3. Burton, K. P., McCord, J. M. and Ghai, G., Myocardial alteration due to free radical generation. *Am. J. Physiol.*, 1984, **84**, H776–H783.
4. Dhalla, N. S., Elmoselhi, A. B., Hata, T. and Makino, N., Status of myocardial antioxidants in ischaemia–reperfusion injury. *Cardiovasc. Res.*, 2000, **47**, 446–456.
5. Downye, J. M., Free radicals and their involvement during long-term myocardial ischaemia and reperfusion. *Ann. Environ. Physiol.*, 1990, **52**, 487–507.
6. Freeman, B. and Csapo, J., Biology of disease: free radicals and tissue injury. *Lab. Invest.*, 1982, **47**, 412–426.
7. Uma, D. P., Ganasoundari, A., Vrinda, B., Sriniwasan, K. K. and Unnikrishan, M. K., Radiation protection by the *Ocimum* flavonoids, orientin and vicenin: mechanism of action. *Radiat. Res.*, 2000, **154**, 455–460.
8. Kelm, M. A., Nair, M. G., Stratsburg, G. M. and DeWih, D. L., Antioxidant and cyclooxygenase inhibitory phenolic compounds from *Ocimum sanctum*. *Phytomedicine*, 2000, **7**, 7–13.
9. Ohkawa, H., Ohishi, N. and Yagi, K., Assay of lipid peroxide in animal tissue by thiobarbituric acid reaction. *Anal. Biochem.*, 1979, **95**, 351–358.
10. Maron, M. S., Depierre, J. W. and Manmerik, B., Level of glutathione, glutathione reductase and glutathione-s-transferase activity in rat lung and liver. *Biochem. Biophys. Acta*, 1979, **582**, 67–78.
11. Paglia, D. E. and Valentine, W. N., Studies on the quantitative and qualitative characterization of erythrocyte peroxidase. *J. Lab. Clin. Med.*, 1967, **2**, 158–169.
12. Misra, H. P. and Fridovich, I., The oxidation of phenylhydrazine: superoxide and mechanisms. *Biochemistry*, 1976, **15**, 681–687.
13. Aebi, H., Catalase. In *Methods of Enzymatic Analysis* (ed. Bergmeyer, H. U.), Verlag Chemie, Weinheim, Germany, 1974, 2nd edn, pp. 213–215.
14. Lowry, O. H., Rosebrough, N. J., Farr, A. L. and Randall, R. J., Protein measurements with the Folin phenol reagent. *J. Biol. Chem.*, 1951, **193**, 265–275.
15. Lamprecht, W., Stan, F., Weisser, H. and Heinz, F., Determination of creatine phosphate and adenosine triphosphate with creatine kinase. In *Methods of Enzymatic Analysis* (ed. Bergmeyer, H. U.), Academic Press, NY, 1974, pp. 1776–1778.
16. Rona, G., Kahn, D. S. and Chappel, C. I., Studies on infarct-like myocardial necrosis produced by isoproterenol: a review. *Rev. Can. Biol.*, 1963, **22**, 241–245.
17. Rona, G., Boutet, M., Huttner, I. and Peters, H., Pathogenesis of isoproterenol-induced myocardial alterations: functional and morphological correlates. *Recent Adv. Stud. Card. Struct. Metab.*, 1973, **3**, 507–525.
18. Sharma, M., Kishore, K., Gupta, S. K., Joshi, S. and Arya, D. S., Cardioprotective potential of *Ocimum sanctum* in isoproterenol induced myocardial infarction in rats. *Mol. Cell. Biochem.*, 2001, **225**, 75–83.
19. Lei, X. L. and Chiou, G. C., Cardiovascular pharmacology of *Panax noto ginseng* (Bark) FH Chen and *Salvia miltiorrhiza*. *Am. J. Chin. Med.*, 1986, **14**, 145–152.
20. Cohen, G. and Heikkila, R. E., The generation of hydrogen peroxide, superoxide radical and hydroxy radical by 6-hydroxydopamine, dialuric acid and related cytotoxic agents. *J. Biol. Chem.*, 1974, **249**, 2447–2452.
21. Handforth, C. P., Isoproterenol induced myocardial infarction in animals. *Arch. Pathol.*, 1962, **73**, 161–165.
22. Csapo, Z. J., Dusek, K. and Rano, G., Early alterations of the cardiac muscle cells in isoproterenol-induced necrosis. *Arch. Pathol.*, 1972, **93**, 356–365.

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Spatial variation of snow-cover properties on small uniform mountain slopes in the Greater Himalayan region

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In the present study three small uniform mountain slopes were selected carefully for snow-pit observation in the Patsio bowl located in the higher latitudes of Himachal Pradesh in the Great Himalayan region. Totally 27 snow-pit observations were taken, with nine snow-pit observations in a study plot of each slope. At each observation point, 19 snow-pack parameters were recorded and analysed statistically. Analysis result of the snow-pack parameters shows a large spatial variation (up to 59%) in the snow-cover properties. Snow-pack parameters vary from one observation point to another point within the same slope as well as from one slope to another. The study reveals that in most cases, the snow-cover properties taken from a single snow-pit do not resemble the average snow-cover properties of the entire study plot with significant confidence level.

Keywords: Great Himalayan region, Snow-pit observation, spatial variation, uniform slopes.

SNOW-cover characteristics are highly dependent on the climatic as well as terrain conditions[1]. The snow-cover properties[2] for different snow climatic zones are different and vary spatially and temporally. Snow climate of Indian Himalaya changes as one moves from the lower latitude to the upper latitude region[3]. The Indian Himalaya has three main parts: Western Himalaya, Central Himalaya and Eastern Himalaya. Western Himalaya is further divided into three main snow climatic zones, in which the Great Himalayan region falls under the Middle Himalayan climatic zone or Mid latitudinal climatic zone. This region has continental-type winter climate characterized by lesser snow fall, colder temperatures and shallow snow-cover. Snow pack of this region is dominated by low-density temperature-gradient grains having low ram resistance and higher temperature gradient[4]. Significant studies have been undertaken in the past on snow-cover properties and avalanche occurrences of this region[3–10], but few attempts have been made for the spatial variation of snow-cover properties of this region. Although substantial work has been done worldwide on the spatial variation of snow-cover properties[11–18], very few attempts were made for such study in the Indian Himalaya[19]. In the present work an attempt has been made to

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study the spatial variation of the snow-cover properties on a small study plot of mountain slopes in the Patsio bowl (3800 m) in Great Himalayan region.

The study area is near Patsio (lat. 32°45′, long. 77°15′) Research Station of SASE in the Great Himalayan Range at an altitude of 3800 m amsl. Northerly slopes were selected for the study, with an altitude from 3825 to 4030 m amsl, between 20 and 28° slope angles (Figure 1).

For the present work, three small slopes were carefully selected, with no prior disturbance by pedestrians, skiers, avalanche workers and avalanches. Slopes generally have planar profile and angle between 20 and 28°, with no vegetation at and around them, without large scree, protruding bedrock and wind-drifting. The slopes selected satisfied all these conditions, so that the variation due to terrain and ground undulations could be neglected. In each small slope a study plot of area of 30 m × 30 m was selected. Visual inspection revealed that the plot exhibits consistent snow-cover properties all over. In each study plot, nine snow-pit observations were taken at a distance of 15 m from each other in three parallel rows to explore the complete study plot.

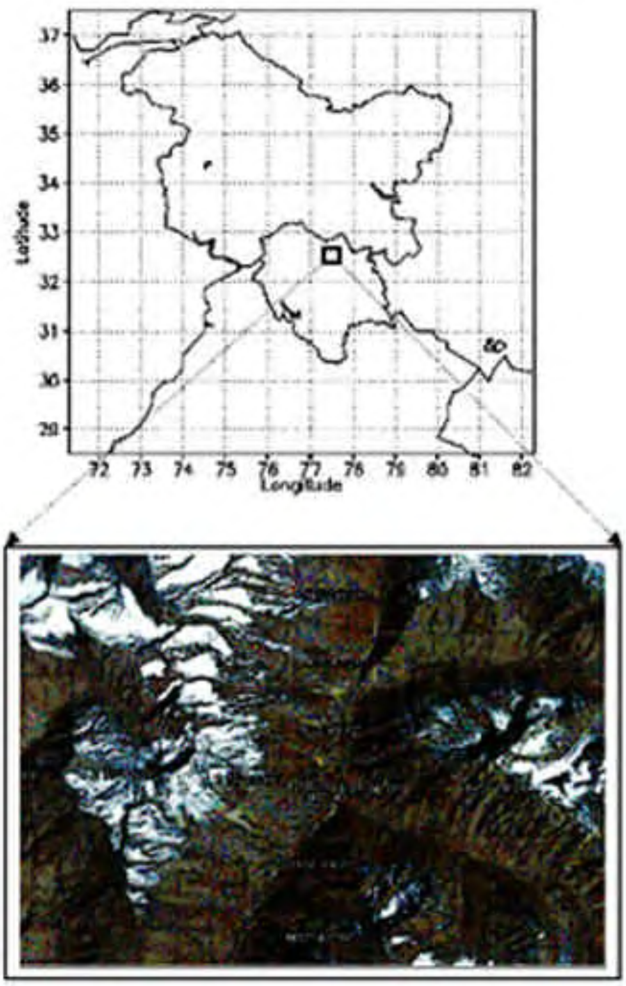

Figure 1. Map of study area.

At each small slope, all the snow-pit observations were taken on a face parallel to the fall line of the slope. At each observation point, the following snow parameters were collected: standing snow, number of layers, layer thickness, layer density, shear strength of layers, ground temperature, snow surface temperature, temperature gradient of the snow pack, ram resistance at a depth of 10 and 20 cm from the top surface of the snow pack, ram resistance at the bottom surface of the snow pack, free ram penetration and failure load of the snow column.

After excavation of the snow-pit of approximate size 2.0 m × 1.5 m up to the ground surface, standing snow was measured using a ruler in centimetres. Different snow layers were marked by observing variations in snow hardness and by brushing the surface gently. Changes of hardness and layer boundaries are detected by sliding the edge of a steel ruler through the snow. The boundaries of the layers were marked and their thickness measured in centimetres. The density of the snow layers was measured in g/cm^3 using a density meter of volume 100 cm^3 and known weight. The shear strength of the layers was calculated using a shear frame of cross-sectional area 100 cm^2. After the layers in the snow-pit wall were identified and marked, the snow was removed up to approx. 5 cm above the layer. The shear frame was then pressed gently into the snow with the edge parallel to and a few millimetres above the layer. With the gauge attached to the frame, a pull is applied rapidly until shear failure occurs. The reading of the pull gauge gives the shear strength of the layer per 100 cm^2. Shear strength of the interface of ground and snow was also measured as few snow columns failed at the ground–snow interface during the column test. Snow surface temperature and ground temperature were measured using the same thermometer in shade, and temperature gradient was calculated in °C/cm. Free ram penetration depth was measured in centimetres with the first section of a standard ram penetrometer, which has approximately a 1 kg mass and a cone diameter of 40 mm. The ram penetrometer was placed on the snow surface and allowed to penetrate the snow under its own weight. The depth of penetration was read from the centimetre scale on the rod. Ram resistance at 10 and 20 cm from the top surface of the snow pack and at the bottom surface of the snow pack was calculated from ram profile. Failure load of column was recorded using a Quantitative Step Loading Block Test, where failure load in kilogram is the load required to fail a snow column of dimension 13 cm × 18 cm and dig deep up to the ground.

The observations on three different slopes were made on 10, 16 and 17 December 2004. The total cumulative snow fall of the season up to 10 December 2004 at the research station Patsio was 67 cm of three snow storms (storm 1: 1–4 October 2004 – 29 cm; storm 2: 11–13 October 2004 – 28 cm and storm 3: 30 November 2004 – 10 cm). The maximum number of layers identified in the snow pack of all the three slopes was three and named as top, middle and bottom layers for the present analysis (Figure 2). The general structure of the snow pack was the top layer consisting of sugar grains of size 1 to 2 mm, middle layer consisting of depth hoar grains of size of 2 to 4 mm and bottom layer consisting the large depth hoar grains of size 4 to 8 mm (Figure 3). At some observation points, a thin crust of the order of a few millimeters to 1 cm was also identified at the top of the snow surface and it was included in the total number of layers at that point. When we compared the top layer properties like thickness, density, shear strength etc. at all observation points of a slope, the crust was not considered as the top layer, while the layer just below the crust was considered as top layer. At some points only one layer was observed and that layer was taken as the bottom layer because of its similarity in grain type and size with the bottom layer of other observation points of the same slope. At some observation points only two layers were identified and these layers were taken as the top and bottom layers, as the snow-grain type and size resembled the top layers and bottom layers at other observation points of the same slope.

Snow parameters observed at nine different observation points in three different small, uniform slopes are given in the Tables 1–3.

Figure 2. Different layers visible in the snow pack.

Figure 3. Depth hoar grains of the order of 4–8 mm observed at the bottom layer of the snow pack.

For each small slope, mean snow-cover properties were calculated by taking the mean of nine snow-pit observations made on the particular slope. Coefficients of variation (C_V) were also calculated for individual parameters at all the three slopes (Figure 4; the line for slope 2 is not continuous as the middle layer is missing in the snow pack).

It is assumed that the mean snow-cover properties represent the properties of the particular small slope. For each pit in a given slope, two-tail t-test analyses[20] were carried out to evaluate the hypothesis that 'mean snow parameter of a particular pit exhibits the mean snow parameter of the slope with significant confidence level'. The confidence level is taken as 95%. The t-score of individual parameters at a snow-pit observation point is calculated as follows:

$$t = \frac{\overline{x} - \mu}{s} \{N - 1\}^{1/2}, \quad (1)$$

where x is the mean snow parameter of the slope, μ is the mean snow parameter at the individual pit observation point, s is the sample standard deviation and N is the sample size.

If the t-score for a parameter lies between the values of $-t_{0.975}$ and $t_{0.975}$, then the hypothesis is selected and the individual pit parameter exhibits the mean slope parameter with 95% confidence level. If the t-score lies outside the above values, then the hypothesis is rejected and the individual pit parameter does not exhibit the mean slope parameter and shows variation from the mean slope parameter.

Thus, the hypothesis selected if

$$-t_{0.975} < t = \frac{\overline{x} - \mu}{s} \{N - 1\}^{1/2} < t_{0.975}. \quad (2)$$

The results of the t-test analyses for individual parameters of all the three small, uniform slopes are shown in Table 4 and the variation shown by the individual parameters is shown in Figure 5.

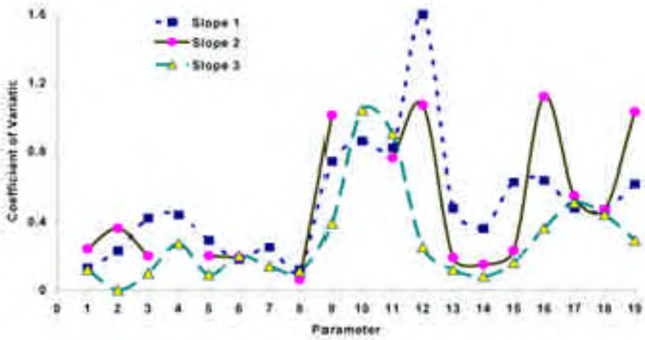

Figure 4. Variation of individual parameters at each slope (parameter index is shown with Figure 5).

Table 1. Snow parameters observed at slope 1 (Slope angle: 20–28°; altitude: 3825–3835 m; aspect: NE)

Parameter	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Pit 7	Pit 8	Pit 9	Average	C_V
Standing snow (cm)	19	19	25	26	22	19.5	19	20	21	21.17	0.13
Number of layers	2	3	3	2	2	2	1	2	2	2.1	0.23
Top layer thickness (cm)	6.5	4.5	6	12.5	7	7.5	–	7	4	6.88	0.42
Middle layer thickness (cm)	–	8	9.5	–	–	–	–	–	–	8.75	0.44
Bottom layer thickness (cm)	12.5	6.5	9.5	13.5	15	12	19	13	17	13.1	0.29
Density – top layer (gm/c^3)	0.22	0.18	0.25	0.17	0.28	0.2	–	0.23	0.25	0.22	0.18
Density – middle layer (gm/c^3)	–	0.2	0.28	–	–	–	–	–	–	0.24	0.25
Density – bottom layer (gm/c^3)	0.26	0.27	0.33	0.23	0.27	0.23	0.26	0.23	0.24	0.26	0.12
Shear strength – top layer (kg/100 cm^2)	0.3	0.2	0.1	0.33	0.4	0.8	–	0.85	0.1	0.39	0.75
Shear strength – middle layer (kg/100 cm^2)	–	0.8	3.3	–	–	–	–	–	–	2.05	0.86
Shear strength – bottom layer (kg/100 cm^2)	1.5	1.0	6.5	2.0	2.3	3.0	10	3.5	2.0	3.53	0.82
Failure load of column (kg)	1.21	1.21	1.21	1.21	1.21	1.21	15.7	2.21	1.21	2.93	1.6
Ground temperature (°C)	–4.0	–1.0	–3.0	–2.5	–6.0	–3.0	–4.0	–2.0	–2.0	–3.06	0.48
Surface temperature (°C)	–6.0	–6.0	–8.0	–6.0	–9.0	–4.0	–5.0	–3.0	–3.5	–5.61	0.36
Temperature gradient (°C/cm)	10.5	26.3	20	13.4	13.6	5.13	5.26	5	7.14	11.81	0.63
Ram resistance at 10 cm from top (kg)	3.25	3.67	2.0	2.0	2.0	2.0	4.5	2.0	4.5	2.88	0.64
Ram resistance at 20 cm from top (kg)	–	–	2.0	5.3	3.25	2.83	–	7.0	7.0	4.56	0.48
Ram resistance at ground (kg)	3.25	12.0	7.0	5.3	4.5	2.83	9.5	7.0	5.33	6.3	0.47
Free penetration (cm)	7	7	21	12	7	13	1	10	5	9.22	0.62

Table 2. Snow parameters observed at slope 2 (Slope angle: 20–28°; altitude: 3905–3915 m, aspect: NW)

Parameter	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Pit 7	Pit 8	Pit 9	Average	C_V
Standing snow (cm)	19.8	24.9	16.5	19.3	25	11	26.4	25	22.3	21.13	0.24
Number of layers	3	3	1	3	3	1	3	2	3	2.44	0.36
Top layer thickness (cm)	7	8.5	–	6.0	6	–	6	5	5	6.21	0.20
Middle layer thickness (cm)	–	–	–	–	–	–	–	–	–	–	
Bottom layer thickness (cm)	12.5	16	16.5	13.0	18	11	20	20	17	16.00	0.20
Density – top layer (gm/c^3)	0.16	0.15	–	0.2	0.20	–	0.25	0.15	0.20	0.19	0.19
Density – middle layer (gm/c^3)	–	–	–	–	–	–	–	–	–	–	
Density – bottom layer (gm/c^3)	0.29	0.28	0.27	0.26	0.26	0.26	0.3	0.26	0.26	0.27	0.06
Shear strength – top layer (kg/100 cm^2)	0.05	0.07	–	0.2	0.6	–	0.2	0.1	0.1	0.19	1.01
Shear strength – middle layer (kg/100 cm^2)	–	–	–	–	–	–	–	–	–	–	
Shear strength – bottom layer (kg/100 cm^2)	2.8	1.1	5.0	1.7	0.5	5.5	1.0	1.5	2.0	2.34	0.76
Failure load of column (kg)	1.21	2.21	11.21	2.21	2.21	8.21	1.21	1.21	1.21	3.43	1.07
Ground temperature (°C)	–7.0	–7.0	–8.0	–7.0	–7.0	–7.0	–6.0	–5.0	–4.0	–6.44	0.19
Surface temperature (°C)	–14.0	–17.0	–15.0	–14.0	–14.5	–12.0	–12.0	–11.0	–11	–13.39	0.15
Temperature gradient (°C/cm)	35.35	40.1	42	36.3	30.0	45.5	22.8	24.0	31.4	34.16	0.23
Ram resistance at 10 cm from top (kg)	2.0	2.0	4.5	1.0	1.0	12.0	2.0	1.0	2.7	3.13	1.12
Ram resistance at 20 cm from top (kg)	3.32	2.0	–	–	5.33	–	2.0	1.0	2.7	2.73	0.55
Ram resistance at ground (kg)	3.32	2.0	4.5	3.67	4.0	7.0	2.0	2.0	2.7	3.47	0.47
Free penetration (cm)	7	0.5	1	12	15	1	1	22	7	7.39	1.03

The *t*-test analysis shows a spatial variation for all the snow-pit parameters and variation ranged from 10 to 59%. Maximum variation is shown by the ram resistance of the snow pack, and 12 to 16 (44 to 59%) snow-pits out of 27 did not exhibit the mean slope ram resistance within 95% confidence interval. The value of C_V for this parameter was found to be high and ranged from 0.36 to 1.12. For failure load of the column, the *t*-test analysis shows a variation of only 15%, while the value of C_V was very high for this parameter and the values calculated for three slopes were 1.6, 1.12 and 0.25. Large values for the first two slopes were found because at one or two observation points, single-layer snow pack existed, which failed under large amount of load. Standing snow (30%), number of layers (18%) and layer thickness (27 to 37%) also show significant spatial variation. Surface temperature (48%), ground temperature (29.6%) and temperature gradient (48%) show high spatial variation. To some extent, the variation in ambient temperature during observations also added to higher variations in surface temperature and temperature gradient, as it takes 4–5 h in digging the snow-pit and taking observations at different observation points at a particular slope, and ambient temperature varies from 1 to 3°C during this period. Density of different layers varies from 30 to 40% and C_V ranged from 0.11 to 0.25. For shear strength of the layers, the variation is from 11

Table 3. Snow parameters observed at slope 3 (Slope angle: 20–28°; altitude: 4020–4030 m; aspect: NW)

Parameter	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Pit 7	Pit 8	Pit 9	Average	C_V
Standing snow (cm)	25	28	31	24	35	26	28	31	30	28.67	0.12
Number of layers	3	3	3	3	3	3	3	3	3	3.00	0.0
Top layer thickness (cm)	5.0	5.0	6	4.0	5	5	5	5	5	5.00	0.1
Middle layer thickness (cm)	9.0	8.0	10	6.0	15	7	10	11	11	9.67	0.27
Bottom layer thickness (cm)	11.0	15	15	14.0	15	14	13	15	14	14.00	0.09
Density – top layer (gm/c^3)	0.25	0.17	0.2	0.27	0.15	0.25	0.20	0.2	0.17	0.21	0.20
Density – middle layer (gm/c^3)	0.26	0.28	0.3	0.28	0.24	0.2	0.28	0.24	0.2	0.25	0.14
Density – bottom layer (gm/c^3)	0.32	0.32	0.32	0.3	0.3	0.28	0.24	0.3	0.24	0.29	0.11
Shear strength – top layer (kg/100 cm^2)	0.3	0.2	0.2	0.15	0.2	0.1	0.2	0.1	0.1	0.17	0.39
Shear strength middle layer (kg/100 cm^2)	0.5	0.3	0.2	1.8	0.2	0.7	3.5	1.0	1.0	1.02	1.04
Shear strength bottom layer (kg/100 cm^2)	2.0	0.4	0.5	2.8	1.0	5.0	2.0	1.1	0.3	1.68	0.90
Failure load of column (kg)	1.21	2.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.32	0.25
Ground temperature (°C)	–6.0	–5.0	–6.0	–5.0	–5.0	–5.0	–5.0	–4.0	–5.0	–5.11	0.12
Surface temperature (°C)	–11.5	–12.0	–12.0	–11.0	–11.0	–10.0	–10.0	–10.0	–10	–10.83	0.08
Temperature gradient (°C/cm)	22.0	25.0	19.4	25.0	17.14	19.23	17.85	19.35	16.67	20.18	0.16
Ram resistance at 10 cm from top (kg)	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	2.0	1.22	0.36
Ram resistance at 20 cm from top (kg)	7.0	2.83	7.0	3.0	4.0	2.0	3.67	2.71	2.0	3.80	0.51
Ram resistance at ground (kg)	7.0	2.83	2.5	3.0	4.0	5.33	2.63	7.0	3.25	4.17	0.44
Free penetration (cm)	10	13	15	18	8	10	13	13	7	11.89	0.29

Table 4. *t*-test analysis for snow parameters of all three slopes

	Slope 1	Slope 2	Slope 3
Parameter	Hypothesis selected	Hypothesis selected	Hypothesis selected
Standing snow	7/9	6/9	6/9
No. of layers	6/9	7/9	9/9
Top layer thickness	7/9	6/9	7/9
Middle layer thickness	7/9	–	6/9
Bottom layer thickness	5/9	4/9	8/9
Density – top layer	6/8	6/7	5/9
Density – middle layer	–	–	3/9
Density – bottom layer	5/9	7/9	4/9
Shear strength – top layer	4/8	6/7	5/9
Shear strength – middle layer	–	–	8/9
Shear strength – bottom layer	6/9	6/9	6/9
Failure load of column	8/9	7/9	8/9
Ground temperature	7/9	6/9	6/9
Surface temperature	5/9	6/9	3/9
Temperature gradient	4/9	5/9	5/9
Ram resistance at 10 cm from top	3/9	1/9	7/9
Ram resistance at 20 cm from top	5/6	4/6	5/9
Ram resistance at ground	5/9	5/9	5/9
Free penetration	7/9	3/9	5/9

to 38%, while C_V is comparatively high and ranged from 0.39 to 1.04. High values of C_V exist because at few observation points of each slope, the deviation in shear strength is high from the mean shear strength of the slope.

A large spatial variation from 10 to 59% was observed in the snow-cover properties within a small study plot of 900 m^2 in the Greater Himalayan region. Different snow parameters show different degrees of variation within the same slope and from slope to slope. This variation is in agreement with studies made in other mountain ranges of the world, e.g. experiments on spatial variation of snow stability showed 52% variation in Bridger and Madison ranges of Southwest Montana, US and Columbia Mountains near Rogers Pass, British Columbia[14]. Neumann *et al.*[18] found 10 to 50% variation in the landscape mean and point snow-pack depth measurement at various sites in Canada. The results of the present study imply that the snow-cover properties from a single observation point on

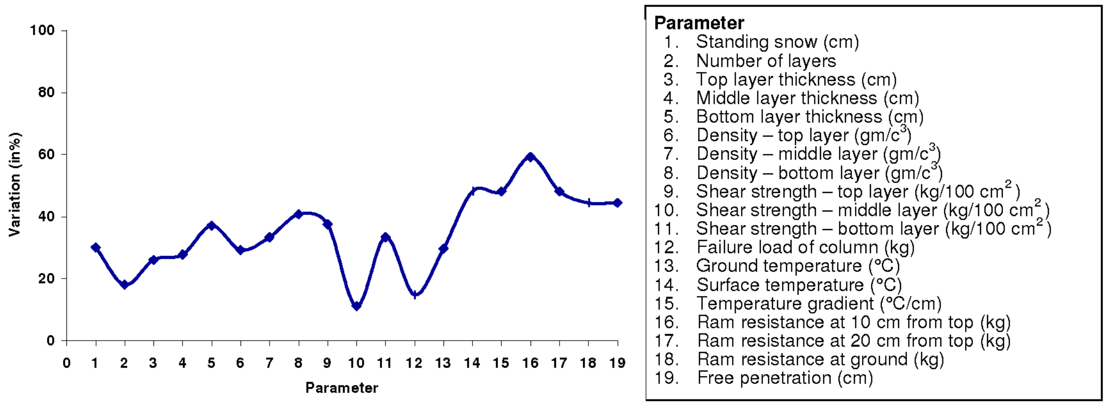

Figure 5. *t*-test analysis.

a slope cannot reliably represent those of the entire slope. More studies in future can provide scientific understanding for simulation of the snow-cover properties on a mountain slope. This will be helpful in extrapolating the snowpack data from snow observatory locations to the formation zone of avalanches for accurate avalanche prediction.

1. Clung, Mc. and Schaerer, P., In *Avalanche Handbook*, The Mountaineers, Washington, 1993.
2. Gray, D. M. and Male, D. H., *Handbook of Snow*, Pergamon Press, Canada, 1982/83.
3. Sharma, S. S. and Ganjau, A., Complexities of avalanche forecasting in Western Himalaya – an overview. *Cold Reg. Sci. Technol.*, 2000, **31**, 95–102.
4. Gusain, H. S., Singh, A., Ganju, A. and Singh, D., Characteristics of the seasonal snow-cover of Pir Panjal and Great Himalayan ranges in Indian Himalaya. In Proceedings ISSMA-2004, Manali, 2004, pp. 97–102.
5. Mohan Rao, N., Some observations on the seasonal snow-cover. In Proceedings of the First National Symposium on Seasonal Snow Cover, 28–30 April 1983, New Delhi, 1983, pp. 65–76.
6. Rangachary, N. and Tej Ram, Density of snow and its variations in Central and Western Himalaya. In Proceedings of the First National Symposium on Seasonal Snow Cover, 28–30 April 1983, New Delhi, 1983, pp. 84–97.
7. Ganju, A., Agrawal, K. C. and Rao, D. L. S., Snowcover model. In Proceedings of the International Symposium on Snow and Related Manifestations, 26–28 September 1994, Manali, 1994, pp. 392–409.
8. Singh, A., Ganju, A., Satyawali, P. K. and Sethi, D. N., Snow cover simulation model: A comparison with snowpacks of Pir Panjal and Great Himalayan ranges. In Proceedings of the National Snow Science Workshop (NSSW-99), Manali, 1999, pp. 67–76.
9. Ganju, A., Thakur, N. K. and Rana, V., Characteristics of avalanche accidents in Western Himalayan region. In National Snow Science Meet 01, 7–10 November 2001, Manali, 2001, pp. 69–78.
10. Singh, D., Singh, A., Ganju, A. and Gusain, H. S., Observational study on snow cover characteristics and associated avalanche activity in Drass sector of North-West Himalaya. In Proceedings ISSMA-2004, Manali, 2004, pp. 501–508.
11. Deems, J. S., Birkeland, K. and Hansen, K., Topographic influence on the spatial patterns of snow temperature gradients in a mountain snowpack. In International Snow Science Workshop (ISSW2002), Petincton, B.C., 2002.
12. Birkeland, K. W., Spatial patterns of snow stability throughout a small mountain range. *J. Glaciol.*, 2001, **47**, 176–186.
13. Kronholm, K. and Schweizer, J., Snow stability variation on small slopes. *Cold Reg. Sci. Technol.*, **37**, 2003, 453–465.
14. Landry, C., Birkeland, K., Hansen, K., Borkowski, J., Brown, R. and Aspinall, R., Snow stability on uniform slopes: Implications for avalanche forecasting, In International Snow Science Workshop (ISSW2002), Petincton, B.C., 2002.
15. Kozak, M. C., Elder, K., Birkland, K. and Chapman, P., Variability of snow layer hardness by aspect and prediction using meteorological factors. *Cold Reg. Sci. Technol.*, 2003, **37**, 2003, 357–371.
16. Harper, J. T. and Bradford, J. H., Snow stratigraphy over a uniform depositional surface: spatial variability and measurements tools. *Cold Reg. Sci. Technol.*, 2003, **37**, 289–298.
17. Birkeland, K., Kronholm, K. and Logan, S., A comparison of the spatial structure of the penetration resistance of snow layers in two different snow climates. In Proceedings ISSMA-2004, Manali, 2004, pp. 3–11.
18. Neumann, N. N., Derksen, C. and Goodison, B. E., Relationships between point snow depth measurement and snow distribution at the landscape level in the Southern Boreal Forest of Saskatchewan. In 61st Eastern Snow Conference, Portland, USA, 2004, pp. 103–106.
19. Satyawali, P. K., Srivastava, P. K., Parminder, Kaur, Sethi, D. N. and Praveen Kumar, Snowpack profiling using high resolution snowmicropen. In Proceedings ISSMA-2004, Manali, 2004, pp. 21–28.
20. Spiegel, R., Murray and Boxer, R. W., *Theory and Problems of Statistics*, McGraw-Hill, Singapore, 1981.

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