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Winter temperature and snowfall trends in the cryospheric region of north-west Himalaya

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सार – इस शोध पत्र का उद्देश्य शरद ऋतु के दौरान पश्चिमोत्तर हिमालय के क्रिसोफेयर क्षेत्र में तापमान और बर्फ गिरने की प्रवृत्तियों का पता लगाना है। इस अध्ययन के लिए पश्चिमोत्तर हिमालय के उन 37 प्रेक्षण केंद्रों को लिया गया है जिन स्टेशनों पर शरद ऋतु के दौरान बर्फ बारी हुई है। वर्ष 1970 से 2011 की अवधि में बर्फीले मौसमी प्राचलों अधिकतम तापमान, न्यूनतम तापमान तथा बर्फ गिरने के आँकड़े एक प्रेक्षण केंद्र से दूसरे प्रेक्षण केंद्रों पर अलग-अलग पाए गए हैं। इन प्राचलों की प्रवृतियों का शरद ऋतु के दौरान मासिक एवं ऋतुनिष्ठ स्तर पर अध्ययन किया गया है। प्रवृत्ति विश्लेषण के लिए रैखिक समाश्रयण विश्लेषण पद्धति का उपयोग किया गया है । इसमें समाश्रयण गुणांक के महत्व की जांच करने के लिए पैरामीट्रिक *t* - टेस्ट का उपयोग किया गया है । मौसम विज्ञानीक प्राचलों पर ऊँचाई के प्रभाव को देखा गया है। ऐसा पाया गया है कि 4000 मी. औसत समुद्र तल से कम ऊँचाई वाले 75 प्रतिशत से अधिक प्रेक्षण केंद्रों पर शरद ऋतु के दौरान अधिकतम तापमान और न्यूनतम तापमान में वृद्धि की प्रवृति है जिसमें से लगभग 25 प्रतिशत स्टेशनों के आँकड़ों की प्रवृति काफी महत्वपूर्ण है। 4000 मी. से अधिक ऊँचाई वाले अधिकांश प्रेक्षण केंद्रों पर अधिकतम और न्यूनतम तापमान में गिरावट की प्रवृति का पता चला है। 4000 मी. से कम ऊँचाई वाले अधिकांश प्रेक्षण केंद्रों पर बर्फ गिरने की घटना में गिरावट की प्रवृति प्रेक्षित की गई है जिसमें से लगभग 20 प्रतिशत स्टेशनों के आँकड़ों की प्रवृति काफी महत्वपूर्ण है। 4000 मी. की ऊँचाई वाले स्टेशनों पर मार्च और अप्रैल के महीनों में बर्फ गिरने की घटनाओं में काफी गिरावट का रूख देखा गया है।

ABSTRACT. The aim of the present study is to investigate the temperature and snowfall trends in the cryosphere region of north-west Himalaya during winter season. 37 observation stations of North-West Himalaya have been considered for the study and these stations receive snowfall during winter season. The snow meteorological data period of the parameters maximum temperature, minimum temperature and snowfall varied from one observation station to other observation station between 1970 to 2011. Monthly and seasonal trends of these parameters during winter have been studied. Linear regression analysis was used for trend analysis. Parametric *t*-test was used to test the significance of the regression coefficient. Altitude effect in the trends of the meteorological parameters has been noticed. It was observed that more than 75% of the observation stations in the altitude range < 4000 m a.s.l. showed increasing trend in maximum temperature and minimum temperature during winter season, out of which around 25% trends were statistically significant. Most of the observation stations in the altitude range > 4000 m showed decreasing trend of maximum and minimum temperature. Decreasing snowfall trend was observed at most of the stations in the altitude range < 4000 m out of which around 20% trends were statistically significant. Significant decrease in snowfall was observed for the months March and April below 4000 m altitude.

Key words – Maximum temperature, Minimum temperature, Northwest Himalaya.

1. Introduction

Many researchers are focused on the study of climate change and global warming all over the world (IPCC, 2001 & 2007). The effects of the climate change are in the form of raising temperature that is leading to the faster melting of glaciers and simultaneously raising the sea levels (IPCC, 2007). In addition to the global effects, various studies have been carried out to observe the regional effects of global warming and climate change in Indian sub-continent (Dash and Hunt, 2007; Dash *et al.*, 2007; Yadav *et al.*, 2004; Shekhar *et al.*, 2010, Kulkarni, 2007; Bhutiyani *et al*., 2009, Bolch *et al.*, 2012). Studies have been carried out on decadal trends in climate and climate of different parts in India (Pant and Borgaonkar, 1984; Srivastava *et al.*, 1992; Thapliyal and Kulshrestha, 1991). The topography of India varies from north to south and from east to west. The great Himalaya in the north plays a very crucial role in maintaining the climate of India as well as that of the Indian sub-continent.

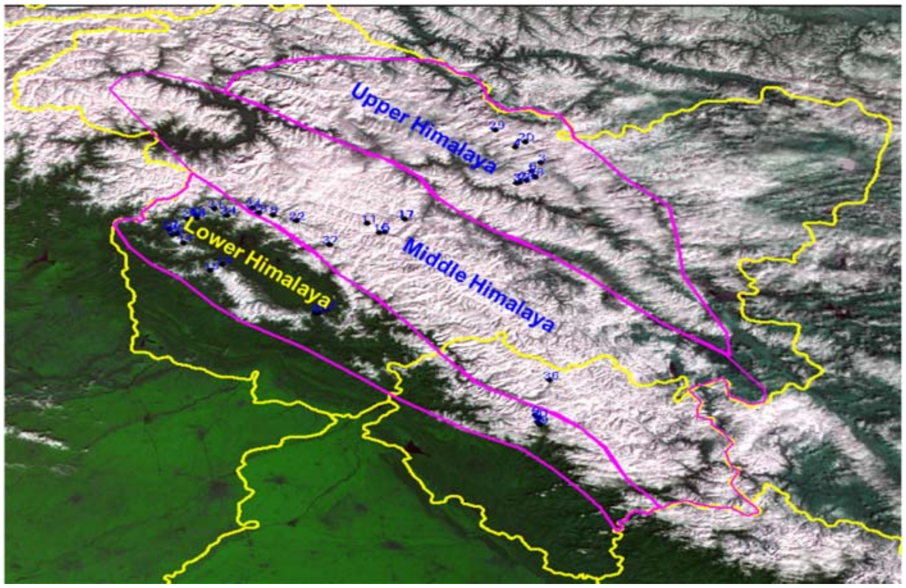

Fig. 1. Indian western Himalaya and data observation stations in different Himalayan ranges

Moreover the Himalaya is the main warehouse of water in the form of glaciers. The excessive melting of these glaciers due to global warming may cause serious scarcity of water in future (Bolch *et al.*, 2012).

Researchers in the past (Bhutiyani *et al.*, 2007; Bhutiyani *et al.*, 2009; Dimri *et al.*, 2007; Shekhar *et al.*, 2010) have reported on climate change, precipitation and temperature variations in the north-west Himalaya. Dimri *et al*. (2007) presented analysis on wintertime climatic extreme over the western Himalayas. Bhutiyani *et al*. (2007, 2009) presented analysis of 10 observation stations data of north-west Himalaya, out of which three stations Srinagar, Shimla and Leh have data for more than 90 years. Shekhar *et al*. (2010) presented temperature and snowfall trends of different Himalayan ranges using data of 18 observation stations. In the present study temperature and snowfall trends of 37 observation stations of north-west Himalaya are presented during winter season. All the stations were categorised into three altitude ranges:

1. Observation stations with altitude < 3000 m (14 stations)

2. Observation stations with altitude range 3000-4000 m (12 stations)

3. Observation stations with > 4000 m altitude (11 stations)

The aim of the present study is to present an analysis of the temperature and snowfall trends of the Himalayan observation stations by including the data of 37 observation stations at different altitude ranges. 9 observation stations are in Pir Panjal range, 9 in Shamshabari range, 9 in Great Himalaya range, 9 in Karakoram range and 1 in Laddakh range. Generally in the mountain region climatic variations are found at small distances due to uneven topographic conditions. In addition to this, the sensitivity to the climate change increases as the elevation increases. The paper also highlights the altitude effect in the snowfall and temperature trends in western Himalaya.

2. Data and methodology

Fig. 1 shows the cryospheric region of Indian western Himalaya and data obervation stations in different Himalayan ranges. Table 1 gives the details of these observation stations, *e.g.*, name, altitude, Himalayan range etc. Maximum temperature, minimum temperature and snowfall data are taken for the analysis. Maximum temperature and minimum temperature are recorded at the observation station daily using precision maximum thermometer and minimum thermometer. The snowfall data recorded at every three hours during snowfall period. The monthly averages were calculated from the daily data by taking the average for the whole month. The daily snowfall was added for the whole month to get the monthly total snowfall. November, December, January, February, March and April months together constitute as winter season. Seasonal average was calculated by taking average of daily data for the complete winter season. Total seasonal snowfall was calculated by adding total snowfall

TABLE 1

Observation stations in different Himalayan ranges and their altitude (Stations with altitude < 3000 m marked as * are 14, stations with altitude 3000-4000 m marked with ** are 12 and stations with altitude > 4000 m marked with * are 11)**

Station number	Station name	Altitude (m)	Range	Zone
1	Bahadur	5450***	Karakoram	Upper Himalaya
2	Bahang	2192*	Pir Panjal	Lower Himalaya
3	Base Camp	3300**	Karakoram	Upper Himalaya
4	Billa	5215***	Karakoram	Upper Himalaya
5	Bimbat	4950***	Great Himalaya	Middle Himalaya
6	Chandan	5320***	Karakoram	Upper Himalaya
7	D-10	3250**	Pir Panjal	Lower Himalaya
8	Dawar	2414*	Great Himalaya	Middle Himalaya
9	Dhundi	3050**	Pir Panjal	Lower Himalaya
10	Drass	3250**	Great Himalaya	Middle Himalaya
11	Firm Base	4760***	Great Himalaya	Middle Himalaya
12	Gugaldhar	3360**	Shamshawari	Lower Himalaya
13	Gulmarg	2800*	Pir Panjal	Lower Himalaya
14	Haddan	3080**	Shamshwari	Lower Himalaya
15	Himmat	3697**	Pir Panjal	Lower Himalaya
16	Jwala	5440***	Karakoram	Upper Himalaya
17	Kaksar	2960*	Great Himalaya	Middle Himalaya
18	Kanzalwan	2440*	Great Himalaya	Middle Himalaya
19	Kothi	2527*	Pir Panjal	Lower Himalaya
20	Kumar	5000***	Karakoram	Upper Himalaya
21	N C Pass	3128**	Shamshawari	Lower Himalaya
22	Niru	2630*	Great Himalaya	Middle Himalaya
23	North Portal	2210*	Pir Panjal	Lower Himalaya
24	Pant	4040***	Great Himalaya	Middle Himalaya
25	Pharkiyan	2960*	Shamshawari	Lower Himalaya
26	Patsio	3800**	Great Himalaya	Middle Himalaya
27	Puttakhan	2972*	Shamshawari	Lower Himalaya
28	Ragini	3160**	Shamshawari	Lower Himalaya
29	Rewari	5040***	Karakoram	Upper Himalaya
30	Siala	5995***	Karakoram	Upper Himalaya
31	Solang	2480*	Pir Panjal	Lower Himalaya
32	Sonamarg	2745*	Pir Panjal	Lower Himalaya
33	Sonapindi	3180**	Shamshawari	Lower Himalaya
34	Stage II	2650*	Shamshawari	Lower Himalaya
35	Verinag	1900*	Pi Panjal	Lower Himalaya
36	Z-Gali	3192**	Shamshawari	Lower Himalaya
37	Zullu	5600***	Karakoram	Upper Himalaya

TABLE 2

Trends of seasonal average of maximum temperature

Altitude Range	Number of stations	Increasing trend	Statistically significant	Decreasing trend	Statistically significant
< 3000 m	14	11	4	3	0
3000 - 4000 m	12	10	4	2	0
> 4000 m	11	5	0	6	0

TABLE 3

Trends of seasonal average of minimum temperature

Altitude Range	Number of stations	Increasing trend	Statistically significant	Decreasing trend	Statistically significant
< 3000 m	14	11	5	3	0
3000 – 4000 m	12	9	6	3	0
> 4000 m	11	2	0	9	2

during the season. Graphs were plotted for the seasonal and monthly data of maximum temperature, minimum temperature and snowfall of all the 37 observation stations. Linear trend in the graph was deduced using least square technique during the data period. Figs. (2-4) show the seasonal trend of maximum temperature, minimum temperature and snowfall for the station 'Bahang' of Pir Panjal range in the lower Himalaya. The trend was analysed for the statistical significance using parametric *t*-test. In parametric analysis, a linear regression equation was obtained by least square method for the given data. In our study the 'parameter of study' is the dependent variable and the 'number of months/seasons' is the independent variable for monthly/seasonal analysis. The slope of the regression line gives the rate of change of dependent variable for unit change in independent variable. Parametric *t*-test was applied to test the significance of the regression coefficient. The hypothesis tested was

H_0 : Population regression coefficient is non-significant, *i.e.*, there is no significant trend in the data.

and the alternate hypothesis was

H_1 : Population regression coefficient is significant, *i.e.*, there is a significant trend in the data.

The test statistic were used as below:

$$t\,cal = \frac{(b-\beta)\sqrt{Sxx}}{\sqrt{[Syy - b^2 * Sxx)/(n-2)]}} \qquad (1)$$

where, *x* is the independent variable, *y* is the dependent variable.

Sxx = Variance (*x*), *Syy* = Variance (*y*)

b = Sample regression coefficient,

β = Population regression coefficient.

n = Total no. of observations.

The parametric test was done under 95% confidence limits.

3. Results and discussion

Table 2 shows the trends of seasonal average of maximum temperature. In the altitude range below 3000 m a.s.l., 14 stations data were available for analysis. Out of 14, 11 stations (more than 75%) showed increasing trend while 3 stations showed decreasing trend of maximum temperature. Out of 11, 4 stations showed statistically significant increasing trend. None of the stations showed statistically significant decreasing trend. In the 3000-4000 m altitude range out of 12 stations 10 (more than 80%) showed increasing trend while 2 showed decreasing trend of maximum temperature. Out of 10, 4 stations (25%) showed statistically significant increasing trend while none of the stations showed statistically significant decreasing trend. In the altitude range above 4000 m, 11 stations data were available for the analysis. Out of 11, 6 stations (~ 55%) showed decreasing and 5 stations showed (~ 45%) increasing trend in maximum temperature. Although none of the stations showed statistically significant trend.

Table 3 shows the trends of seasonal average of minimum temperature. In the altitude range below 3000 m a.s.l., out of 14 stations, 11 stations (more than 75%) showed increasing trend while 3 stations showed decreasing trend of minimum temperature. Out of 11 increasing trends, 5 (45%) were statistically significant. None of the stations showed statistically significant decreasing trend. In the 3000-4000 m altitude range, out of 12 stations 9 (75%) stations showed increasing while 3 stations showed decreasing trend of minimum temperature. Out of 9 increasing trends, 6 (66%) were statistically significant increasing trends while none of the

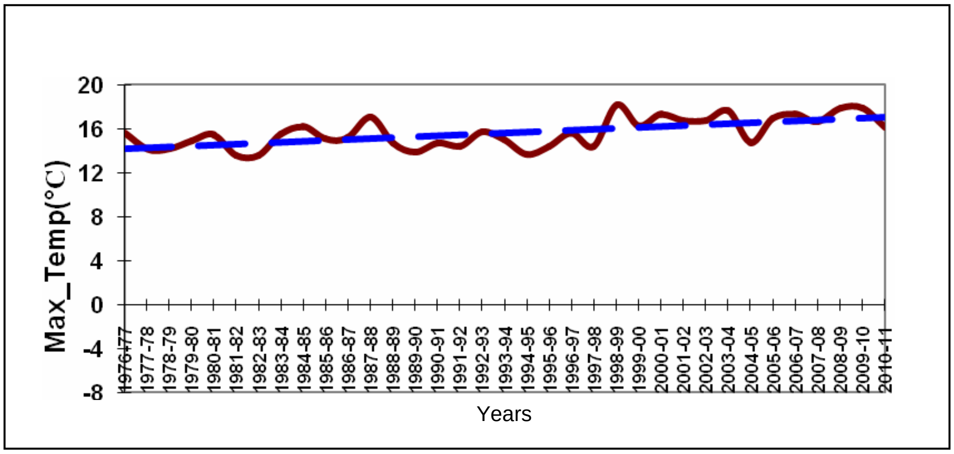

Fig. 2. Seasonal trend of maximum temperature of the observation station 'Bahang'. Increasing trend of 0.83 °C/decade observed. Trend is statistically significant

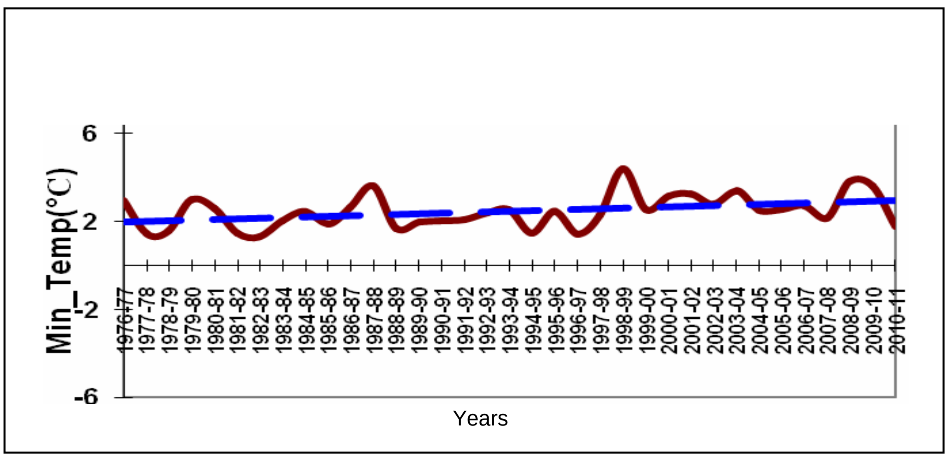

Fig. 3. Seasonal trend of minimum temperature of the observation station 'Bahang'. Increasing trend of 0.28 °C/decade observed. Trend is statistically significant

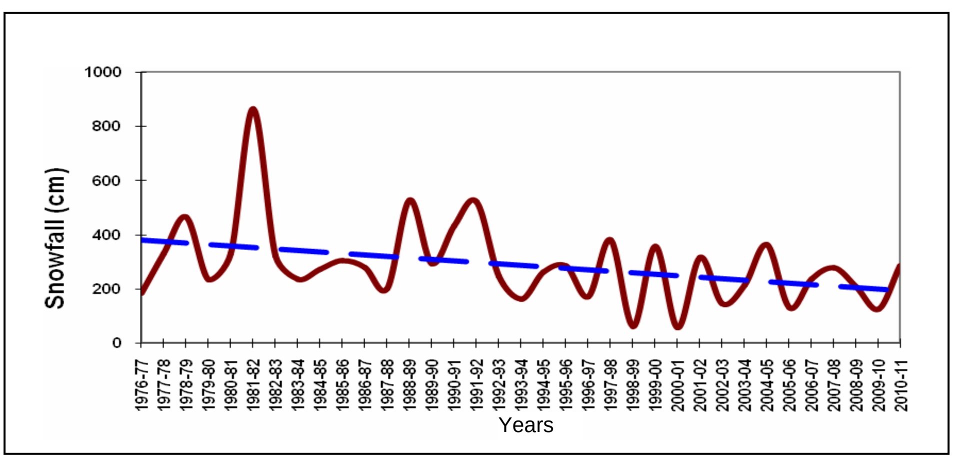

Fig. 4. Seasonal trend of snowfall of the observation station 'Bahang'. Decreasing trend of 64.4 cm/decade observed. Trend is statistically significant

TABLE 4

Trends of total seasonal snowfall

Altitude Range	Number of stations	Increasing trend	Statistically significant	Decreasing trend	Statistically significant
< 3000 m	14	4	1	10	2
3000 – 4000 m	12	3	0	9	2
> 4000 m	11	5	1	6	2

stations showed statistically significant decreasing trend. In the altitude range above 4000 m, the trends are different from the stations of below 4000 m altitude range. In this altitude range, out of 11 stations, 9 stations showed decreasing while 2 stations showed increasing trend. Out of 9 decreasing trends, 2 were statistically significant while none of the station showed statistically significant increasing trend.

Table 4 shows the trends of seasonal snowfall. In the altitude range below 3000 m a.s.l., out of 14 stations, 10 stations (more than 70%) showed decreasing trend while 4 stations showed increasing trend of seasonal snowfall. Out of 10 decreasing trends, 2 were statistically significant decreasing trends while out of 4 increasing trends, 1 was statistically significant increasing trend. In the 3000-4000 m altitude range out of 12 stations, 9 (75%) showed decreasing while 3 showed increasing trend of seasonal snowfall. Out of 9 decreasing trends, 2 were statistically significant while none of the station showed statistically significant increasing trend. In the altitude range above 4000 m, the trend of seasonal snowfall was not very clear and out of 11 stations, 6 stations (55%) showed decreasing trend while 5 stations (45%) showed increasing trend of seasonal snowfall. 2 stations showed statistically significant decreasing trend while 1 station showed statistically significant increasing trend.

Tables (5-7) show monthly trends of maximum temperature, minimum temperature and snowfall during winter months of the observation stations in the altitude range below 3000 m, 3000-4000 m and above 4000 m respectively. '+' sign in the table shows increasing trend while '-' sign shows the decreasing trend. Number in the table represents the number of stations showing increasing or decreasing trends. In the altitude range below 3000 m a.s.l., most of the stations showed increasing trend of maximum temperature and minimum temperature for all the months except January. More than 70% stations showed increasing trend of maximum temperature during the months November, February, March, April and increasing trend of minimum temperature during the months February and April. In the altitude range 3000-4000 m a.s.l., most of the stations showed increasing trend of maximum temperature during the months November, January, February, March, April, and increasing trend of minimum temperatures during the months February, March and April. More than 90% stations showed decreasing trend of snowfall during the months March and April in the altitude range below 4000 m a.s.l. In the altitude range above 4000 m, most of the stations showed increasing trend of maximum temperature during November, February, March and decreasing trend of maximum temperature during December, January and April. An important fact was noticed that in this altitude range, most of the stations showed decreasing minimum temperature for all the winter months. Most of the stations showed increasing trend of snowfall during the months November, January, February and decreasing trend of snowfall during the months December, March and April. However all the stations showed decreasing snowfall trend during the month of March.

In the monthly analysis although majority of stations showed increasing trends of maximum and minimum temperature and decreasing trend of snowfall during different months in the altitude range below 4000 m, but there are sufficient reverse trends also. Temperature and snowfall trend at a particular station depends on number of factors, *e.g.*, number of cloudy days, cloud amount and type, sun shine hour, frequency of western disturbance, precipitation amount, number of days snow covered exists at the station etc. During different months the distribution and variability of these parameters are very high and that may be the reason for high variability in temperature and snowfall trends during different months. In the seasonal analysis the results are more consistent. In the altitude range below 4000 m a.s.l., out of 26 stations 21 stations showed increasing trend of maximum temperature, 20 stations showed increasing trend of minimum temperature and 19 stations showed decreasing trend of snowfall. More than 40% increasing temperature trends and more than 20% decreasing snowfall trends are statistically significant. A reverse trend was shown by the observation stations at altitude range above 4000 m a.s.l., where most of the stations showed decreasing trend of maximum and minimum temperature. In a previous work, Shekhar *et al.* (2010) had shown that stations in Karakoram range of western Himalaya, had shown decreasing trend of temperature, while Pir Panjal, Shamshabari and Great Himalaya range had shown increasing trend of temperature. Results of this paper are broadly in agreement with the results of Shekhar *et al.* (2010) as most of the stations in the altitude range below 4000 m are showing increasing temperature trends and stations above

TABLE 5

Monthly trends of stations below 3000 m a.s.l. altitude (Total number of 14 stations, + sign in first row indicate the number of stations with increasing trend, - sign in second row indicate the number of stations with decreasing trend)

November			December			January			February			March			April		
Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall
+12	+9	+5	+9	+6	+7	+7	+6	+8	+12	+14	+8	+10	+8	+1	+13	+12	+1
-2	-5	-9	-5	-8	-7	-7	-8	-6	-2	0	-6	-4	-6	-13	-1	-2	-13

TABLE 6

Monthly trends of stations in 3000 m – 4000 m a.s.l. altitude (Total number of 12 stations, + sign in first row indicate the number of stations with increasing trend, - sign in second row indicate the number of stations with decreasing trend)

November			December			January			February			March			April		
Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall
+9	+6	+5	+5	+3	+6	+10	+6	+8	+10	+9	+7	+11	+10	+1	+11	+10	+2
-3	-6	-7	-7	-9	-6	-2	-6	-4	-2	-3	-5	-1	-2	-11	-1	-2	-10

TABLE 7

Monthly trends of stations above 4000 m a.s.l. altitude (Total number of 11 stations, + sign in first row indicate the number of stations with increasing trend, - sign in second row indicate the number of stations with decreasing trend)

November			December			January			February			March			April		
Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall	Max. Temp.	Min. Temp.	Snow fall
+8	+5	+7	+3	+2	+3	+3	+2	+7	+6	+4	+7	+6	+3	0	+4	+4	+4
-3	-6	-4	-8	-9	-8	-8	-9	-4	-5	-7	-5	-5	-8	-11	-7	-7	-7

4000 m altitude range are showing decreasing temperature trends. But here we would like to highlight that stations below 4000 m altitude in Karakoram range (*e.g.*, Base Camp) also showed increasing trend of maximum and minimum temperature and decreasing trend of snow fall. Similarly, stations above 4000 m altitude in other than karakoram ranges (*e.g.*, Firm Base, Pant) also showed decreasing trends of temperature. These facts indicate that temperature trends in western Himalaya are also influenced by the altitude of the station apart from the Himalayan ranges. Although some of the stations also showed decreasing trend of seasonal mean maximum and minimum temperature in the altitude range below 4000 m a.s.l., but such stations are very small in numbers and these trends are not statistically significant.

Rate of increasing or decreasing trend of temperature and snowfall also varied from one station to other and ranges from 0.1 ºC/decade to 2.5 ºC/decade during winter season. This requires future investigation on to how the local topography play a role in varying rate of increasing or decreasing trend among the observation stations within the same Himalayan range. We also conclude that researchers should be careful while deducing the results about the Himalayan ranges on the basis of one or two observation stations in a range as the results may be misleading or may not represent the results for the entire range.

4. Conclusion

Analysis of temperature and snowfall trends of 37 observation stations in the cryosphere region of north-west Himalaya have been presented. The snow meteorological data period of the stations varied from 12 years to 37 years. All the stations were categorised into three altitude zones, *i.e.*, below 3000 m, between 3000-4000 m and above 4000 m. More than 75% of the stations in the altitude range below 4000 m shown increasing trend of maximum temperature and minimum temperature. While, most of the observation stations in the altitude range above 4000 m showed decreasing trend of maximum and minimum temperature. In the altitude range, below 4000 m most of the stations showed decreasing trend of snowfall out of which more than 20% trends were statistically significant. No clear trend was observed in the snowfall in the altitude range above 4000 m as some stations showed increasing and some stations showed decreasing trend. An important fact was noticed that most of the stations showed decreasing snowfall trend during the months of March and April in all altitude ranges, though, we have not analysed the rainfall trends. Varying rate of increase or decrease in the snowfall and temperature were observed among the observation stations and ranges from 0.1 °C/decade to 2.5 °C/decade. It has been noticed that temperature and snowfall trends were also influenced by the altitude apart from the Himalayan ranges.

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References

Bhutiyani, M. R., Kale, V. S. and Pawar, N. J., 2007, "Long-term trends in maximum, minimum and mean annual air temperatures across the northwestern Himalaya during the 20th century", *Climate Change*, **85**, 159-177.

Bhutiyani, M. R., Kale, V. S. and Pawar, N. J., 2009, "Climate change and the precipitation variations in the northwestern Himalaya: 1866-2006", *Int. J. Climatol*. **29,** 000-000 (2009) DOI: 10.1002/joc.

Bolch, T., Kulkarni, A., Kaab, A., Huggel, C., Paul, F., Cogley, J. G., Frey, H., Kargel, J. S., Fujita, K., Scheel, M., Bajracharya, S. and Stoffel, M., 2012, "The State and Fate of Himalayan Glaciers", *Science*, **336**, 310-314.

Dash S. K. and Hunt, J. C. R., 2007, "Variability of climate change in India", *Current Science*, **93**, 6, 782-788.

Dash, S. K., Jenamani, R. K., Kalsi, S. R. and Panda, S. K., 2007, "Some evidence of climate change in twentieth-century India", *Climate Change*, DOI 10.1007/s10584-007-9305-9.

Dimri, A. P., Sarwade, R. N. and Kumar, A., 2007, "Wintertime Climatic Extreme Analysis over the Western Himalayas", *Technical Report* (R-273), Snow and Avalanche Study Establishment, Him Parisar, Sector 37A, Chandigarh, India.

IPCC, 2001, "Climate Change : The IPCC Third Assessment Report, Vol. I, the scientific basis, II - Impacts, Adaptation and Vulnerability, III - Mitigation", Cambridge University Press: Cambridge and New York.

IPCC, 2007, "Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability, Working Group II Contribution to the Intergovernmental Panel on Climate Change - Fourth Assessment Report Summary for Policymakers", Cambridge University Press: Cambridge and New York.

Kulkarni, A. V., 2007, "Effect of global warming on the Himalayan cryosphere", *Jalvigyan Sameeksha*, **22**, 93-108.

Pant, G. B. and Borgaonkar, H. P., 1984, "Climate of the hill regions of Uttar Pradesh", *Himalayan Research and Development* **3**, 13-20.

Shekhar, M., Chand, H., Kumar, S., Srinivasan, K. and Ganju, A., 2010, "Climate change studies over western Himalayan region", *Ann. Glaciol.* **51**, p105.

Srivastava, H. N., Dewan, B. N., Dikshit, S. K., Prakash Rao, G. S., Singh, S. S. and Rao, K. R., 1992, "Decadel trends in climate over India", *Mausam*, **43**, 7-20.

Thapliyal, V. and Kulshrestha, S. M., 1991, "Decadal changes and trends over India", *Mausam*, **42**, 333-338.

Yadav, R. R., Won-Kyu, Park, Singh, J. and Dubey, B., 2004, "Do the western Himalaya defy global warming?", *Geophysical Research Letters*, **31**, L17201.