

The Influence of The Terrain on The Monsoon Climate in Kathmandu and Darjeeling Regions of the Himalayas

-Will Kiesewetter*

Introduction

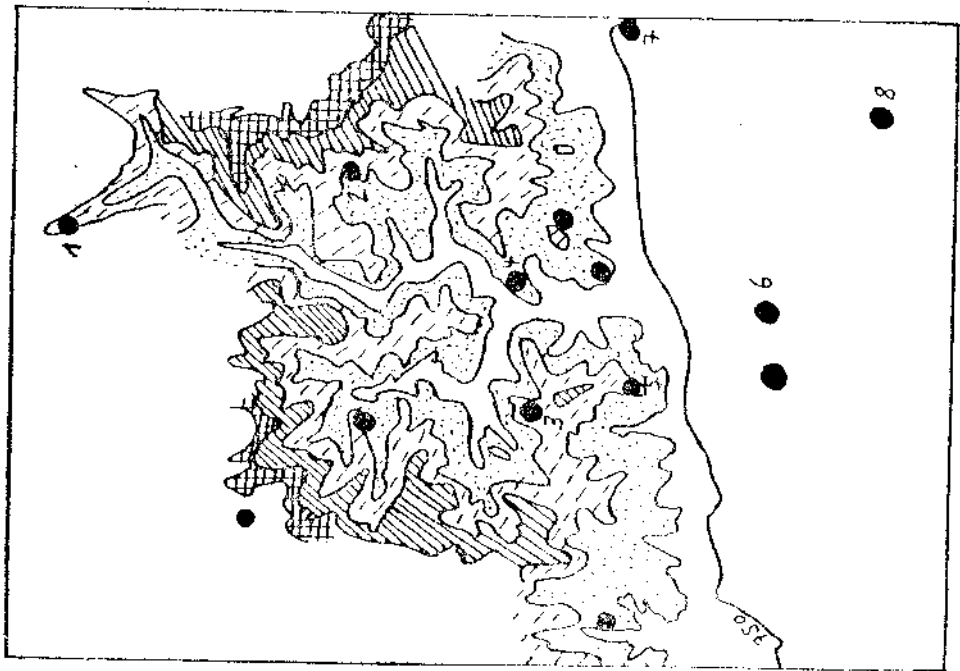
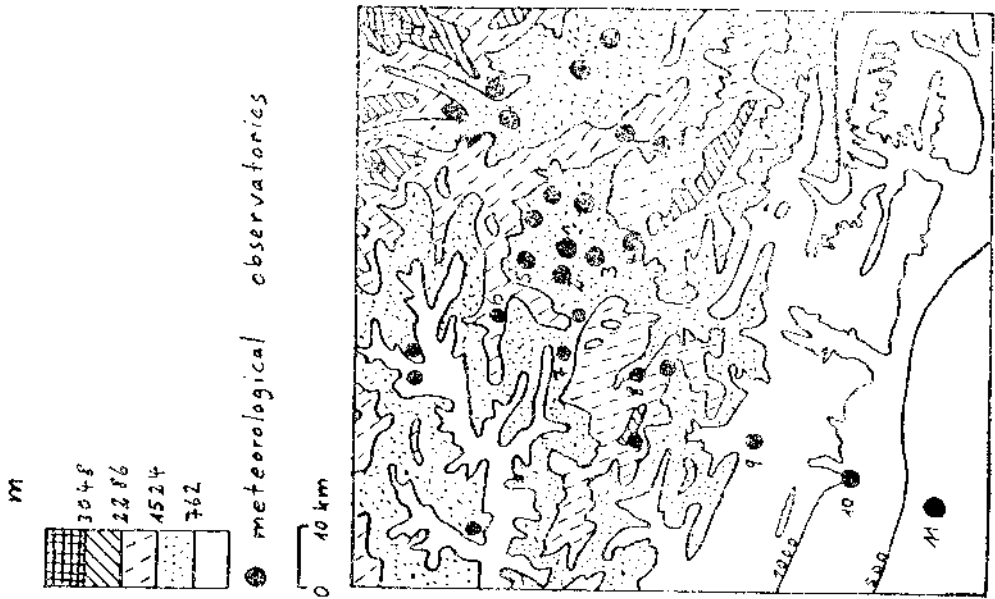
In this article the influence of terrain on the monsoon climate is depicted in an exemplary manner on the basis of areas in the Himalayas. The regions are situated south of the high Himalayas which, as a climatic divide, separates the dry Tibetan plateau in the rain shadow from the south flank at the edge of Southern (monsoon) Asia. The examination of the two areas is especially attractive on the one hand because of the fact that they represent the transition type of south-east Asian monsoon climate and on the other hand because of the differing surface forms. During the European summer, the moist SW monsoon prevails in Southern Asia which, North of the ITC, which itself is situated above the Ganges plain, is reversed to SE winds. On the other hand, during European winter both of the areas examined lie within the areas of influence of the extra-tropical Westerlies. For both of the areas under investigation, therefore, there is no typical seasonal contrast between the SW monsoon with its heavy rainfall and the relatively dry NE monsoon.

The areas under investigation

The Darjeeling region (Fig. 1, profile Fig. 7) was examined which, stretching from the Terai to the central parts of the Himalayas, includes all parts of the Himalayan system with the exception of the upper Himalayas. Due to the Teesta and its tributaries the North-South strike-slip line of the Valleys and mountain chains is dominant. The second example is the Kathmandu region (Fig. 1, profile Fig. 8) which also stretches from the Terai to the central parts. In this region the Kathmandu basin is a separate natural region in a richly divided terrain. It has a diameter of ap-

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1. H. Flohn, "Comments on a synoptic climatology of Southern Asia," WOM-TN. Vol. 68 (1965), pp. 245-252.



Darjeeling Area

1. Lachen 2. Gangtok 3. Darjeeling 4. Kalimpong 5. Kurseong 6. Siliguri 7. Nagarkata 8. Jalpaiguri

Kathmandu Area

1. Kath. Airport 2. Kath. I. E. 3. Khumaltar 4. Godavari 5. Tokha 6. Kakani 7. Dhunibise 8. Markhu Gaun 9. Hetaunda 10. Amelkhanj 11. Simra Airport

Fig. 1: Topography of the Darjeeling Area and the Kathmandu Area.

proximately 20 kms and is surrounded by mountains on all sides. Apart from this basin, the valleys and mountain chains in the area examined run mainly in an East-west extension. The relief allows one to expect a variety of climatic conditions.

Climatic observation, data and method of examination

The density of the weather stations in both areas examined (compare Fig. 1) is normal when compared with the Indian Subcontinent. In addition, the spatial distribution of stations is uneven; the plain and the edge of the mountains are characterized by a greater density than the mountains. The density of station reflects the contrast between a lower density, and high densely populated areas with a correspondingly greater station density. At each of the stations there are two measurements daily: 8.40 NST (Nepal standard time) and 17.40 NST or, respectively, 8.30 IST (India standard time) and 17.30 IST by a ten minute time difference between both countries. For the examination in question only climatic data from the official stations of the Nepalese, or, respectively, the Indian weather service were used. The unpublished observation data available from tea plantations in the Darjeeling area could not be obtained, as this area was closed for foreigners.

The 30 year meteorological standard period from 1931 to 1960 forms as far as possible —the basis for representative climatic observatin. However, the observation periods were in part shorter than the standard period or were outwith this period or did not correspond fully with this.

In order to depict the climatic conditions in both of the areas under examination, the mean values of the climatic elements were calculated and, moreover, extreme values and frequency values and also climatic observations in the field were evaluated. As all climatic elements were not recorded at all stations, it was necessary to draw empirical conclusions.

Surface Winds

From December to May westerlies dominate at Darjeeling (Fig. 2), from June to September easterlies, while in October and November Westerlies and Easterlies occur in almost equal proportions.

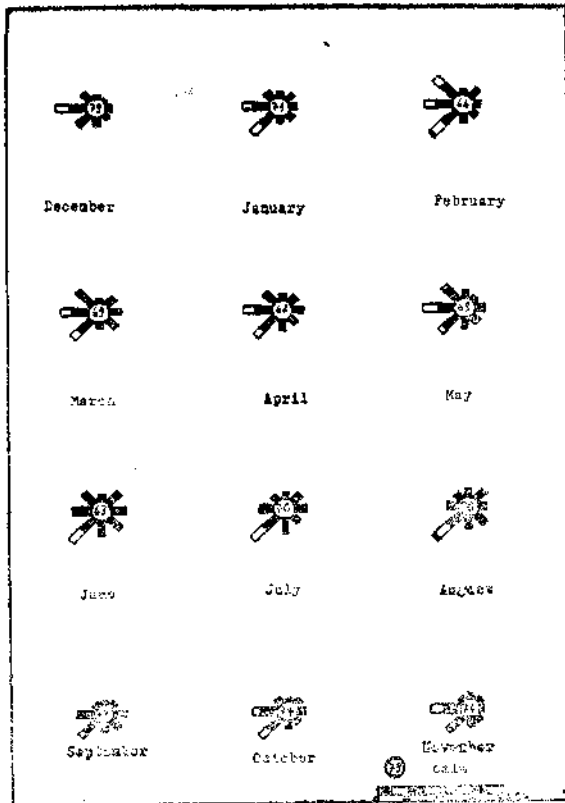


Fig. 3: Monthly distribution of wind directions at Kathmandu Airport, in %, average 1971-75.

the winds generally blow from opposite directions in the mornings and afternoons (Fig. 4). This indicates that in the mountains in both of the areas examined a system of local winds can be assumed, namely the mountain and valley winds caused by the daily irradiation and nightly radiation. Of course, the mountain and valley wind system also occurs at the Indian stations of Darjeeling and Kalimpong in that the morning (E or, respectively, NW) and afternoon (W or, respectively, SE) winds almost always blow from opposite directions. At Darjeeling, the valley winds (W) are suppressed in July and August by the general East winds. The calculation of the average values shows that, in the monsoon period, the North winds at

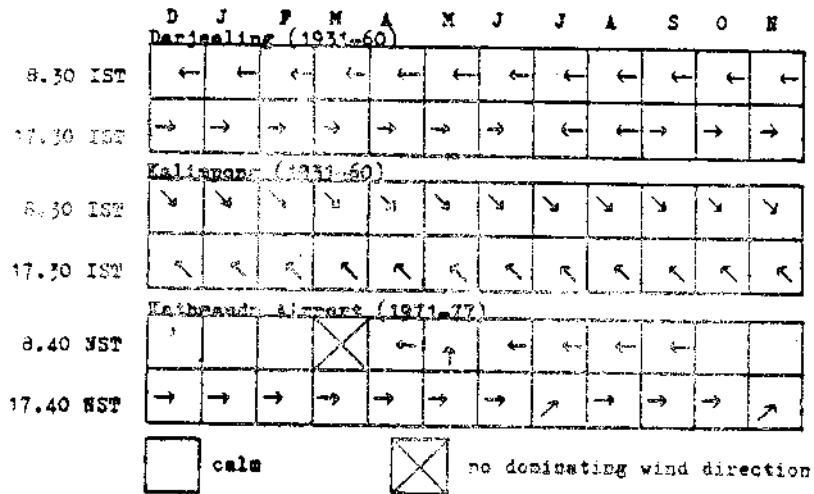


Fig. 4: The dominating wind direction (surface of the earth) at Darjeeling, Katimpong and Kathmandu Airport.

Katimpong are replaced in 30% of all cases by South winds

In the Kathmandu Valley, the local winds dominate completely from June to September (described in the following as the monsoon period) as opposed to the general surface winds. The valley winds, which in the area of the Kathmandu Airport blow from the West, clearly suppress the Easterly flow at 17.40 NST (Fig. 4). From October to February there are no mountain winds present at 8.40 NST as there is calm as a result of ground inversion. Observations of Talla that S and SE winds are predominant in the monsoon period are not verified by the observations.²

Wind velocities at Kathmandu Airport (Fig. 5) are low, but to some extent variable in the course of the year. The highest wind velocities were observed from March to May when the irradiation is at its greatest and the local winds attain their maximum intensity. During the monsoon period a decrease in wind speed is noted which is attributed to the heavy cloud and correspondingly the reduced irradiation. In October and November the wind speed decreases further as the sun has meanwhile moved further South. In principle the same annual course is to be found in Darjeeling whereby the wind speed is greater.

2. U. M. Malla, "Climatic Elements And Seasons in Kathmandu Valley", *The Himalayan Review*, Vol. I (1968), pp. 271-280.

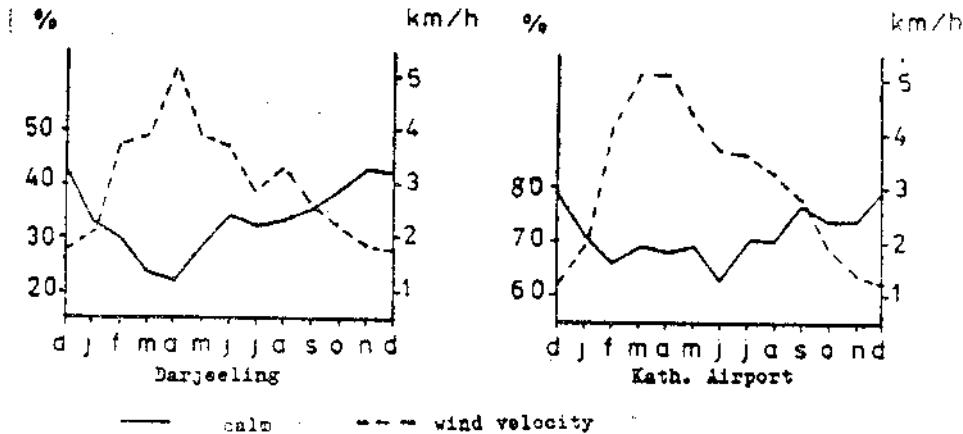


Fig. 5: Average monthly frequencies of calms relating to the number of days (per month) and average monthly wind velocity at Darjeeling(1931-60), Kathmandu Airport (1970-75 calms 1970-77 wind velocity).

In accordance with the general rule, that the frequency of calm periods is less, the stronger the local winds are, the frequency of calms is a mirror image of the wind velocity (Fig. 5). The variations in the calms in the course of the year are relatively small. As a result, a relatively great degree of regularity can be assumed in the occurrence of the local winds in the course of the year.

Table 1: Average monthly wind velocity at Kathmandu Airport (1970-77), km/h

	D	J	F	M	A	M	J	J	A	S	O	N	Year
8.40 NST	0	0,2	0,6	0,6	0,6	1,5	1,3	1,9	1,5	1,3	0,4	0,2	0,8
17.40 NST	2,4	3,7	7,6	9,6	9,6	7,4	6,1	5,4	5,2	4,3	3,5	2,6	5,6

In the daily course of the wind speed, it can be seen that the afternoon values are greater than the forenoon values (Fig. 6, Tab. 1) as valley winds are more pronounced than mountain winds. In principle, the fact that the prevailing wind direction either weakens or strengthens the local winds is also to be taken into consideration.

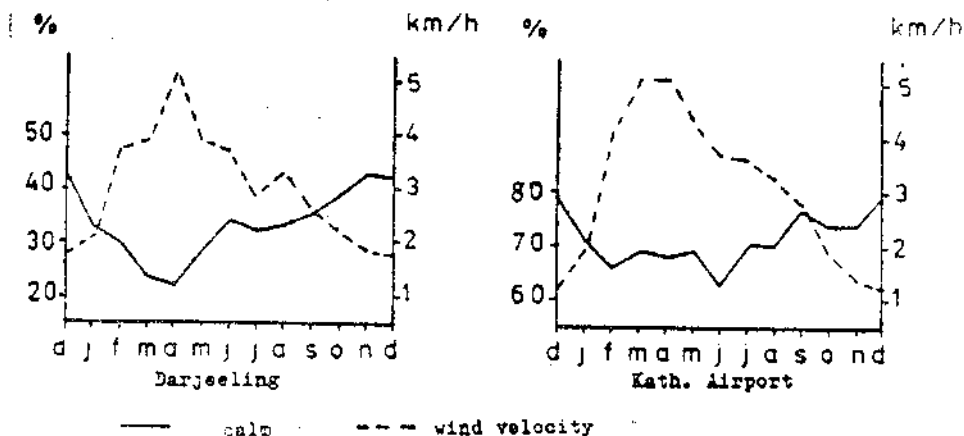


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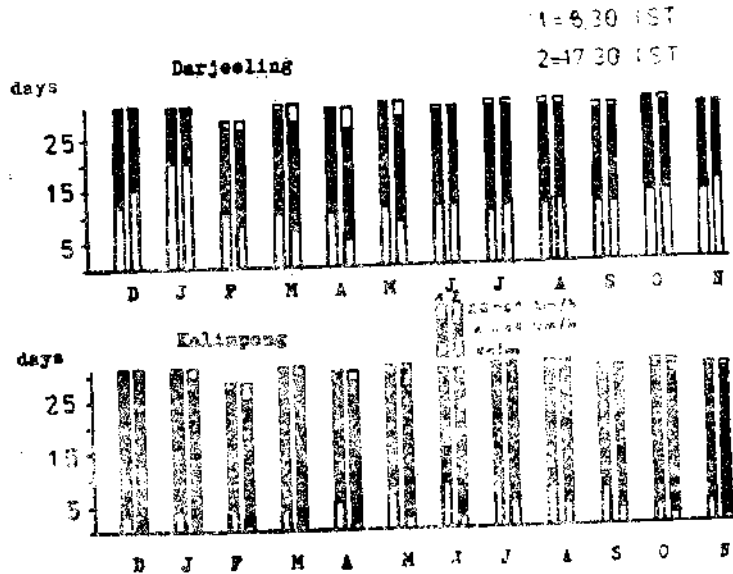


Fig. 6: Number of days per month with wind velocities of 0 km/h and 20-61 km/h at Darjeeling and Kalipong (1931-60).

Precipitation

The average annual precipitation. In the Darjeeling area the totals of precipitation clearly prove a precipitation

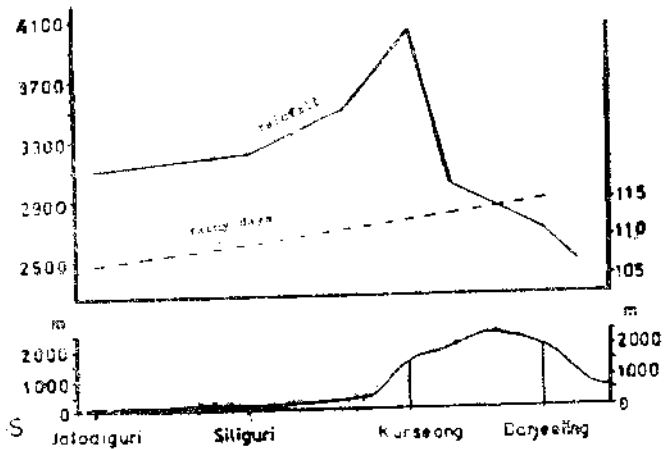


Fig. 7: Average annual rainfall and average annual number of rainy days along a N-S profile across the Darjeeling Area.

inversion.³ The more one nears the mountain the precipitation increases constantly. The increase continues in the Mahabharat/Siwalik Himalayas. However, from the level specified below onwards, in spite of increasing height, the amount of precipitation decreases. The precipitation inversion occurs between 1600 and 2100m. The assumption and comment by Kraus that there is an even decrease in precipitation in a southern direction in the Eastern Himalayas is refuted with that.⁴

Precipitation frequency was evaluated by use of wet days, which are defined by more than 2.54mm of rain within 24 hours. In both areas, greater precipitation frequency was accompanied by the high precipitation quantities and vice versa. It can, therefore, be stated that in respect to the annual precipitation frequency, the annual course and the influence of the terrain, the same results occur as in the case of the precipitation quantities. There is, however, one exception, that above the level of precipitation inversion, the number of wet days (Fig.7) increase.

In the Kathmandu basin also, it is determined that the closer one comes to the Himalayas and in the air mass barrier there is a clear increase in precipitation while in a northern direction in the lee of the mountain chain with descending winds the precipitation decreases.

In the Kathmandu basin the precipitation in the centre of this is less than at its edges. In addition, the rainfall in the southern part is less than in the northern part, which is proof of the fact that the valley winds at the southern edge of the basin are weakened by the prevailing surface winds from the east while those at the northern edge of the basin are strengthened.

In both of the areas under examination, the relative distribution of the precipitation on an annual average corresponds to that in the monsoon period from June to September in which approximately 80% of the annual rainfall occurs (Tab. 2).

3. O. N. Dhar, D. C. Mantan, and B. C. Jain, "A Brief study of Rainfall over the Teesta Basin," *Indian Journal of Meteorology and Geophysics*, Vol. 17 (1966), pp. 59-66.
4. H. Kraus, *Das Klima Von Nepal, Khumbu Himal*, Vol. I (Munich : n. 1964-1967), pp. 301-321.

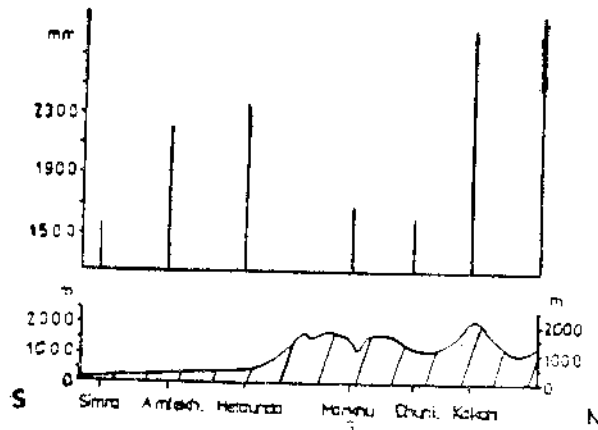


Fig. 8: Average annual rainfall along a N-S-profile across the Kathmandu Area.

Tab. 2 : Average seasonal distribution of rainfall, expressed in % of the average annual rainfall at selected stations,

station	period	elevation (m)	dec-feb	march-may	june-sep	oct-nov
plain						
Jalpaiguri	1931-60	83	0,8	14,4	80,2	4,7
mountains						
Kurseong	1901-50	1640	1,1	10,5	84,0	4,3
Darjeeling	1931-67	2127	2,0	12,7	80,7	4,7
Gangtok	1957-56	1766	3,7	23,9	67,5	4,9
Kathmandu Valley						
Kath. Airp.	1968-77	1336	2,6	13,2	79,0	5,2
Godavari	1960-76	1400	3,0	11,4	82,1	3,6

The annual course of the precipitation, (based on the mean monthly figure.) There is little rainfall from December to February; no station however is free of precipitation. From March to May, precipitation increases considerably. The "Burst of the monsoon" which is typical for the Indian monsoon climate does not occur in either of the regions under examination.

The highest rainfall occurs in the Monsoon period from June to September which stands out clearly as the rainy period. In most of the cases, July is month with the maximum precipitation. In October and November the precipitation again decreases rapidly.

From the annual course of the precipitation, the year can be divided into 4 periods: I. very low rainfall from December to February, II. constantly increasing rainfall from March to May, III. heavy rainfall in the monsoon period, and IV. decreasing rainfall in October and November. The percentage of these periods in the annual precipitation is shown in Table 2.

The period from December to February is characterized by dryness and cloudless skies. The explanation for the low rainfall is found in the fact that Western disturbances seldom occur. The Subtropical Jet Stream (27°N) whose course is followed by the Western disturbances with their origin in the Mediterranean area is embedded in the extra-tropical Westwinds prevailing throughout both of the areas under examination.⁵ The very small increase in precipitation from month to month can be explained by their more frequent occurrence.

The obvious increase in the amount of precipitation occurring in March cannot be interpreted on the basis of the Western disturbances as their frequency remains unchanged. The convective type of precipitation is now the determining factor, a fact which is especially obvious on the southern slopes. These are caused by the increased irradiation which has its origin in the fact that the sun is moving North. The increase in the precipitation in April is explained by further increase in convection rainfall. In April, a heat depression forms over the southern Dekhan Plateau which causes South winds or, respectively, South-east winds over the Gulf of Bengal which reach the Ganges-Brahmaputra Delta laden with moisture. Flohn, 1965, sees the origin of the heavy precipitation now occurring in North-East India and Bangla Dosh (violent thunderstorms — Nor'wester) in the combination of

5. H. Flohn, *Bemerkungen zur Klimatologie Von Hochasien*, Akademie der Wissenschaften und der Literatur, *Abhandlungen der Mathematisch-Naturwissenschaftlichen Klasse*, No. 14 (1959), pp. 1410-1430; I. L. Singha, "Rainfall Distribution in Nepal", *The Rising Nepal* (September 9, 1974); Malla, *Op. Cit.*

these South winds with the trough of the upper troposphere. The Nor'wester have an effect on the area under examination in Darjeeling in April and May but do not have any effect on the Kathmandu region. Generally, the heavy rainfall in the monsoon period is caused by the moisture laden SE winds from the Bay of Bengal. Genetically, it is above all a case of orographic rainfall. In the monsoon period, monsoon depressions (Eastern disturbances) occur in the Northern part of the Bay of Bengal. They move in a Northwestern direction along the monsoon trough and are guided by the upper troposphere.⁶ Heavy rainfall in the area of the monsoon trough in its normal position and light rainfall at the edge of the Himalayas is known as the "active monsoon". It sometimes occurs that the conditions are reversed so that there is heavy rainfall at the edge of the Himalayas while precipitation further south is less. These situations are known as "break" or monsoon pauses. A break is characterized by the movement of the monsoon trough to the edge of the Himalayas. Breaks are possible rain bearers in both areas examined.

Influence of the precipitation condition by a monsoon depression following the normal course is excluded. The distance of 300 kms to the mountain is, as Mooley confirmed, too great.⁷ In addition, most of the precipitation occurs in the SW sector of an Eastern disturbance while those in the North are of little importance. The reduction of precipitation in October and November can be attributed to the withdrawal of the SW monsoon and the corresponding replacement of the SE winds. Convective precipitation becomes prevalent.

In the periods from March to May and October/November convective precipitation must lead to heavier rainfall above the Southern slopes than the valley bottoms. The topo-climatic contrast between the slopes with heavy rainfall and the valleys with little precipitation is therefore an important characteristic for these periods and are especially clearly visible in the Kathmandu basin.

6. M. Doures "Zur Frage der Niederschlagsaufigkeit im Gebirgs- und Berg-Pak-tanischen Subkontinent nach Jahresabschnitten." *Deutsche geographische Rundschau*, Vol. 31 (1958), pp. 35-43

7. D. A. Mooley, "Some Aspects of Indian Monsoon Depressions and the Associated Rainfall", *Monthly Weather Review*, Vol. 101 (1973), pp. 271-280

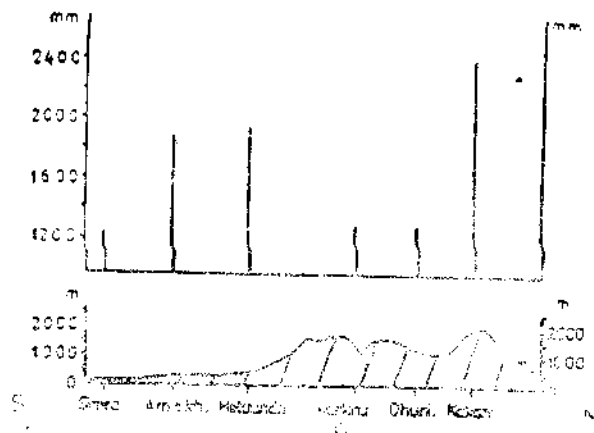


Fig. 9 : Average rainfall along a N-S profile across the Kathmandu Area during the monsoon period

In the monsoon period precipitation increases as a result of the barrier effect the nearer it comes to the mountain (Fig.9). In addition Stations in lee side positions (descending air/Markhu Gaun, Dhunibesi) receive light rainfall, whereas Kakanu on the windward side (ascending air) receives heavier rainfall. In the Darjeeling region, the monsoon precipitation also increases the nearer it comes to the mountain (Jalpaiguri 2686mm/Siliguri 2946 mm). Since monsoon precipitation determines the annual precipitation pattern, an empirical conclusion may be drawn as to a precipitation inversion in the Darjeeling area of examination in the monsoon period.

The more pronounced the local winds are, the greater their influence on the precipitation distribution must be and the more the windward leeward differences must be reduced.

Godauli on the Southern edge of the Kathmandu basin in a leeward position in respect to the monsoon SE winds, receives relatively heavy rainfall as the valley wind gains the upper hand over the prevailing general surface winds (Fig. 10). On the other hand the nocturnal mountain wind brings no precipitation to the Southern edge as the lee side situation cannot be eliminated by this. As opposed to this, the valley winds promote the windward position on the Northern edge

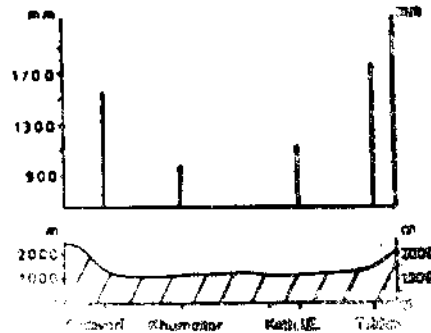


Fig. 10: Average rainfall along a NW-SE profile across the Kathmandu Valley during the monsoon period

of the Basin (Tokhu). During the day, the winds ascend at the edge of the Basin while descending wind is experienced in the centre of the Basin. This is supported by the daily precipitation course (see below) and by the fact that in the period of the year in question Kathmandu Airport, which is situated in the centre of the valley, can be reached by plane as this is often free of cloud.⁹

Influence of the terrain on precipitation caused by Western disturbance cannot be determined. However, precipitation North of the Jet axis (27° N) is greater than South of this (compare Lachen in the North with Kurseong and Jalpaiguri in the period from December to February).

Dry months and dry periods. A dry month was defined as a month with less than 50mm of rain in order to be able to make a comparison of the results within the Indian Subcontinent.⁹ The months of December to February are, without exception, dry months for almost all stations. From March to May, their number decreases, in the Darjeeling area (1 dry month on average) more than in Kathmandu (2 dry months). In the monsoon period there is no dry month at any station in either of the areas under examination. In the period of October / November the number of dry months again increases. The relief has no effect on the number of the dry months. It does, however, influence the amount of precipitation, but not to such an extent that this could have an effect on

8. H. J. Lengerke, *The Nilgiris, Weather and climate of a mountain area in South India* (Wiesbaden: n, 1977).

the number of dry months. For this purpose, compare in Table 3, Kathmandu India Embassy in the centre of the Basin with Godavari at the edge of the Basin or Jalpaiguri in the flat land or with Darjeeling.

Tab. 3 Average seasonal and annual number of dry months.

station / period	elevation (m)	average number of dry months					ave	maxi.ann.
		dec-feb	mar-may	jun-sep	oct-nov	months	no. of dry months	
plain								
Jalpaiguri 1921-50	83	3	1	0	1	5	7	
mountains								
Kurseong 1921-50	1640	3	1	0	1	5	7	
Darjeeling 1921-50	2127	3	1	0	1	5	6	
Kathmandu Valley								
Kath. I. E 1947-76	1324	3	2	0	2	6	8	
Godavari 1960-76	1400	3	2	0	2	6	7	

The calculation of the dry months does not exclude the possibility that a moist month can force its way in between two dry months. For this reason, dry periods are calculated, i. e. periods in which such an interruption by a moist month are excluded. A dry period is a period of at least three consecutive months in which in each individual month less than 76.2mm of rain may fall.⁹

In both areas, a maximum dry period of 8 months can be attained whereas the minimum duration normally exceeds the minimum period of 3 months. These long dry periods with their far-reaching consequences for the agricultural economy highlight the importance of such observations. A further complication is that, with the exception of the Gangtok station where heavier rainfall is experienced from December to February (compare to the above), the dry periods occur with a 100% probability, i. e. they occur each year without exception. Dry periods generally last throughout the whole period from December to February and extend further, to a greater or lesser extent, into the adjoining periods of the year. In no case whatsoever does the dry

9. Ibid.

period extend into the monsoon period from June to September. The uniformity of the data in Table 4 shows that the terrain has no effect

Tab. 4: Average duration, extremes and percentage probability of a dry period.

station / period / elevation / duration of the dry period in months / percentage	(m)	average	maximum	minimum	probability of the occurrence
plain					
Jalpaiguri 1921-50 83	5	7	4	100	
mountains					
Kurseong 1921-50 1640	5	7	3	100	
Darjeeling 1921-50 2127	5	7	4	100	
Kalimpong 1922-50 1209	6	8	4	100	
Gangtok 1957-66 1756	4	5	3	55	
Kathmandu Valley					
Kath. I. E. 1947-76 1324	7	8	4	100	
Godavari 1960-76 1400	6	3	7	100	

Dry spells. A dry spell is a period of 5 consecutive days in which less than 2.54 mm of rain falls each day. In addition to the annual course of events, the months of June to September, in which the monsoon prevails, were examined as in this period neither dry months nor dry periods were experienced. The influence of the terrain can be clearly seen in the Kathmandu Valley, where the station Kathmandu Indian Embassy experiences a greater number of dry spells in the centre of the Basin than the Godavari station situated at the edge of the Basin which has a greater amount of precipitation.

There is obviously a certain connection between the amount of precipitation and the number of dry spells. It is, therefore, empirically possible to conclude that there is a windward-leeward dependence with a greater number of dry spells on the leeward side.

The dry spells generally exceed on average the minimum length of 5 days and are, in extreme cases, 12 days in length (Tab. 5). This observation, however, is modified when the proportional probability of occurrence

of 1 dry spell is considered. As a rule one dry spell occurs in far less than half of the years observed in the individual months of the monsoon period. The probability is less in the case of the occurrence of 2 and 3 dry spells per month. In this case also the above mentioned contrast between Godavari and Kathmandu Indian Embassy, i. e. between edge of the Basin and the centre, is apparent. 4 dry spells are never present.

Tab. 5: Average number of dry spells per year, percentage probability of the occurrence in the monsoon period and average and maximum duration in days.

station/period	average number of dry spells per year	percentage probability of 1 dry spell				percentage probability of 2 dry spells			
		june	july	aug	sep	june	july	aug	sep
Darjeeling 1931-60	10	37	0	15	44	0	0	0	4
Jalpaiguri 1931-60	9	25	21	39	54	4	0	4	7
Kath. I. E. 1948-75	10	64	11	18	64	18	0	4	39
Godavari 1953-76	9	33	7	7	60	7	0	0	7

Station	percentage probability of 3 dry spells				average duration in days				maximum duration in days					
	June	July	Aug.	Sept.	June	July	Aug.	Se- pt. ar	ye- ar	June	July	Aug.	Se- pt. ar	
Darjeeling	0	0	0	0	7	0	7	7	20	11	0	10	11	121
Jalpaiguri	0	0	0	0	7	6	6	7	23	8	8	11	10	168
Kath I. E.	11	0	0	11	7	7	6	7	23	12	11	7	19	122
Godavari	0	0	0	0	6	5	6	8	22	8	5	6	11	136

The daily course of the precipitation:

Due to the lack of data, except for Kathmandu Airport, only empirical conclusions can be drawn: An afternoon maximum can be assumed only in the case of convective precipitation.

The daily course of rainfall at Kathmandu Airport has been examined from June to September. The mean values (1971-1975) for

July are as follows :

86 mm	-	1-6 NST
36 mm	-	7-12 NST
66 mm	-	13-18 NST
101 mm	-	19-24 NST

(the same results are shown by DHAR 1963).¹⁰ These figures show quite clearly that the nocturnal precipitation dominates. The daily course of the precipitation confirms ascending air at night above the centre of the Basin and descending air during the course of the day.

The average precipitation intensity and probability

The intensity of precipitation was computed by dividing the amount of precipitation and the number of rainy days, while the precipitation probability was calculated with the aid of a "constant precipitation amount analysis". In both instances there was parallel annual course to that of the precipitation amounts, i.e. in the case of increasing precipitation, intensity and probability increases, and vice versa.

Windward-leeward differences with higher values in the leeward positions exist during the monsoon period in respect to intensity and probability and in the transition periods of March to May and October to November, it was possible by means of the convection precipitation to determine a difference between the valley centre with its lower intensity and probability. The leeward position in the South is cancelled out by local winds so that there in the period from June to September differences between the edge of the Basin and the centre also exist with lower values.

Snow. There are no details available about the amount of snow for the Darjeeling area but instead there are only quantitative values which state on how many days per month snow or sleet fell.

Snow occurs in the Darjeeling area during the cold season from December to April in the mountains only, but not in the flat lands. There are no snow records available for the Kathmandu region as the Nepalese weather stations convert snowfall immediately to precipitation.

10. O. N. Dhar "The diurnal variation of rainfall of Barakshetra and Kathmandu during Monsoon months," *Indian Journal of Meteorology and Geophysics*, Vol. 11 (1960), pp. 153-156.

amounts. In respect to the snow conditions in the Kathmandu Valley, Malla stated that each year in January and February snow covers the mountain peaks around the valley. "This snow is due to Western disturbances. Sometimes snow may also fall in the Basin itself, however, this happened according to reports the last time in January 1945.

Table. 6: Average number of days with snow (period: 1957-66) in the Darjeeling Area.

station	elevation (m)	nov	dec	jan	feb	mar	apr
plain							
Jalpaiguri	83	0	0	0	0	0	0
mountains							
Kalimpong	1209	0	0	0	0	0	0
Darjeeling	2127	0	0.2	0.3	0.1	0.1	0
Gangtok	1756	0	0	0.1	0	0	0.1
Lachen	2697	0	0.7	1.7	4.0	1.5	0

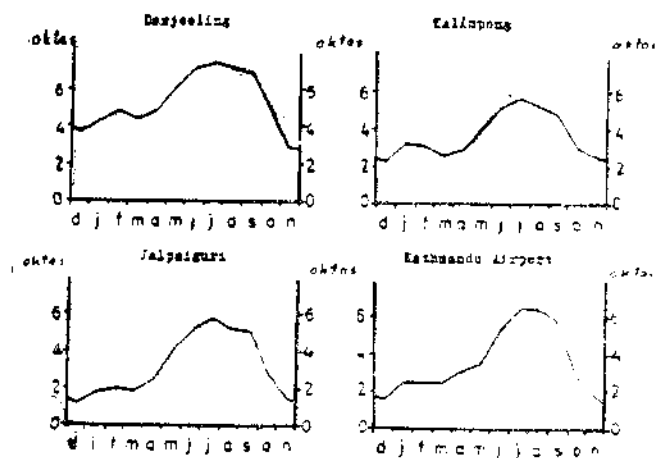


Fig. 14 : Average monthly cloud amounts at Darjeeling (1931-60), Kalimpong (1931-60), Jalpaiguri (1931-60) and Kathmandu Airport (1968-77)

The annual and daily course of cloudiness

Independent of local conditions, all stations have a strongly varying annual course and, as such, correspond with each other (Fig. 14). December is the month with the minimum value and July is the one with the maximum value. From June to September moist winds from a southeastern direction occur which are coupled with heavy precipitation and which as a matter of course necessitate a high degree of cloud. From December to February cloudiness occurs in conjunction with the Western disturbances only infrequently. Convective precipitation and Nor'wester in the Darjeeling region cause the ascending rate of cloudiness from March to May.

It can be concluded from the precipitation and wind conditions in the Kathmandu basin, that, as a result of the strong convection and in the rainy season from June to September as a result of the influence of the local winds, a greater degree of cloudiness can be expected at the edge of the Basin than in its centre in both of the annual transition periods. Similarly, the empirical conclusion can be drawn in respect to the windward-leeward differences in the latter named period of time with higher values in the windward position. In the stations situated in the mountains the afternoon values of the cloudiness are higher than the forenoon values (Fig. 12). This is not true of Jalpatguri in the flat land. The differences here are then greatest when convection dominates.

The annual and daily course of visibility.

The annual course of visibility runs contrary to that of cloudiness (Fig. 14) Kathmandu Airport (Fig. 13) offers from this standard point of view and has an approximately equally good visibility for all months. This is a result of the local conditions: visibility is reduced from December to February on average by the mist which occurs slowly every morning. From March to May the values remain high as Kathmandu Airport is situated in the centre of the Basin and cloudiness, which occurs in connection with the convective precipitation is confined for the most part to the edge of the Basin. Visibility is good from June to September as local winds prevail and, therefore, lead to a lower degree of cloudiness at the centre of the Basin and to a higher degree at the edge of the Basin.

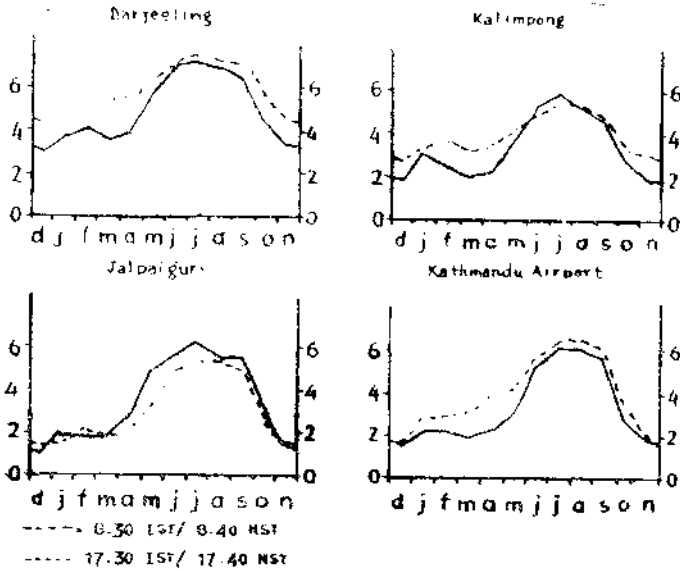


Fig. 12 : Average annual course of daily cloud amount at Darjeeling (1931-60), Kalimpong (1931-60), Jalpaiguri (1931-60), and Kathmandu Airport (1968-77), oktas

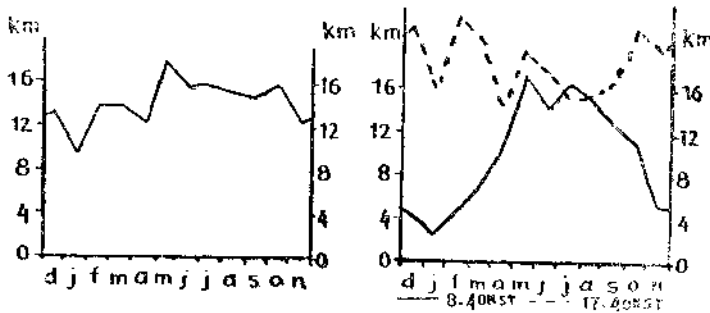


Fig. 13 : Average annual course and diurnal course of visibility at Kathmandu Airport (1968-76)

The topographical situation of Kathmandu Airport is also depicted in the daily course of visibility (Fig. 13). The greatest differences are caused from December to February by the mist blanket occurring each morning

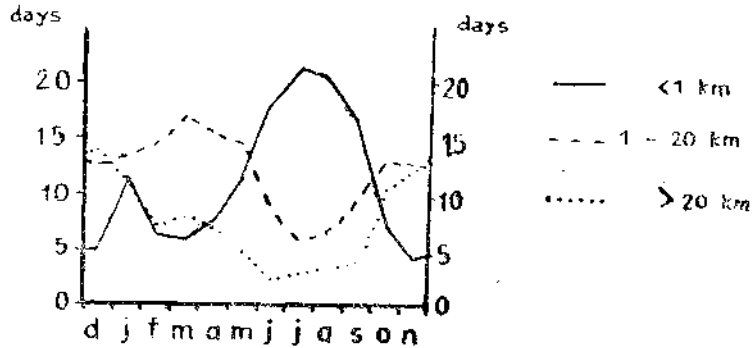


Fig. 14: Average annual course of visibility at Darjeeling, expressed by number of days per month of different visibility ranges, 1931-60

whereby these diminish as the frequency of the mist occurrence diminish. The afternoon values remain approximately at the same level throughout the year while the afternoon values have a pronounced annual course. The situation in the centre of the valley make it possible to have approximately the same values from April to September.

Radiation mist. During field work in the Kathmandu Basin in November and December of 1978, it was possible to undertake observations of radiation mist. It was not so common in November as it was in December when it occurred almost every morning. The conditions of clear, calm nights were given and as a result of cooling and falling below the dew points, a blanket of mist was formed which filled the whole Basin and dispersed some time after sunrise (a maximum of 2 to 3 hours), depending upon the strength which varied on individual days, dispersion being caused by the air being warmed. During the above mentioned period of time the maximum depth of the bank of mist was determined as being 80 m. Malla recorded the frequency of mist for Kathmandu to 79 day per year.¹²

It can be concluded that the occurrence of mist in the valleys, basins and depressions occurs in the period from November to February. Its occurrence is interrupted by Western disturbances.

12. Ibid

Heat is released in the formation of mist and radiation frost occur in the same period of the year. As a result, mist moderates the temperature drop and the corresponding intensity of the frost; or even prevents the formation of frost.

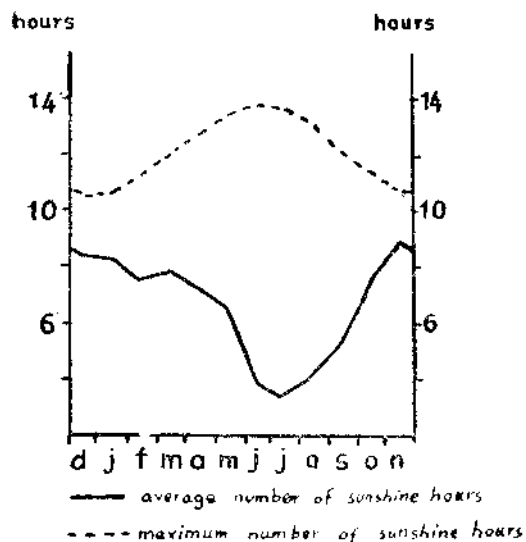


Fig. 15: Average and maximum number of sunshine hours per day at Kathmandu

The duration of sun-shine.

As opposed to the central latitudes the duration of the sunshine depends exclusively on the amount of cloud and not on the length of the day. The maximum possible duration of sunshine (Fig. 15) corresponds to the length of the day and depicts an annual course contrary to that of the average duration of sunshine. A high degree of cloud is combined with a short duration of sunshine and vice versa.

The average annual duration of sunshine is approximately at the same level for all of the stations (Tab. 7). The values in the mountains are not lower than those of the flatland as the barrier effect at the time of the SE. monsoon must be taken into consideration. As only cloud can influence the duration of sunshine, local conditions must be of the great-

est importance, i.e. from June to September differences between windward and leeward positions are present and from March to May and in October/November differences between valley rims and the middle of the valley with higher values in the leeward position and the middle of the valley. The comparison between Kathmandu and Khumaltar (Tab.7) shows differences between the edges of the Basin and the centre of the Basin for the monsoon period also, whereby Khumaltar is not situated at the rim of the valley but is situated nearer to it. This is a result during the day of the ascending air over the centre of the Basin.

Tab. 7: Average number of sunshine hours per day on a monthly basis.

station	elevation (m)	period	D	J	F	M	A	M	J	J	A	S	O	N	yr.
plain															
Nagarkata	750	2-65	8.4	8.3	7.6	7.9	7.1	6.4	3.7	<u>3.3</u>	4.1	5.3	7.5	<u>8.9</u>	6.5
(x)															
Kathmandu Valley															
Kath. airp.	1336	1968-75	7.6	7.3	<u>8.5</u>	8.4	8.1	8.3	6.2	<u>4.7</u>	5.6	5.0	7.7	8.2	7.1
Khumaltar	8350	1968-75	7.1	<u>6.5</u>	<u>7.9</u>	7.5	7.0	7.4	4.3	4.3	<u>5.3</u>	<u>4.2</u>	6.6	7.6	6.3

(x) = Source: RAO and GANESAN 1972

3.3 = Minimum

8.9 = Maximum

Temperature

The mean annual temperature.

It can be reduced from the annual temperatures in both areas that there is a clear dependence upon the altitude of the station; temperature drops with increasing altitude. (e. g. Jalpaiguri - 83m above sea level - 24.0° C mean annual temperature/ Kalimpong - 1209m - 18.0° C/ Gangtok - 1750m - 15.6° C/ Darjeeling - 2127m - 13.3° C/ Jachen - 2697m - 9.5° C ,

The annual course of temperature. January is the coolest month as in this period of year, in spite of clear skies, the sun is low in the sky and the irradiation is low. Although it has moved somewhat further North in

January the minimum occurs in this month as this follows the lowest position of the sun. As the sun moves further North, this is accompanied by a constant temperature increase. The convection precipitation and Nor'wester in the period from March to May are unable to stop the temperature increase but do however, prevent the occurrence of a maximum temperature. The temperature only begin to fall after the monsoon rains were started. In the case of the maximum occurring in August it can be assumed that the precipitation can not lead to a reduction in temperature but does in any case retard the increase. After the monsoon rains have finished, the sun which has now moved further South again, is unable to cause a further increase in temperature.

As a result of the little data available no windward-leeward differences can be shown for the period of the monsoon. They can be calculated empirically, however, with higher temperatures in the leeward positions, as a dry adiabatic warming of the air takes place. Godavari at the edge of the Kathmandu Basin and Kathmandu Airport in the centre of the local wind conditions in the centre of the Basin, higher temperature prevail in the periods mentioned. This difference in temperature is also given in the periods of the year with convective precipitation.

The average daily temperature amplitude. From December to February higher amplitudes prevail as there is undisturbed irradiation during the day on the one hand and undisturbed radiation at night on the other (Fig. 15). Convective precipitation and Nor'wester lead to a continuous decrease of the temperature amplitude until this reaches its minimum in the monsoon period. After cloudiness and precipitation have decreased, the amplitude increases in the second half of the year.

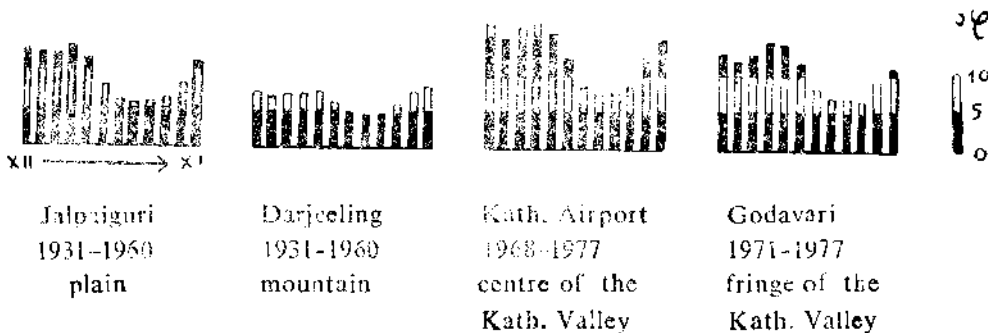


Fig. 16: Monthly averages of diurnal range of temperature at selected stations

Frost.**Darjeeling area.**

Quantitative data are available for the period 1957-66 in respect to the surface temperature. In the case of the stations in the flat land ground frost does not occur at any time of the year. This is only recorded at Gangtok (1756m) for the period from December to February with a maximum of 2.7 days in January on average. No ground frost was recorded in the case of the higher situated Darjeeling station (2127m). For this the topographical situation of the station must be taken into consideration. Since cold and therefore heavy air flows downward it is possible that a lower lying station in the valley records ground frost while a station in a ridge position or upon the valley rim remains frost-free. Ground frost is not widespread but is present in the form of cold air blankets, in depressions, valleys and basins. It is a case of radiation frost which only occurs at night and in the early morning.

Kathmandu Basin.

Tab. 8: Number of days with frost at Kathmandu Airport, ground temperature, 8. 40 NST

Year	Jan	Feb	Mar	Oct	Nov	Dec
1973	x	5	0	0	x	26
1974	9	x	x	x	x	x
1975	0	0	0	0	0	1
1976	x	x	x	x	x	x
1977	x	x	x	x	x	x
1978	x	x				

x = no data

From 1973 onwards temperature at the ground was measured at Kathmandu Airport (Tab 8). Due to the observations, the occurrence of ground frost is limited to the period from December to February. During this period there are generally ideal preconditions for radiation frost: the air has a relatively (!) low water vapour content, the sky is clear, the ground dry and there is no wind. By means of long

wave radiation an energy loss occurs which leads to a cooling of the earth. According to the measurements of the Nepalese weather service, the length of the period subject to ground frost is about 3 months. The data show great variability in the occurrence of frost from year to year. The minimum temperature reached in the individual months (daily temperature values) were : February 1973 (-1.8°C), December 1973 (-4.8°C), January 1974 (-3.5°C) and December 1975 (-1.2°C). The lowest ground temperature measured amounted to -4.8°C on December 24, 1973. Ground frost is possible on individual days but also day by day over a longer period of time. Frost occurs only at night while during the day the temperatures are above freezing point.

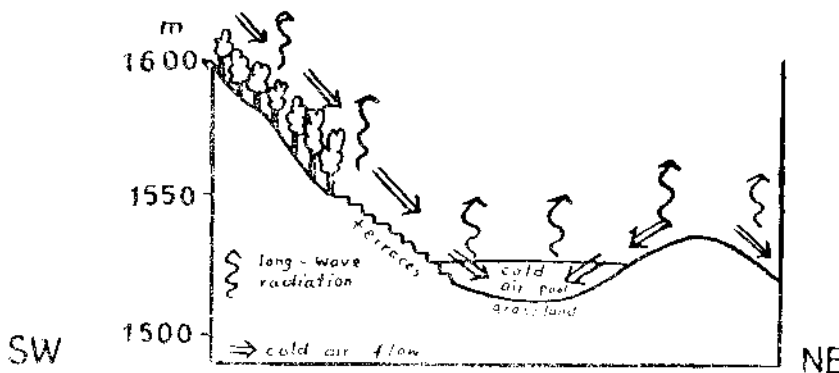


Fig. 17: Profile across the valley near Sanga.

During the field work in November/December 1978 in the Kathmandu Basin numerous observations were carried out in respect to ground frost. Examinations carried out in a south eastern valley of the Kathmandu Basin, south-east of the base of Sanga on 7.12.1978 proved the existence of cold air blanket in this valley while the upper slopes were free of frost (Fig. 17). The nocturnal flow of cold air led to the formation of the cold air blanket. The night frost melted a short time after sunrise.

On the basis of the observations in the Kathmandu Basin it is shown that the ground frost occurs partly in small depressions of only

a few centimeters in depth, on other days these cold air pockets had a dimension of a few decimeters or several metres depending upon the radiation and the order of magnitude of the cold air flow.

On those days in which these observations were carried out no frost was measured at the Kathmandu Airport station at 8.40 NST at height of 5 cms above the ground. It is obvious that a ground temperature measurement at a height of 5 cms above the ground is unsuitable for determining if ground frost is present. Measurements must be made directly on the surface of the earth. These are available for a relatively short period. The measurement time of 8.40 NST is too late as in a number of cases the temperatures have already risen above 0°C. In addition, radiation frost occurs in deeper parts of the valley which is not recorded by Kathmandu Airport. Finally it is not possible to record frost with instruments only when the frost appears in part only in very small areas. The period in which frost occurs is, therefore, probably longer than the ground temperature disclose.

It can be deduced from these remarks that frost is limited to depressions, valleys and basins while the surrounding slopes are frost-free. The occurrence of the frost is, therefore, to a great extent dependent upon the relief, the possibility of occurrence upon the general conditions which appear above all in the period from December to February.

The influence of the terrain on the climate. The previous observations have shown that in both areas under examination the climatic conditions are determined by the circulation is modified to a considerable extent by the influence of the terrain.

Valleys running in a West-East direction have the following effect in the period from June to September in which the monsoon blows from SE: the SE winds leads to windward-leeward differences, whereby the South sides of the valleys are in the leeward position and the North sides in the windward. Ascending winds in the windward and descending winds in the leeward sides lead to decisive effects on the climatic elements in this part of the year. These have already been discussed above. In the periods from March to May and October/November on the other hand the situation at the edge of the valley or in the centre of the valley is decisive for the climatic differences determined by the terrain.

The period from December to February is characterized by the occurrence of mist and radiation frost in the valleys while the higher regions remain untouched.

Valleys running in a North-South direction were not examined due to the lack of data.

The influence of the altitude can be shown by a precipitation inversion in the Darjeeling region in the annual average and for the monsoon period while the frequency of precipitation in this area under examination increased with increasing altitude after the zone of maximum precipitation had been crossed. From a certain altitude onwards snow fell in both areas under examination in the cooler period of the year, whereby the exact altitude could not be determined. The temperature decreases with increasing altitude.

Windward-leeward differences were already discussed in connection with the valleys running in West-East direction.

The valley or slope position is of great importance for the climate especially in the period from March to May but also in October/November as the irradiation above the slopes (especially the South slopes) leads to a convective air ascent. The effects on the individual climatic elements have already been described.

In the Kathmandu Basin, a local wind circulation develops, which reverses itself at night, and prevails over the general SE wind in the period from June to September so that the leeward position at the southern edge is neutralized and, therefore, leads to differences between the central area and edges of the Basin. These differences between the edges and the centre are also present in the period from March to May and in October/November (compare above). Mist and radiation frost are typical from December to February while the higher lying edges of the Basin are free of frost.