551.588.2 : 551.578.4

EFFECT OF ALTITUDE ON SNOWFALL PATTERN AND DENSITY

1. Two typical representative study areas have been chosen for evaluation of altitude effect on snowfall pattern in Himachal Pradesh and Jammu & Kashmir. The stations in H.P. are Manali or Bahang (station A), Kothi (station B) and in J & K, North Portal at Bannihal Tunnel (station D) and Varinag (station C). The Snow & Avalanche Study Establishment (SASE) meteorological observatories are located at all the above four stations which are having from simple snow gauges to automatic weather station equipments and snow density measuring instruments of CREEL (Cold Regions Research Engineering Laboratory, Hanover, USA) origin. The data have been recorded daily.

The results of snow precipitation has been recorded for ten years period (1976-86) and analysed for its altitude and density variational studies. The results arrived at should serve a very fruitful purpose for prediction of snow precipitation for the higher inaccessible reaches of snow-bound Himalayan terrain.

2. *Review of literature*—So far no concerted effort has been made in this country regarding determination of altitude factor as far as snowfall is concerned. Rao and Rangachari (1987) have made a passing reference of snowfall with differing values of altitude, but the values arrived at appears to be high and are limited to a very short period durations (about 20 days of snow-storm). For European conditions Kuzmin (1961) has analysed melting of snow cover under those altitudinal conditions. Also Geiger (1961) has analysed the snowfall pattern variations with the increase of altitude in Swiss-Alps conditions. Frutiger and Martinelli (1966) have attempted density change with altitude variation in European conditions. Upadhyaya *et al.* (1981) have also analysed snow cover density of a uniform snowpack in Indian environmental conditions to a limited extent.

Pathak (1987, 1989) has described the effect of vegetation and other environmental conditions obtaining in the Western Himalayas in some of the research papers.

3. *Experimental programme* – About 10 years of snowfall data of four stations, two each in J. & K. and H.P. have been collected and studied (Annual Reports, SASE). The altitude of the four stations have been determined. The daily data of snowfall and its density has been recorded by automatic weather station & snow gauges and CRREL density sampler. The density variations of fresh snowfall have been noted for a period of 5 years in H.P. sector. The snowfall pattern under various environmental effects have been discussed with Salm and Schaerer for European and Canadian conditions. The snowfall and density data have been given in the Table 1.

4. *Altitude factor determination* – The various findings are given below :

(*a*) The snowfall has been found to be varying from year to year.

TABLE 1

Snowfall data altitude effect for station A : Manali (Bahang) (2192m) ; B : Kothi (2527 m) ; C : Vering (1900 m) and D : North Portal (2200 m)

Year	Station	Total snowfall (P) (cm)	log P	Density (gm/cc)	Altitude ratio
1985-86	A	231	5.44	0.165	B/A=3.87
	B	895	6.80	0.118	
	C	274	5.61	—	D/C=2.30
	D	630	6.45	—	
1984-85	A	278	5.62	0.270	B/A = 2.35
	B	653	6.48	0.110	
	C	174	5.16	—	
	D	508	6.23	—	D/C = 2.91
1983-84	A	235.8	5.46	0.090	B/A = 2.28
	B	537	6.30	0.070	
	C	322	5.77		
	D	670	6.51		D/C = 2.08
1982-83	A	362	5.89	0.175	B/A = 3.29
	B	1190	7.10	0.130	
	C	261	5.56		
	D	641	6.46		D/C = 2.45
1981-82	A	450	6.10	0.175	B/A = 2.58
	B	1161	7.06	0.100	
	C	442	6.09	—	
	D	790	6.72	—	D/C = 1.78
1980-81	A	385	5.95		B/A = 2.20
	B	845	6.74		
	C	509	6.23		
	D	650	6.48		D/C = 1.27
1979-80	A	157	5.07		B/A = 2.96
	B	465	6.14		
	C	125	4.83		
	D	420	6.04		D/C = 3.36
1978-79	A	280	5.63		B/A = 1.96
	B	550	6.31		
	C	302	5.71		
	D	458	6.13		D/C = 1.51
1977-78	A	200	5.30		B/A = 2.50
	B	500	6.22		
	C	218	5.40		
	D	459	6.13		D/C = 2.10
1976-77	A	120	4.79		B/A = 3.41
	B	410	6.02		
	C	111	4.71		
	D	378	5.94		D/C = 3.40

Altitude factor : (a) Average altitude ratio for H.P. sector =2.40. (b) Average altitude ratio for J. & K. sector=2.30. Thus average of (a) & (b) Fc=2.35 (alitude factor)

(*b*) The snowfall has been found to increase with the altitude again both in J. & K. and H.P. sectors up to a certain level and decreases thereafter.

(*c*) Regarding the rainfall, the level of maximum precipitation varies between 1.5 & 2.5 km a.s.l. Variability with altitude in respect of snowfall is, however, much higher. The data recorded at four stations in J. & K. and H.P. for the period 1976-86 have been plotted for snowfall ratio against years in Fig. 1 and an average altitude factor evaluated. It is inferred that the snowfall can be even more than twice for an altitude difference of about 300 m (~1000 ft). The actual altitude factor has been computed as 2.35 graphically (Fig. 1) and its range of validation is around approximately 1.5 to 3.5 km a.s.l. The snowfall between this range of altitude is generally appreciable in the Western Himalayas.

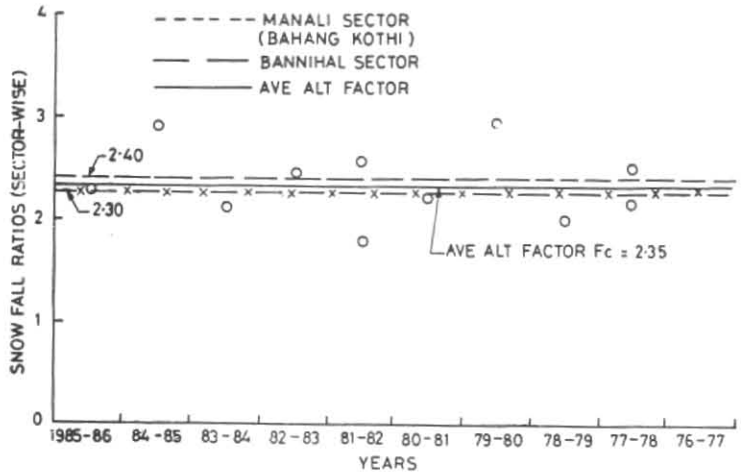

Fig. 1. Altitude factor evaluation

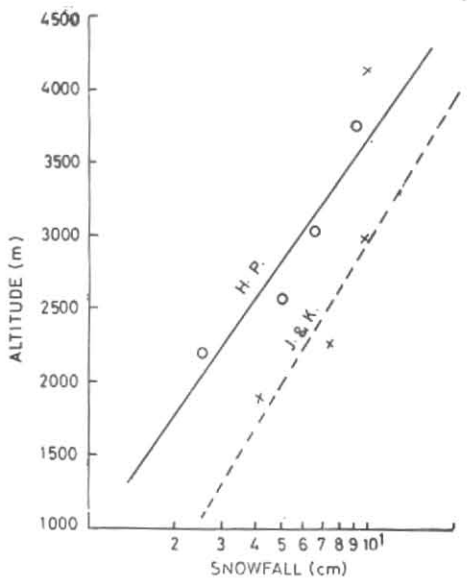

Fig. 2. Effect of altitude on precipitation

Snowfall data (1986-87)

J. & K.	*Himachal Pradesh*
Verinag (1900 m) = 410 cm	Bahang (2200 m) = 246 cm
North Portal (2200 m) = 741 cm	Kothi (2550 m) = 536 cm
Haddantaj (3080) = 941cm	Sissu (2000 m) = 687 cm
	Barlachala (4900 m) = 746 cm

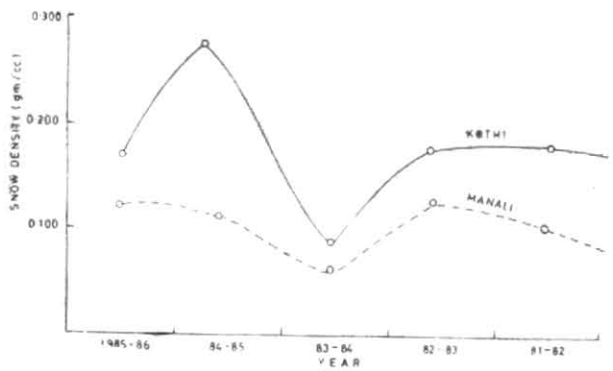

Fig. 3. Variation of snow density

(*d*) The data given at Table 1, once plotted on a logarithmic scale, represents a straight line pattern. A set of snowfall data with the differing altitudes in H.P. and J. & K. sectors have been plotted on logarithmic graph for the year 1986-87 (Ref. Fig. 2), which culminates into a straight line. These findings highlight the fact that the snowfall pattern in Western Himalayas generally conforms to a trend of exponential variation with the altitudinal variations.

5. *Density variation with altitude*

(*a*) The density of snowfall varies appreciably with the type of vegetation, terrain and environmental effects. The effect of altitude is also found to be pronounced for the density. A decrease in snow density with altitude increase (or lapse rate) has been computed as —0.012 gm/cc/100 m in the present study. The average density of snow at Manali is about 0.175 g/cc and at Kothi is 0.132 g/cc for a difference of altitude of 335 m.

(*b*) The fresh snowfall densities of station A and station B are plotted in Fig. 3. The decreasing trend of density with increasing altitude is fully justified as at higher altitudes the fresh snowfall will have lesser fresh water (moisture content) and temperature.

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