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Climatic change and variability in mid-Himalayan region of India

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सार - मध्य-हिमालयी क्षेत्र में जलवायु परिवर्तन एवं विविधता को समझने के लिए, हिमाचल प्रदेश के पालमपुर, बजुआरा, धौलाकुआँ, शिमला एवं सलूनी तथा उत्तराखंड़ के रानीचौरी के अधिकतम व न्यूनतम तापमानों एवं वर्षा के 22 से 28 वर्षों के आँकड़ों का विश्लेषण किया गया। चार स्थानों पर वार्षिक अधिकतम तापमान में (0.5 से 1.1º सेंटीग्रेड प्रति दशक) महत्वपूर्ण उच्च सकारात्मक प्रवृत्ति, रानीचौरी में वार्षिक न्यूनतम तापमान में (-0.4º सेंटीग्रेड प्रति दशक) महत्वपूर्ण रूप से नकारात्मक प्रवृत्ति एवं शिमला में (22 मि.मी. प्रति वर्ष) वर्षा की उच्च वृद्धि की महत्वपूर्ण प्रवृत्ति देखी गई। रानीचौरी को छोड़कर सभी स्थानों में गर्मी में अधिकतम तापमान ने महत्वपूर्ण वृद्धि की प्रवृत्ति दर्शाई। शिमला के सभी स्थानों में अधिकतम तापमान में महत्वपूर्ण वृद्धि हुई । रबी मौसम के दौरान पालमपुर, बजुआरा एवं शिमला के अधिकतम तापमान में महत्वपूर्ण वृद्धि की प्रवृत्ति एवं बजुआरा एवं धौलाकुआँ में वर्षा में महत्वपूर्ण रूप से घटती प्रवृत्ति देखी गई। मार्च में अधिकतम एवं न्यूनतम तापमानों ने अधिकतर स्थानों में दशक दर दशक महत्वपूर्ण वृद्धि दर्ज की । सभी स्थानों पर, पिछले तीन दशकों से तापमान या वर्षा संबंधी तीव्र घटनाओं में न तो तगातार वृद्धि और न ही कमी आई है । जबकि पूर्व समय मान की तुलना में वर्तमान समय मान के दौरान पालमपुर में एक महीने पहले औसत तापमान अधिकतम तक पहुँचा। रानीचौरी, बजुआरा एवं धौलाकुआँ में एक महीने पहले तथा शिमला में एक महीने बाद अत्यधिक वर्षा हुई। इस प्रकार की जलवायु प्रवृत्तियों या विविधताओं से रबी फसलों पर प्रतिकूल एवं खरीफ फसलों पर अनुकूल प्रभाव पड़ सकता है ।

ABSTRACT. To understand the climatic changes and variability in mid-Himalayan region, 22 to 28 years data on maximum and minimum temperatures and rainfall of Palampur, Bajaura, Dhaulakuan, Shimla and Salooni of Himachal Pradesh and Ranichauri of Uttarakhand were analysed. Highly significant positive trend (0.5 to 1.1 °C/decade) in annual maximum temperature at four locations, significant negative trend (-0.4 °C/decade) in annual minimum temperature at Ranichauri and highly significant increasing trend of rainfall (22 mm/year) at Shimla was observed. Maximum temperature in summer showed significant increasing trend at all the locations except Ranichauri. Maximum temperature showed significant increase in all the seasons at Shimla. During *Rabi* season, significant increasing trend in maximum temperature at Palampur, Bajaura and Shimla and significant decreasing trend in rainfall at Bajaura and Dhaulakuan was noticed. Both maximum and minimum temperatures in March registered significant increase decade after decade at most of the locations. At all the locations, temperature or rainfall related extreme events have not significantly increased or decreased continuously for the past three decades. Though peak of average temperature occurred one month earlier at Palampur, peak of rainfall occurred one month earlier at Ranichauri, Bajaura and Dhaulakuan and one month later at Shimla during the present time scale compared to the previous time scale. These climatic trends or variability may adversely affect the *Rabi* crops and positively affect the *K*harif crops.

Key words – Climatic change, Himalayan region, Maximum and minimum temperatures, Rainfall, Annual and seasonal trends, Extreme events, Shifts in weather.

1. Introduction

Increased concentration of carbon dioxide (CO_2) and other trace gases in the atmosphere, over the last century due to rapid industrialization and population growth resulted in global warming. The Intergovernmental Panel on Climate Change (IPCC) reported that the Earth's average surface temperature increased by 0.6 ± 0.2 °C in

the 20th century and is projected to rise further by 1.4 to 5.8 °C by the end of 21st century (IPCC, 2001). Evidence of climate change in Himalayas as in other parts of the world was reported (Yao *et al*., 2006; Sharma *et al*., 2009; Pathak *et al*., 2010). The Himalayas extending 3000 km in length and covering nearly 750,000 sq km of northern Pakistan, Nepal, Bhutan and North-western and north-eastern states of India is a source of eight major rivers of Asia and is known as "water tower of Asia" (IPCC, 2007; Xu *et al*., 2009). The climate change in Himalayan region is a matter of global concern in view of its unique biological diversity and its rivers and tributaries sustaining about 1.4 billion people. The Himalayan region is one of the most complex mountain systems in the world and is extremely vulnerable to global warming (Bandyopadhyay and Gyawali, 1994).

Limited studies on temperature or precipitation at few places in Himalayan region showed three times higher warming than the global average (Xu *et al*., 2009; Shrestha *et al*., 2012). Some other studies also showed much higher warming in the Himalayas than the global level warming during the last hundred years (Du *et al*., 2004 and IPCC, 2007). Though Himalayas are vulnerable to climate change (Xu *et al*., 2009) and undergoing rapid environmental change (Bawa *et al*., 2010), there is no systematic analysis of climate change in this region (Sharma *et al*., 2009; Shrestha *et al*., 2012). First and foremost research gap identified by Sharma *et al*. (2009) is the lack of knowledge on rate of climate change at regional and local levels. Lack of daily weather data for more number of years and locations in the region is the main constraint for assessment of climate change and related extreme climatic events. Few available climatic change studies in this region were only based on monthly average weather parameters at limited number of stations or grid points.

Main objective of this study is to analyse long-term daily data on temperature and rainfall of six locations varying in latitude and altitude for understanding the differences in climatic changes and climatic extremes taking places in these places.

2. Data and methodology

2.1. *Description of locations of the study*

Six locations, Palampur, Bajaura, Dhaulakuan, Shimla and Salooni of Himachal Pradesh and Ranichauri of Uttarakhand located in Mid-Himalayan region were selected for the study. The latitude, longitude and altitude of all the six locations, along with their climatic types are mentioned in tabular form.

Location	*Latitude*	*Longitude*	*Altitude*	*Climate type*
Palampur	32°10' N	76°54' E	1291 m	Sub humid temperate wet
Ranichauri	30°87' N	78°03' E	1600 m	Warm humid to per-humid
Bajaura	31°84' N	77°16' E	1090 m	Sub humid temperate dry
Dhaulakuan	30°56' N	77°30' E	468 m	Sub tropical
Shimla	31°10' N	77°17' E	2398 m	Sub humid temperate dry
Salooni	32°72' N	76°04' E	1764 m	Sub humid temperate dry

Out of these six locations, Palampur receives highest mean annual rainfall of 2596 mm in 89 rainy days and Bajaura receives lowest mean annual rainfall of 942 mm in 67 rainy days. Rest of the four locations *viz*., Salooni, Dhaulakuan, Shimla and Ranichauri receives 1866, 1609, 1295 and 1245 mm of rainfall, respectively in 67, 64, 77 and 72 days. At Palampur, daily averaged maximum temperature varies from 14.2 °C (3rd week of January) to 31.1 °C (1st week of June), while daily averaged minimum temperature varies from 4.5 °C (3rd week of January) to 20.3 °C (1st week of July). At Ranichauri, daily averaged maximum temperature varies from 10.9 °C (2nd week of January) to 26.2 °C (3rd week of May), while daily averaged minimum temperature varies from 2.2 °C (2nd week of January) to 17.1 °C (last week of July). At Bajaura, daily averaged maximum temperature varies from 15.2 °C (3rd week of January) to 32.4 °C (3rd week of June) and daily averaged minimum temperature varies from 0.4 °C (last week of December) to 21.2 °C (last week of July). At Dhaulakuan, lowest (19.0 °C) and highest (37.9 °C) maximum temperature are recorded in 1st week of January and last week of May, respectively while lowest (3.7 °C) and highest (24.4 °C) minimum temperature are recorded in last week of December and last week of July, respectively. At Shimla lowest and highest maximum temperature of 11.7 and 26.0 °C, respectively are recorded in 3rd week of January and last week of May while lowest (3.4 °C) and highest (16.8 °C) minimum temperature are recorded in 2nd week of January and last week of June, respectively. At Salooni, maximum temperature ranged from 16.0 °C (2nd week of February) to 26.6 °C (3rd week of September) while minimum temperature ranged from 7.0 °C (2nd week of February) to 14.9 °C (3rd week of September).

2.2. *Data collected*

Daily maximum temperature, minimum temperature and rainfall data of six locations, *viz*., Palampur, Bajaura, Ranichauri, Dhaulakuan, Shimla and Salooni for the years 1985-2012, 1986-2012, 1985-2012, 1987-2012, 1985-

2012 and 1991-2012, respectively were used for the study. These data were collected from the Agromet data bank of the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad.

2.3. *Calculation of means*

Annual means of weather parameters (maximum and minimum temperatures and rainfall) were calculated by averaging each weather parameter over 365 days of each year. Similarly, seasonal and monthly means of weather parameters were calculated by averaging weather parameters over the days of respective season or month of each year. The four seasons considered in this paper: summer or pre-monsoon (March-May), southwest monsoon (June-September), post-monsoon or northeast monsoon (October-December) and winter season (January-February) are as per the classification of India Meteorological Department (IMD). The monthly means of weather parameters were further averaged over time periods 1985-94, 1995-2004 and 2005-2012 at Palampur, Ranichauri and Shimla for working out decadal averages at these locations. Decadal averages were calculated by averaging monthly weather parameters over time periods 1986-1995, 1996-2005 and 2006-2012 at Bajaura; 1987-1996, 1997-2006 and 2007-2012 at Dhaulakuan; and 1991-2000 and 2002-2012 at Salooni. Days with rainfall more than or equal to 50, 100 and 200 mm; maximum temperature $\geq$ 30 and 35 °C and minimum temperature $\leq$ 0° were considered as rainfall, maximum temperature and minimum temperature related extreme events, respectively. The decadal averages of these extreme events were also worked out by averaging these events over time periods mentioned above for each location.

2.4. *Analysis of data*

Trends in weather parameters were assessed through simple linear regression between weather parameters (Annual, seasonal and monthly) and the calendar years of the time series. Significance of regressions (or trends) was assessed through *F*-test and P-levels. Student's *t*-test was used to test the significance of difference between decadal means of weather parameters. Descriptive statistics like maximum and minimum limits, arithmetic mean and coefficient of variation in maximum and minimum temperatures and rainfall were worked out for all six locations.

3. Results and discussion

3.1. *Descriptive statistics of weather*

The daily mean maximum temperature and minimum temperature at Dhaulakuan, located at comparatively lower elevation than other locations, are higher than the means of these weather parameters at other locations (Table 1). The mean maximum temperature was lowest (19.7 °C) at Shimla and Ranichauri while the mean minimum temperature was lowest (10.1 °C) at Bajaura and Ranichauri. The daily mean rainfall, however, was lowest at Bajaura and highest at Palampur. The range

TABLE 1

Descriptive statistics of daily weather parameters at six locations

	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
Palampur (1985-2012)			
Highest	38.0	26.6	280.6
Lowest	5.0	-1.0	0.0
Mean	23.7	13.4	5.9
CV (%)	23.2	43.6	284.8
Ranichauri (1985-2012)			
Highest	34.2	21.7	206.9
Lowest	0.4	-4.2	0.0
Mean	19.7	10.1	3.4
CV (%)	27.0	56.0	317.7
Bajaura (1986-2012)			
Highest	39.8	27.7	112.8
Lowest	1.5	-4.6	0.0
Mean	25.4	10.1	2.6
CV (%)	26.5	75.4	302.3
Dhaulakuan (1987-2012)			
Highest	45.5	30.5	293.2
Lowest	4.0	-2.5	0.0
Mean	29.0	14.4	4.4
CV (%)	21.3	54.7	342.4
Shimla (1985-2012)			
Highest	37.8	29.0	177.1
Lowest	1.0	-3.8	0.0
Mean	19.7	11.1	3.5
CV (%)	26.5	48.2	294.8
Salooni (1991-2012)			
Highest	38.5	26.0	375.0
Lowest	0.1	-9.0	0.0
Mean	21.5	10.8	5.2
CV (%)	35.4	59.2	383.0

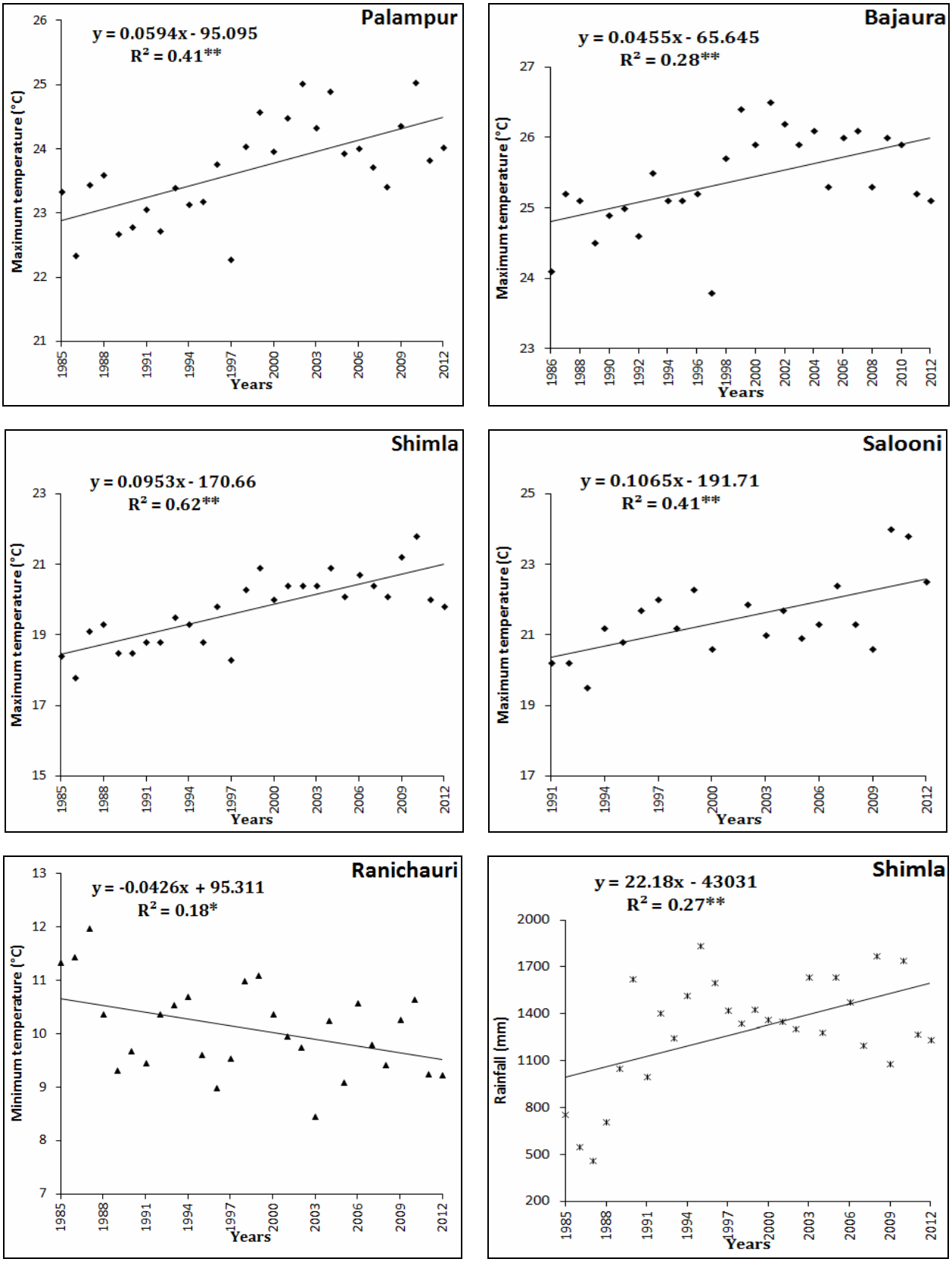

Fig. 1. Trends of mean annual maximum and minimum temperatures and rainfall at six locations

(difference between highest and lowest) of maximum temperature is lowest at Palampur and highest at Dhaulakuan while the range of minimum temperature is lowest at Ranichauri and highest at Salooni. The range of rainfall, however, was lowest at Bajaura and highest at Salooni. At all the locations, daily rainfall was highly variable (CV of 284.8 to 383.1%) over the years followed by minimum temperature and maximum temperature in decreasing order of variability. However, at Shimla, minimum temperature and rainfall are less variable (with lower CV) than at Dhaulakuan. Comparatively lower variability in rainfall and minimum temperature at Shimla of higher altitude than at Dhaulakuan does not agree with Jangra and Singh (2011), in which higher variability in minimum temperature with increase in altitude was reported in nearby Kullu valley of Himachal Pradesh. This type of observation might have been obtained due to factors other than the altitude.

3.2.1. *Trends in mean annual weather parameters*

Trends of mean annual maximum temperature, minimum temperature and rainfall over the last 22-28 years at Palampur, Bajaura, Dhaulakuan, Shimla, Salooni and Ranichauri showed highly significant positive trend in maximum temperature at Palampur, Bajaura, Shimla and Salooni, and significant negative trend in minimum temperature at Ranichauri and highly significant positive trend in rainfall at Shimla (Fig. 1).

The maximum temperature at Salooni showed a highest increasing trend of 1.1 °C/decade, closely followed by the trends at Shimla (1 °C/decade), Palampur (0.6 °C/decade) and Bajaura (0.5 °C/decade) in decreasing order while minimum temperature at Ranichauri showed a decreasing trend of -0.4 °C/decade. The rainfall, however, has not shown any trend at all the locations except Shimla, in line with the earlier observations of no trend in annual rainfall (Pant and Borgaonkar, 1984). Though higher rate of increase of maximum temperature than minimum temperature is contradictory to the global trends, it is in agreement with the observation of higher rate of increase of maximum temperature in Northwestern Himalayas (Bhutiyani *et al*., 2007), central Himalayas (Kattel and Yao, 2013) and in western Himalayas (Islam *et al*., 2008). No significant trend in precipitation in some parts of Himalayan region was also reported earlier (Archer and Fowler, 2004).

3.2.2. *Trends in seasonal weather parameters*

Similar to the trends of mean annual rainfall, seasonal mean rainfall has not shown any significant increasing or decreasing trend in any of the four IMD specified seasons, *viz.*, winter, summer, southwest monsoon and northeast monsoon across all the six locations. The non-significant seasonal rainfall trends are in line with the observations in nearby Kashmir valley (Kumar and Jain, 2010). However, summer rainfall is showing significant ($P \leq 0.05$) decreasing trend at Ranichauri (-3.8 mm/year) and Bajaura (-7.9 mm/year) while rainfall in northeast monsoon season is showing significant decreasing trend of -4.4 and -24.1 mm/year at Ranichauri and Salooni, respectively. Shimla is the only location showing highly significant increasing trend in the rainfall of southwest monsoon season (19.7 mm/year). However, at Shimla maximum temperature in all the seasons showed significant to highly significant ($P \leq 0.05$ to ≤ 0.01) increasing trend of 0.07 to 0.15 °C/year. Similar observation with slight exception was made by Islam *et al*. (2008), in which significant increase in the rate of increase of maximum temperature was reported in all seasons except in southwest monsoon season in western Himalayas from the year 1985 onwards. The significant increasing trend of maximum temperature in summer, ranging from 0.07 to 0.6 °C/year observed at all locations (except Ranichauri) is in agreement with the report of rapid increase of maximum temperature in summer (Islam *et al*., 2008). Three locations, namely Palampur, Salooni and Ranichauri witnessed significant decreasing trend in minimum temperature of -0.03, -0.54 and -0.07 °C/year, respectively during northeast monsoon season. At Salooni, winter is going to be colder with significant negative trend (-0.55 °C/year) in minimum temperature during the season.

3.2.3. *Trends in monthly weather parameters*

At three locations, namely Palampur, Ranichauri and Dhaulakuan rainfall during December month showed significant decreasing trend of -2.3, -2.5 and -2.8 mm/year, respectively. This observation is partially agreeing with the decreasing trend reported by Shrestha *et al*. (2012) during December to February in Himalayan region. Significant increasing trend in maximum temperature of 0.08 to 0.11 °C/year in December and of values 0.08 to 1.0 °C/year in pre-monsoon months (March to May) at three to four locations was observed. However, highly significant increasing trend of maximum temperature in March at four locations *viz*., Palampur (0.15 °C/year), Bajaura (0.21 °C/year), Dhaulakuan (0.13 °C/year) and Shimla (0.18 °C/year) may cause terminal heat stress in winter crops. At Shimla, all the 12 months except January showed significant to highly significant increasing trend of 0.05 to 0.18 °C/year in maximum temperature. However, minimum temperature in most of the post rainy season months (October to December) showed highly significant decreasing trend at both Salooni (-0.19 to -0.82 °C/year) and Ranichauri (-0.05 to -0.08 °C/year).

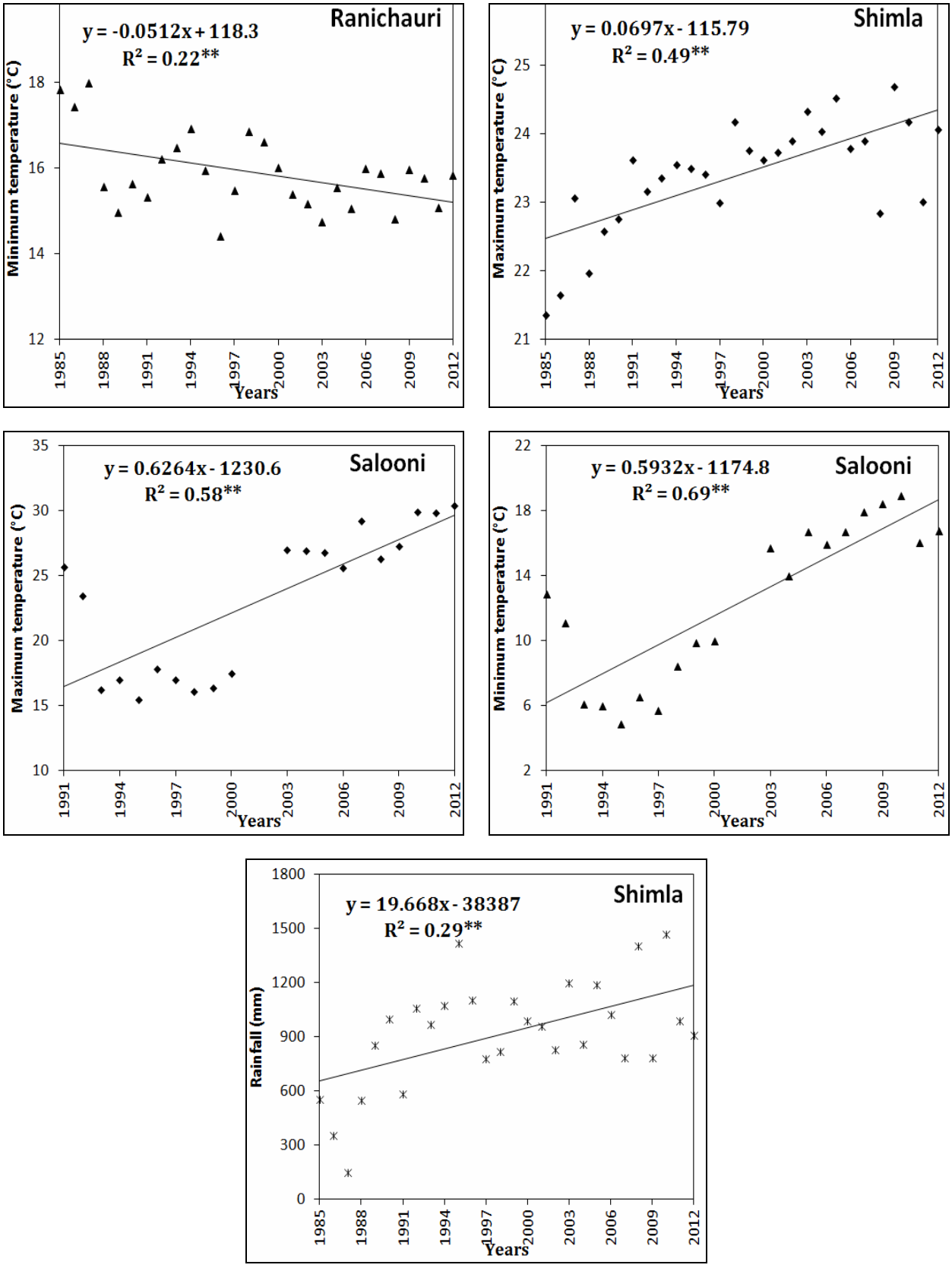

Fig. 2. Trends of mean weather parameters during *Kharif* at Ranichauri, Shimla and Salooni

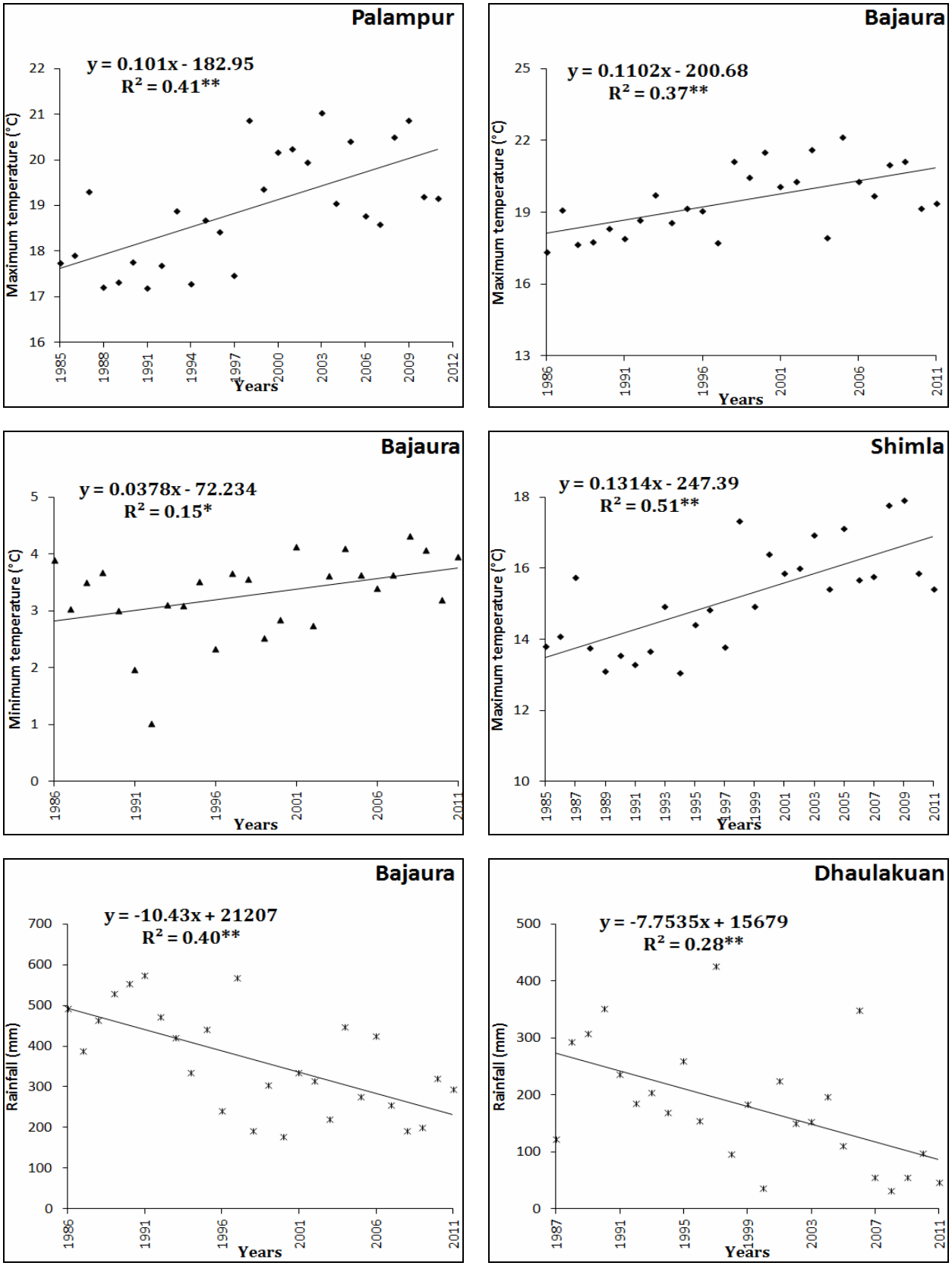

Fig. 3. Trends of mean weather parameters during *Rabi* at Palampur, Bajaura, Shimla and Dhaulakuan

TABLE 2

Decadal averages of rainfall (mm) at six locations

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palampur												
1985-94	85.2	107.1	126.3	59.7	90.2	185.5	650.5	685.8	240.5	29.9	19.4	70.6
1995-04	65.2	59.7	56.0	35.0	40.4	193.6	416.8	622.0	203.3	36.0	15.1	19.8
2005-12	90.4	114.6	96.5	47.2	104.5	248.5	603.0	702.7	300.0	39.8	12.9	31.8
Ranichauri												
1985-94	51.4	79.9	83.1	41.2	99.2	111.8	286.5	244.2	125.8	32.0	19.8	66.0
1995-04	72.0	109.1	75.5	58.6	53.3	118.2	236.1	272.3	142.3	58.3	11.1	20.1
2005-12	40.7	82.2	45.0	36.7	70.2	116.6	338.8	299.9	187.3	23.7	6.3	22.8
Bajaura												
1986-95	78.1	113.8	147.4	83.4	91.3	46.3	151.9	120.9	78.0	20.4	23.3	45.9
1996-05	58.4	97.5	111.6	67.4	67.6	83.1	142.6	124.9	80.1	42.2	19.7	24.5
2006-12	62.8	88.5	68.6	58.5	54.1	79.1	131.5	171.9	117.9	14.2	15.4	28.1
Dhaulakuan												
1987-96	53.4	72.0	40.9	21.3	48.3	177.3	510.6	534.2	184.8	7.0	8.1	45.9
1997-06	49.2	58.4	36.5	25.9	60.3	196.6	465.9	399.8	184.8	25.5	4.6	14.9
2007-12	9.2	43.1	28.7	15.2	38.0	191.4	496.5	497.5	244.9	14.2	5.6	10.6
Shimla												
1985-94	49.6	60.7	50.7	30.3	53.6	102.0	271.9	229.8	110.7	24.1	12.3	35.6
1995-04	68.0	80.0	84.2	66.4	80.8	216.5	309.7	332.2	147.4	40.0	10.8	19.6
2005-12	54.4	73.2	65.1	41.8	80.8	190.4	348.0	333.6	197.3	13.6	6.9	19.6
Salooni												
1991-00	282.3	70.6	87.5	70.7	78.2	206.6	216.3	163.7	114.0	116.8	189.8	339.2
2002-12	167.2	215.9	170.6	128.2	55.0	145.2	307.9	364.1	105.3	57.2	38.7	47.8

3.2.4. *Trends in weather parameters during two agriculturally important seasons*

The seasons from June to September, known as *Kharif* and from November to April, known as *Rabi* are important for growing summer and winter crops, respectively at all six locations. Though long-term trends in weather parameters *viz*., maximum and minimum temperatures and rainfall were worked out for both the seasons at all the locations, only significant trends in any of these parameters at any location were presented, separately for *Kharif* (Fig. 2) and *Rabi* (Fig. 3). Minimum temperature during *Kharif* at all the locations is not showing significant trend, except decreasing trend at Ranichauri (-0.04 °C/year) and rapid increasing trend at Salooni (0.59 °C/year). Maximum temperature in *Kharif* showed highly significant positive trend only at Shimla and Salooni, with rate of increase nine times higher at Salooni (0.63 °C/year) than at Shimla (0.07 °C/year). The increasing trend of rainfall at the rate of 19.7 mm per year in *Kharif* season at Shimla is likely to compensate the adverse effect of increasing maximum temperature. However, at Salooni, steep increasing trends of both maximum and minimum temperatures during *Kharif* may adversely affect the *Kharif* crops. In *Rabi*, increasing trend in maximum temperature of 0.10, 0.11 and 0.13 °C/year, respectively at Palampur, Bajaura and Shimla was observed. Bajaura along with another location Dhaulakuan witnessed significant decrease in rainfall during *Rabi* season. At Salooni, both maximum and minimum temperatures showed significant decreasing trend in *Rabi* season.

3.3. *Decadal variations in weather parameters*

Common feature in decadal averages of monthly rainfall at most of the locations (Table 2) is the increase in August and September rainfall and decrease in November and March rainfall from decade to decade. These results partially confirm the earlier findings of increased rainfall

TABLE 3

Decadal averages of maximum and minimum temperatures (°C) at six locations

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palampur												
1985-94	15.0 (5.3)	16.4 (6.6)	20.0 (9.7)	25.1 (14.0)	29.1 (17.8)	30.3 (20.2)	26.6 (19.8)	25.9 (19.4)	25.7 (17.7)	24.5 (13.6)	20.8 (9.8)	16.8 (6.7)
1995-04	15.7 (5.1)	17.5 (6.8)	21.8 (10.3)	26.9 (15.2)	30.7 (18.6)	29.8 (19.3)	27.2 (20.0)	26.6 (19.4)	26.3 (17.6)	25.1 (13.6)	22.0 (9.9)	18.6 (6.7)
2005-12	15.9 (4.6)	17.4 (6.9)	22.5 (10.6)	27.0 (14.5)	30.3 (18.1)	30.6 (19.6)	26.8 (19.9)	26.0 (19.3)	26.2 (17.3)	25.3 (13.0)	21.8 (8.9)	18.4 (5.8)
Ranichauri												
1985-94	12.4 (3.0)	13.5 (3.5)	17.8 (6.9)	22.5 (11.0)	25.1 (13.8)	25.6 (16.1)	23.3 (17.0)	22.7 (17.2)	22.1 (15.5)	20.6 (11.0)	17.2 (7.0)	13.4 (3.9)
1995-04	11.0 (1.9)	12.5 (3.0)	17.3 (6.7)	22.6 (10.8)	25.5 (13.8)	24.8 (15.5)	23.2 (16.7)	22.5 (16.2)	22.0 (14.1)	20.4 (9.9)	17.2 (6.3)	13.8 (3.6)
2005-12	12.3 (1.9)	13.8 (3.5)	18.5 (7.1)	23.2 (10.6)	25.3 (13.1)	26.1 (15.6)	22.9 (16.5)	22.7 (16.1)	22.2 (14.1)	20.9 (9.7)	17.8 (5.9)	15.0 (3.1)
Bajaura												
1986-95	15.1 (1.0)	16.7 (3.1)	20.1 (5.6)	25.5 (8.3)	29.8 (12.3)	32.9 (17.4)	31.0 (20.6)	30.4 (20.5)	29.8 (16.9)	27.3 (8.3)	22.9 (3.2)	17.2 (1.0)
1996-05	16.3 (0.9)	17.7 (3.1)	23.0 (6.2)	26.9 (9.5)	30.8 (12.6)	32.0 (17.3)	31.2 (20.9)	30.4 (20.5)	29.9 (17.3)	27.5 (9.0)	23.6 (3.7)	19.1 (0.3)
2006-12	16.3 (1.4)	18.7 (4.4)	23.3 (6.3)	27.3 (9.7)	30.8 (13.2)	31.9 (17.1)	31.0 (21.0)	29.9 (21.0)	29.2 (17.2)	27.3 (9.4)	23.4 (4.0)	18.2 (1.3)
Dhaulakuan												
1987-96	19.9 (4.4)	22.1 (6.3)	26.7 (9.6)	33.4 (13.5)	37.0 (18.7)	36.9 (23.1)	32.0 (24.3)	30.9 (23.8)	30.9 (21.2)	29.8 (12.8)	25.7 (7.4)	21.8 (4.5)
1997-06	19.2 (4.2)	22.6 (6.3)	27.6 (10.0)	33.8 (14.1)	36.7 (19.2)	35.4 (22.4)	32.0 (24.3)	31.1 (23.9)	31.0 (21.1)	29.6 (14.1)	26.1 (8.5)	21.9 (4.4)
2007-12	19.6 (4.5)	22.6 (6.6)	29.1 (10.3)	34.6 (14.9)	37.0 (19.4)	36.2 (22.3)	32.0 (24.2)	31.2 (23.9)	30.9 (21.8)	29.8 (14.1)	26.0 (8.5)	22.0 (4.6)
Shimla												
1985-94	11.5 (3.9)	12.1 (4.5)	15.6 (7.3)	20.1 (11.8)	23.9 (16.2)	24.7 (16.9)	22.3 (16.5)	21.9 (16.1)	22.0 (14.6)	20.7 (11.4)	17.1 (8.1)	13.4 (5.7)
1995-04	12.0 (3.4)	13.4 (4.3)	17.6 (8.0)	22.3 (12.4)	25.5 (15.6)	25.2 (16.3)	23.6 (16.6)	23.0 (16.2)	23.2 (14.6)	21.4 (11.6)	17.8 (8.4)	15.0 (5.9)
2005-12	12.9 (3.5)	14.5 (4.9)	18.9 (8.6)	22.8 (12.3)	25.8 (15.0)	26.1 (16.5)	23.5 (16.7)	22.9 (16.3)	23.0 (14.7)	21.6 (11.6)	18.5 (8.5)	15.5 (5.4)
Salooni												
1991-00	23.8 (13.7)	22.9 (12.1)	19.8 (9.2)	16.4 (5.7)	13.3 (3.7)	13.1 (4.0)	13.0 (4.9)	21.1 (10.0)	25.9 (13.7)	27.4 (15.5)	28.5 (17.1)	26.7 (16.9)
2002-12	11.0 (2.4)	10.7 (3.2)	19.4 (8.2)	24.7 (12.0)	28.7 (14.5)	29.8 (16.1)	28.7 (17.2)	26.8 (16.6)	25.9 (15.2)	24.4 (11.7)	19.0 (7.4)	13.9 (4.2)

Note : Values in parenthesis represents minimum temperature (°C)

in June, July and August months (Shrestha *et al*., 2012). The June and October rainfall at Palampur and July rainfall at Shimla also witnessed increasing trend with each passing decade. From decade to decade, during February to May months at Bajaura and during December to March at Dhaulakuan, rainfall showed decreasing trend.

At most of the locations, maximum temperature showed increasing trend in March and April and both maximum and minimum temperatures showed increasing trend in March at Palampur, Bajaura, Dhaulakuan and Shimla (Table 3). Though decadal averages of maximum temperature of the months November to June (next year)

TABLE 4

Decadal variation of extreme events related to rainfall, maximum and minimum temperatures at six locations

Years	Rainfall (mm)			Maximum temperature (°C)		Minimum temperature (°C)
	≥ 50	≥ 100	≥ 200	≥ 30	≥ 35	≤ 0
Palampur						
1985-1994	12.4*	2.4	0.3	37.9	1.7*	0.9**
1995-2004	7.6**	1.4	0.2	44.8	5.6	0.0*
2005-2012	13.1	1.8	0.5	44.6	4.6	0.9
Ranichauri						
1985-1994	3.8	0.2*	0.0	2.2	0.0	8.4
1995-2004	4.0	0.6	0.1	3.4	0.0	9.9
2005-2012	5.5	1.0*	0.0	5.8	0.0	11.5
Bajaura						
1986-1995	2.3	0.10	0.0	116.6*	11.9	33.8
1996-2005	1.7	0.10	0.0	130.0	8.8	38.8**
2006-2012	1.7	0.14	0.0	123.0	7.6	22.9
Dhaulakuan						
1987-1996	9.1	1.4	0.1	178.0	61.6	0.6
1997-2006	8.0	1.2	0.2	187.1	57.6	1.8
2007-2012	9.2	2.3	0.0	186.3*	62.8	3.8
Shimla						
1985-1994	2.5*	0.1	0.0	1.0	0.1	1.9
1995-2004	4.4	0.4	0.0	2.5	0.0	0.9
2005-2012	5.3*	0.8**	0.0	3.5*	0.0	2.9
Salooni						
1991-2000	9.5	3.1	1.0	29.8	1.3	15.9
2003-2012	9.4	3.2	1.0	49.4	4.4	9.1

* Significant ($P \leq 0.05$), **Highly significant ($P \leq 0.01$)

at Shimla showed progressive increase from decade to decade, the increase in last decade compared to the first decade, was higher during February to April (2.4 to 3.1 °C). These results partially agree with the observations of Bhutiyani *et al*. (2007), who reported relatively higher rate of warming in winter months during last two decades in Northwestern Himalayas. At Ranichauri only, minimum temperature in all the months from June to December showed decreasing trend from decade to decade, with a steep decrease of 1.3 °C in the month of October. These results are contrary to the finding of increased rates of minimum temperature in western Himalayas (Islam *et al*., 2008).

3.4. *Extreme events*

Decadal averages of the number of events with rainfall, maximum temperature and minimum temperature exceeding or falling below certain thresholds of extreme values (Table 4) at all the locations brought out that either temperature or rainfall related extreme events have not shown any increase or decrease with each passing decade. The low temperature events with minimum temperature less than or equal to 0 °C were observed to be a rare phenomena at Palampur while they were occurring more frequently, *i.e.*, 23 to 39 days in a year at Bajaura. High temperature events with maximum temperature ≥ 35 °C were found to be rare (zero) at Ranichauri and Shimla while they are 58 to 63 per year at Dhaulakuan. At Ranichauri and Shimla, high rainfall events with rainfall ≥ 50 mm and high temperature events with maximum temperature ≥ 30 °C are increasing decade to decade, though the trend is statistically non-significant at Ranichauri. At these same locations, number of extreme rainfall events with rainfall ≥ 100 mm in present decade (2005-2012) is significantly higher compared to those in

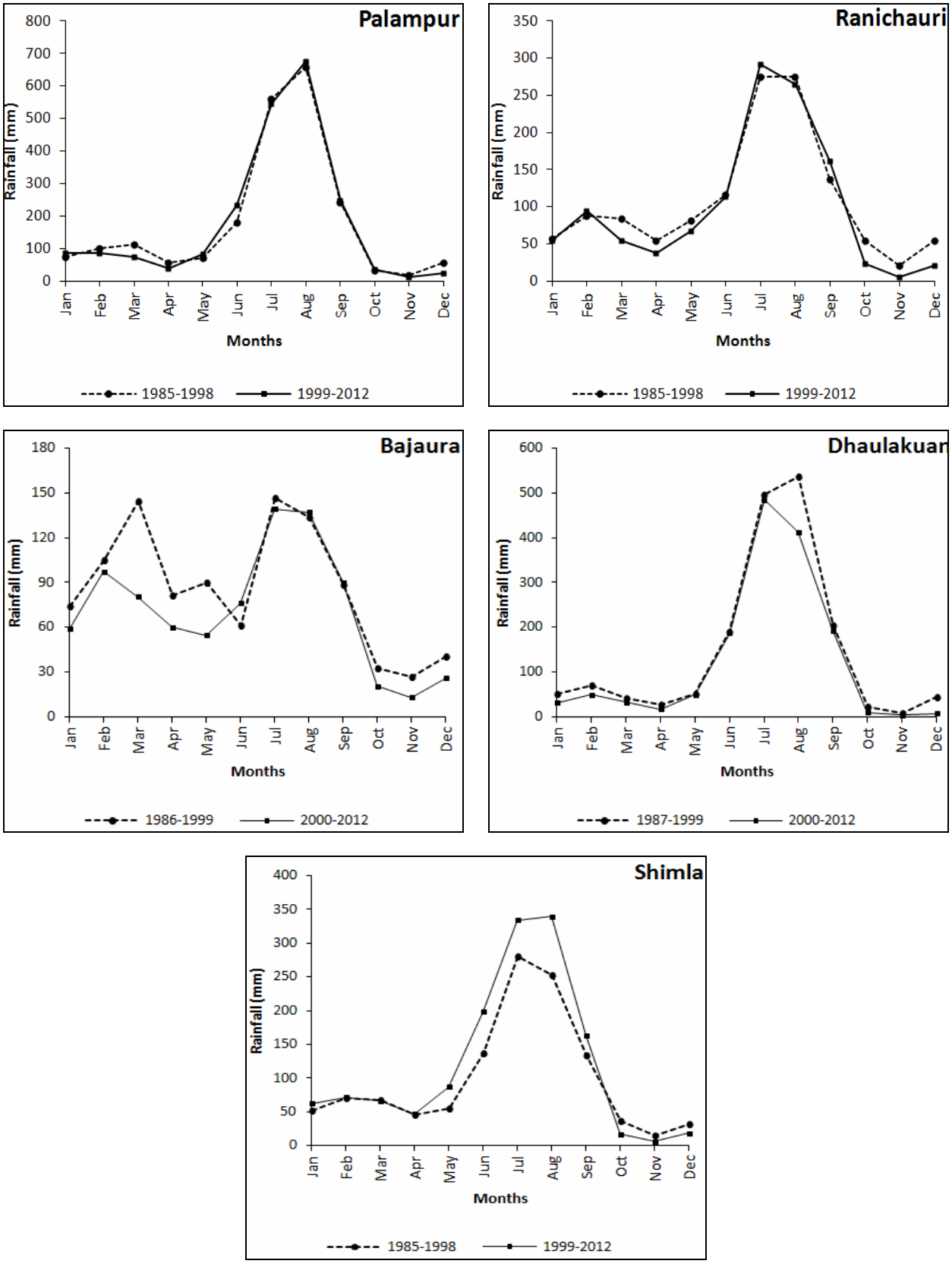

Fig. 4. Shifts in rainfall (mm) at Palampur, Ranichauri, Bajaura, Dhaulakuan and Shimla

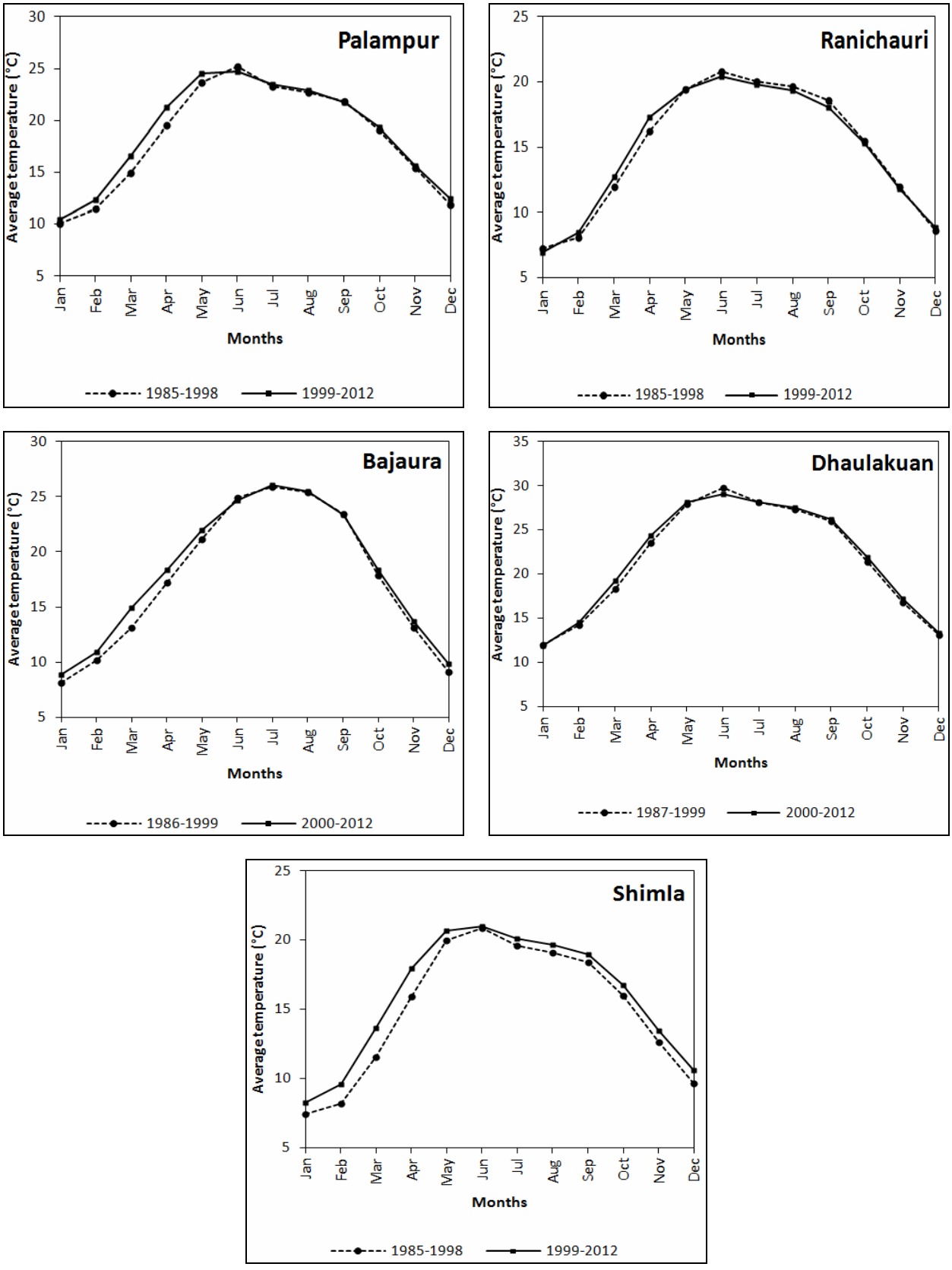

Fig. 5. Shifts in average temperature (°C) at Palampur, Ranichauri, Bajaura, Dhaulakuan and Shimla

the decade 1985-1994. Nandargi and Dhar (2011) presented contrary results of decreasing frequency of extreme rainfall events during 2001-2007 in the entire Himalayas. However, if the chronological history of cloud bursts in the Himalayan region is examined, during 1985-1994 no cloud burst took place and during 2001-2007 three cloud bursts and during 2001 to till date nine cloud bursts occurred in Himalayan region (Wikipedia). This is supporting our results of increased frequency of heavy rainfall events during the current decade.

3.5. *Shifts in weather parameters*

Plot of monthly rainfall and average temperature at Palampur, Ranichauri, Bajaura, Dhaulakuan and Shimla (Figs. 4 & 5) revealed no shift in the month of peak rainfall at Palampur and shift from August to July at Ranichauri, June to July at Shimla during present time scale (1999-2012) compared to the previous time scale (1985-1998). The month of occurrence of peak rainfall over the period (1986-1999) at Bajaura shifted from March to February in the present time scale (2000-2012), while the peak at Dhaulakuan shifted from July to June in the present time scale. The differences in the time or month of occurrence of peak rainfall may be due to differences in longitudinal position of different locations. At Ranichauri, Bajaura, Dhaulakuan and Shimla no shifts in the month of occurrence of peak average temperature were observed during the present time scale compared to previous one. However, at Palampur peak temperature occurring in the month of June during 1985-1998 shifted to the month of May during 1999-2012. Shifts in rainfall and temperature are in line with the perceptions of farmers in western Himalayas (Vedwan and Rhoades, 2001) on shifts in these weather parameters. Differences in rainfall of December between two time scales were only significant across most of the locations. Average temperature of April during the present time scale was significantly higher than the average temperature during its previous time scale, at all locations. Same is the case with average temperature of March at four locations, namely Palampur, Bajaura, Dhaulakuan and Shimla.

4. Conclusions

Important conclusions drawn from long-term analysis of rainfall and temperature at six locations of mid-Himalayan region are: Mean annual maximum temperature showed highly significant positive trend (1.1 °C/decade) at Salooni followed by the trends 1 °C, 0.6 °C and 0.5 °C per decade at Shimla, Palampur and Bajaura, respectively. Mean annual minimum temperature showed significant negative trend (-0.4 °C/decade) at Ranichauri and no significant trend at other locations. Annual rainfall showed no significant trend at all the locations except Shimla, where highly significant increasing trend of 22 mm/year was observed. At Shimla, significant increase in maximum temperature was observed in all the seasons. Maximum temperature in summer showed significant increasing trend at all locations, except Ranichauri. Three locations namely, Palampur, Salooni and Ranichauri showed highly significant decreasing trend in minimum temperature during northeast monsoon season. Significant increasing trend in maximum temperature during *Rabi* at Palampur (0.10 °C/year), Bajaura (0.11 °C/year and Shimla (0.13 °C/year) and significant decreasing trend in minimum temperature during *Kharif* at Shimla (0.07 °C/year) and Salooni (0.63 °C/year) was observed. Bajaura as well as Dhaulakuan witnessed significant decrease in rainfall during Rabi season. Decade to decade increase of rainfall in August and September and decrease of rainfall in November and March at most of the locations, increase of both maximum and minimum temperatures in March at Palampur, Bajaura, Dhaulakuan and Shimla are some significant features of decadal variations in monthly weather conditions. At all the locations, temperature or rainfall related extreme events have not significantly increased or decreased continuously from one decade to another. At Palampur only, peak of average temperature occurring in the month of June during the previous time scale shifted to the month of May during the present time scale. Peak rainfall occurred one month earlier at Ranichauri, Bajaura, and Dhaulakuan and delayed by one month at Shimla during the present time scale compared to the previous time scale.

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