=52)$ consecutive weeks. The mean having been computed from a sufficiently long period. The rainfall series X is smoothed by the 5 weeks weighted moving average; Y defined by

$$Y= (X_{i-2} +4X_{i-1} +6X_i +4X_{i+1} +X_{i+2})/16$$

The above method of smoothing has been suggested by Brooks and Carruthers (1953) and used by Raj (1990) for determining onset/withdrawal of monsoon in southern penninsula. If a series Z is defined as : $Z_i = Y_i - Y_{i-1}$ then Z_i represents increase of rainfall on the ith week from the $(i-1)$th week. If Z are plotted, the onset of monsoon could be identified from a peak of the Z curve. Similarly the withdrawal would correspond to a trough.

The Z graphs for Gangtok and Tadong are presented in Fig. 2(b). It is seen that rainfall at Gangtok and Tadong followed a similar trend in all the weeks. In most of the occasions the peaks and troughs have occurred either in the same week or with a lag of one week. It can be seen from the figure that the Z values are positive during week numbers 4 (22-28 January) to 29 (16-22 July) except week numbers 9, (26 February-4 March), 21 (21-27 May) and 22 (28 May-3 June) when it is negative. The prominent peaks correspond to week numbers 18 (30 April-6 May) and 19 (7-13 May) respectively for Tadong and Gangtok in pre-monsoon season followed by a mild trough in week numbers 21-22 (21 May-3 June). Another moderate peak is seen in standard week number 24 (11-17 June). The mid point of this comes out as 14 June which is considered as onset of monsoon at both Tadong and Gangtok. Though pre-monsoon peaks are more prominent than those in other periods such peaks may be attributed due to pre-monsoon thundershowers. According to India Met. Dep. (1943) southwest monsoon sets in over Krishnanagar and Jalpaiguri the two locations closer to Sikkim, on 8 June. Thus it seems reasonable to assume 14 June as the normal date of onset of southwest monsoon over Sikkim. From the rainfall pattern standard week number 40 (1-7 October) appears to be the date of withdrawal of monsoon from the region.

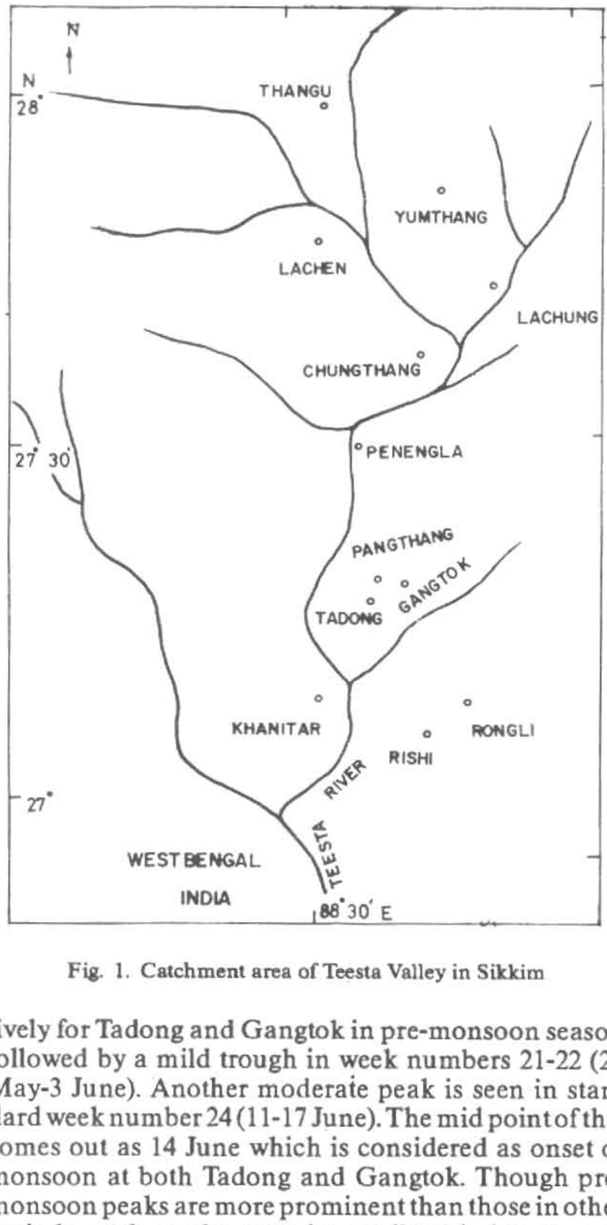
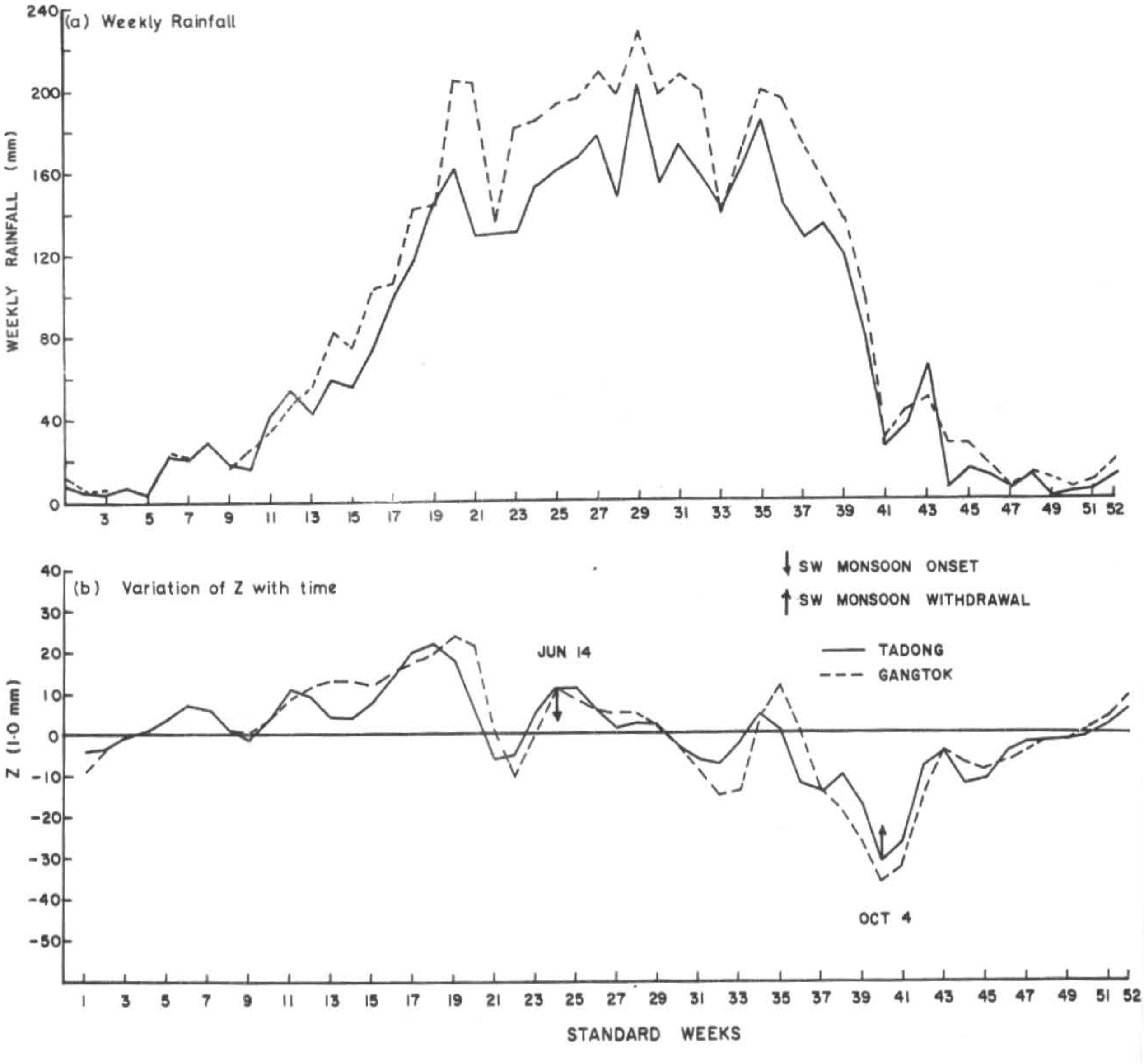


Fig. 1. Catchment area of Teesta Valley in Sikkim

4. Seasonal and annual rainfall

Table 1 shows the mean seasonal and annual rainfall for 12 stations in the Teesta valley. It can be seen from the table that in most parts of the valley, substantial amounts of rainfall, *i.e.,* between 58% and 76% of the annual totals are received during southwest monsoon followed by 16-30% in pre-monsoon season. The least rainfall occurs during winter. At none of the stations except in Thangu it exceeds 10% of the annual total.



Figs. 2(a & b). (a) Weekly rainfall over Gangtok & Tadong, and (b) variation of Z with time at Gangtok and Tadong

4.1. *Annual mean rainfall*

The annual rainfall of Teesta valley shows a steady increase from about 200 cm, in the extreme south to about 400 cm in the central part of the valley [Fig. 3(a)]. The pocket of heavy rainfall (400 cm) lies in the centre. Outward, the rainfall decreases more in east-west direction than in north-south. Pangthang with an elevation of 1905 m experiences a maximum average annual rainfall of nearly 450 cm. With increase in elevation of the terrain there is a sharp drop in rainfall to the north of Penengla. The rainfall decreases more towards the north than south. North of Chungthang the decrease is more rapid.

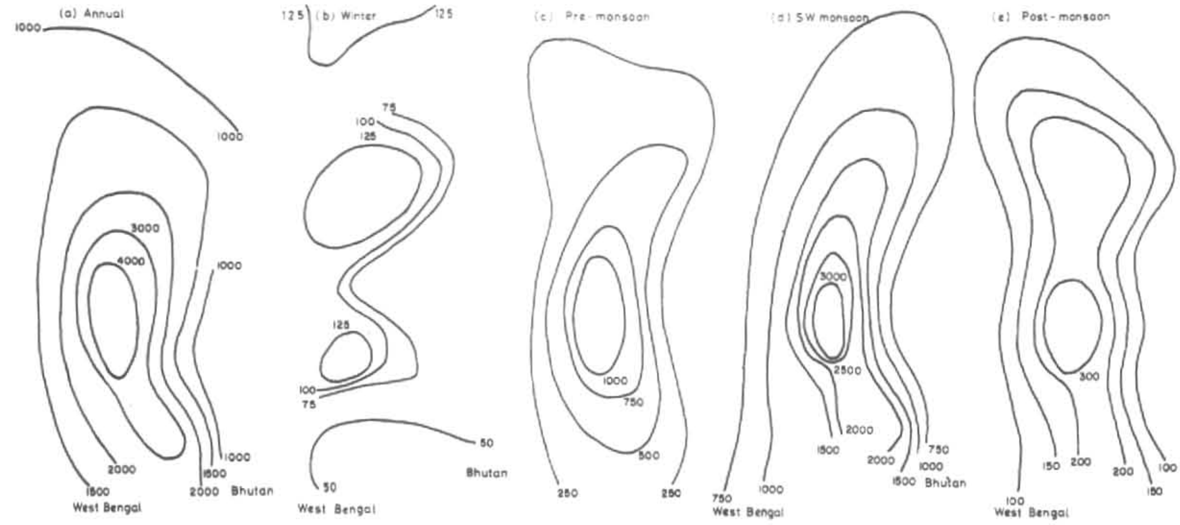
The effect of orography on rainfall is clearly brought out in the analysis. It seems that the high rainfall locations bear correspondence with the height of the stations. This observation appears to be valid up to about 2 km. Further increase in height shows steep decrease in rainfall in the valley.

4.2. *Winter (January-February) rainfall*

January and February are the months of minimum precipitation. The mean winter precipitation decreases from about 12.5 cm in the north of the valley to less than 5 cm in the south [Fig. 3(b)]. The winter rainfall contributes less than 2% of the annual rainfall for the south and about 5% for the northern parts of the valley.

4.3. *Pre-monsoon (March-May) rainfall*

During the pre-monsoon season thunderstorm activity increases progressively due to uplift of warm, moist air over the cool ridges. This orographic lifting of warm moist air appears to be the chief mechanism in causing



Figs. 3 (a-e). Rainfall pattern : (a) annual, (b) winter (Jan-Feb), (c) pre-monsoon (Mar-May), (d) SW monsoon (Jun-Sep), and (e) post-monsoon (Oct-Dec) in Teesta vallev

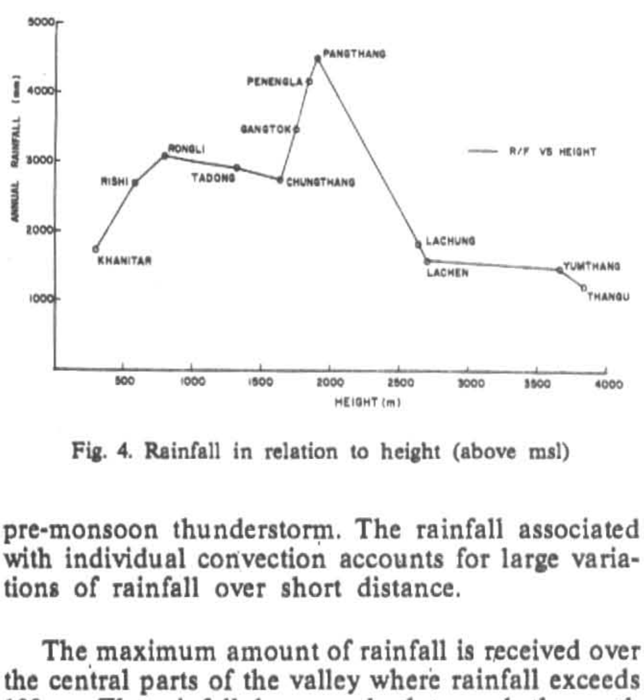


Fig. 4. Rainfall in relation to height (above msl)

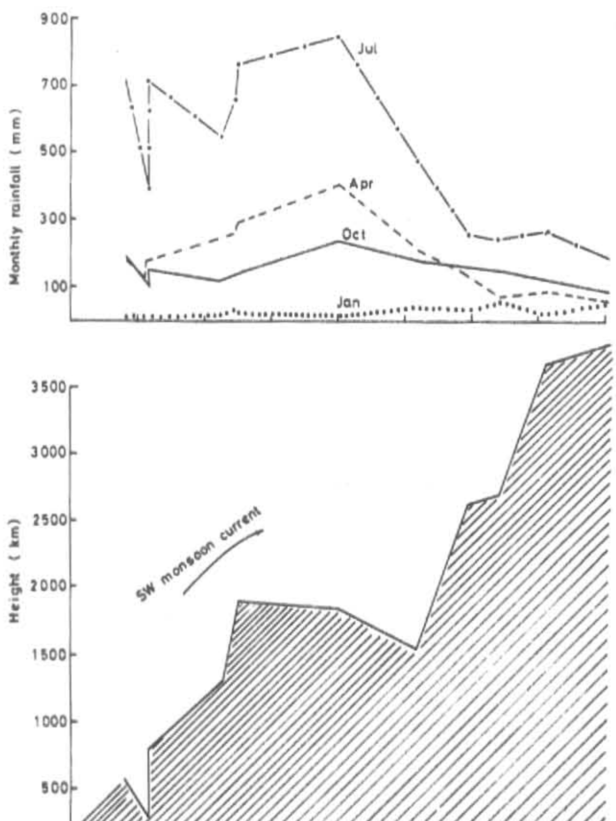


Fig. 5. Rainfall in relation to altitude and distance from the Bay of Bengal

pre-monsoon thunderstorm. The rainfall associated with individual convection accounts for large variations of rainfall over short distance.

The maximum amount of rainfall is received over the central parts of the valley where rainfall exceeds 100 cm. The rainfall decreases both towards the north and south. The south Teesta valley gets about 50 cm while the northern parts of the valley receive less than 25 cm [Fig. 3(c)]. The seasonal rainfall contributes about 15-20% of the annual for the south of the valley, 25-30% of the annual for the central part and about 20-25% for northern parts of the valley. Though gradual increase in rainfall occurs from March onward, a considerable increase is observed in May. This high May rainfall may be due to incursion of moisture in the valley due to early onset of southwest monsoon in some years.

4.4. *Southwest monsoon (June-September) rainfall*

The rainfall in this season increases progressively from about 120 cm at the extreme south of Teesta

TABLE 1

Seasonal and annual rainfall (mm)

Station	Altitude of the station (m)	Winter (Jan-Feb)	Pre-monsoon (Mar-May)	Southwest monsoon (Jun-Sep)	Post-monsoon (Oct-Dec)	Annual
Khanitar	302	31.0 (1.79)	381.6 (22.05)	1199.2 (69.30)	118.7 (6.86)	1730.5
Rishi	580	38.2 (1.42)	455.0 (16.93)	1964.9 (73.14)	228.5 (8.51)	2686.6
Rongli	800	41.0 (1.34)	487.8 (15.98)	2326.2 (76.20)	197.1 (6.46)	3052.8
Tadong	1322	73.5 (2.53)	774.0 (26.65)	1872.5 (64.48)	184.0 (6.34)	2904.0
Gangtok	1765	91.6 (2.60)	897.0 (25.49)	2316.6 (65.82)	214.2 (6.09)	3519.4
Pangthang	1905	149.1 (3.31)	1024.9 (22.79)	3015.9 (67.07)	306.7 (6.83)	4496.6
Penengla	1840	67.5 (1.61)	1239.7 (29.54)	2587.3 (61.66)	301.5 (7.18)	4196.0
Chungthang	1560	128.7 (4.73)	656.6 (24.11)	1705.6 (62.63)	232.4 (8.53)	2723.2
Lachung	2633	102.4 (5.57)	505.5 (27.50)	1060.3 (57.69)	169.8 (9.24)	1838.0
Lachen	2697	122.7 (7.68)	341.8 (21.38)	930.1 (58.19)	203.8 (12.75)	1598.4
Yumthang	3673	67.2 (4.54)	305.9 (20.64)	960.7 (64.83)	148.0 (9.99)	1481.8
Thangu	3834	125.9 (10.22)	251.0 (20.38)	727.2 (59.05)	127.4 (10.35)	1231.5

Values in the parenthesis indicate per cent of the annual rainfall.

valley to over 300 cm at Pangthang situated at an altitude of 1905 m in the central part of the valley. The central part of the valley with an average altitude of 1500-2000 m receives about 250-300 cm of rainfall. In general, rainfall decreases with increase in height of the terrain. The reduction of rainfall to the north of Chungthang as shown by isohyet of 75 cm [Fig. 3(d)] is a noteworthy feature.

The southwest monsoon season contributes about 60% of the annual rainfall over the extreme north of the valley, about 65% in the central part and about 70-75% in the extreme south.

4.5. *Post-monsoon (October-December) rainfall*

During post-monsoon season the rainfall distribution pattern generally remains similar to that in other seasons [Fig. 3(e)]. The maximum rainfall (30 cm) continues to be recorded in the central part of the valley. The rainfall decreases both towards the north and south. The southern parts get about 15-20 cm while the northern parts receive 10-20 cm. With the withdrawal of southwest monsoon from the region during October, the rainfall decreases progressively, yet october receives maximum rains during the season (about 65-80%). The seasonal rainfall is about 6-8% of the annual total for the central and southern parts of the valley but a little higher, *i.e.*, 8-13% for northern parts.

5. Rainfall as influenced by orography

5.1. *Annual rainfall as influenced by orography*

It is generally believed that rainfall increase with altitude (Bergeron 1965, 1967). Dhar *et al.* (1984) working with rainfall distribution over the Garhwal-Kumaun, Himalayas, observed that precipitation is of the order of 100 cm in the foothill region. It increases to about 200 cm in the central region. As one moves further northwards across the hilly ranges, the precipitation decreases to about 50 cm or so. Thus they concluded that the precipitation over Garhwal-Kumaun region of Himalayas varies from 50 cm to about 200 cm during the three monsoon months. In this study also an attempt was made to find out the nature of this increase. Fig. 4 depicts the nature of rainfall variation in the mountainous terrain. A conspicuous increase in rainfall with height is pronounced in parts of the hilly terrain directly exposed to southwest monsoon by the depth of the moisture layer which is far greater in depth than the height of the ridges situated in the southern

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and central parts of Sikkim. Many stations located at an average altitude of 1500-2000 m receive 2-3 times the annual rainfall of 150 cm which characterizes large parts of plains of northeast India and foothills of eastern Himalayas.

The monthly and annual rainfall patterns in hilly terrain of Sikkim also confirm that the bulk of the enhancement takes place at the lowest 1-2 km. In general, increasing trend was noticed up to a height of 2 km with mild depression at two stations, *viz*., Tadong and Chungthang. This may be attributed due to partially screening of moist air by the high ridges situated south of these stations. Rainfall decreased subsequently with further increase in height.

5. 2. *Monthly rainfall as influenced by orography*

Fig. 5 depicts rainfall profiles across the ridges. A profile of the altitude of the stations along the mountainous slope is also shown in the diagram. It may be seen that rise in altitude from the south of Sikkim is quite steep. The height of the mountain remains more or less same from 25 to 50 km and then increased abruptly from 50-70 km. All stations in the valley recorded reasonably heavy rainfall during April to September followed by relatively less rainfall in the month of October. Fig. 5 also shows two distinct rainfall patterns, one in southwest and pre-monsoon seasons and other one in post-monsoon and winter seasons. Rainfall gradually increased up to a distance of 615 km (40 km from south of Sikkim border) except at Khanitar where minimum rainfall was recorded in all the months. Sharp fall in rainfall was recorded at Chungthang situated at a distance of 627 km from the Bay of Bengal and at an altitude of 1560 m amsl. This fall in rainfall may be attributed due to the fact that moist air was partially blocked by the higher ridges located south of Chungthang. At higher altitude particularly at Chungthang and north of it, the fall in rainfall is not that well marked during post-monsoon and winter months. This is probably due to the fact that precipitation at higher altitude other than rainfall might have caused considerable amount of precipitation in post-monsoon and winter months.

6. Conclusions

(*i*) Pre-monsoon season contributes considerably higher amount (about 16-30% of the annual) of rainfall compared to winter and post-monsoon seasons.

(*ii*) The onset and cessation of southwest monsoon in the central part of the valley are probably on 14th June and 4th October respectively.

(*iii*) Maximum rainfall in the Teesta valley occurs either in July or in August.

(*iv*) Maximum rainfall is greatly enhanced by the orography and occurs at an average altitude of 1500-2000 m amsl.

(*v*) The rainfall/precipitation decreases sharply at higher elevation (>2000 m) in all seasons except in winter.

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