MAUSAM, **62**, 1 (January 2011), 77-84

551.58 : 551.501.724 : 551.501.777

Analysis of rainfall and temperatures for climatic trend in Kullu valley

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(*Received 12 March 2010, Modified 13 August 2010*)

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सार – कुल्लु घाटी पर्यटन और कृषि से संबंधित कार्यों के लिए प्रसिद्ध है। परन्तु हाल ही में इसे जलवायविक भिन्नताओं के लिए महत्वपूर्ण माना जाने लगा है। यहाँ पर न्यूनतम और अधिकतम तापमानों की प्रवृति में बढ़ोतरी देखी गई है परन्तु वार्षिक वर्षा की प्रवृति में कोई बदलाव नहीं आया है। वार्षिक वर्षा की प्रवणता बजौड़ा में समाश्रयण रेखा से ऋणात्मक (नीचे) तथा कटरान में धनात्मक (अधिक) देखी गई है परन्तु दोनों की स्थितियों में कोई महत्वपूर्ण बदलाव नहीं देखा गया है। वार्षिक वर्षा (22%) और मानसून ऋतु की वर्षा (33%) के भिन्नता गुणांक में वार्षिक वर्षा तथा दक्षिणी पश्चिम मॉनसून वर्षा के साथ स्थिरता को दर्शाते हैं परन्तु ऐसा देखा गया है कि मानसून अधिक वर्षा वाले महीनों में बदल गया है। बजौड़ा में पश्च मानसून ऋतु के दौरान होने वाली वर्षा में और कटरान में सर्दी में होने वाली वर्षा में अधिक भिन्नता देखी गई है। पिछले दशक की अवधि की तुलना में हाल के वर्षों में हुई वर्षा की मात्रा में गिरावट अधिक देखी गई है। बजौड़ा में मासिक, मौसमी और वार्षिक औसत न्यूनतम तापमान में गिरावट का रूख देखा गया है जबकि कटरान में इसमें बढ़ोतरी का रूख देखा गया है परन्तु दोनों ही स्टेशनों के अधिकतम तापमान में बढ़ोतरी देखी गई है। शरद ऋतु के दौरान न्यूनतम तापमान में काफी भिन्नता रहती है जबकि ग्रीष्म ऋतु में अधिकतम तापमान में भिन्नता रहती है। हाल के समय में अधिकतम और न्यूनतम दोनों ही तापमानों में अधिक बढ़ोतरी की स्थिति का पता चला है।

ABSTRACT. Kullu valley is famous for tourism and agricultural activities but recently it has assumed importance for studies on climatic variability. There is an increasing trend in minimum and maximum temperatures but no trend in annual rainfall. The slope of regression line for annual rainfall was negative at Bajaura and positive at Katrain but both were non significant. The coefficient of variation for annual rainfall (22 %) and for monsoon rainfall (33 %) was showing the consistence of annual and southwest monsoon rainfall but, a shifting of monsoon from its wettest months was observed. The rainfall was most variable during post monsoon season at Bajaura and in winter at Katrain. The decreasing rate in rainfall was higher during the recent period than the decadal period. Monthly, seasonal and annual average minimum temperature was showing decreasing trend at Bajaura and an increasing trend at Katrain, but, maximum temperature is increasing at both the stations. The minimum temperature was most variable during the winter season whereas the maximum temperature was during summer. Higher the altitude higher the variability in minimum temperature but lower the altitude higher the variability in maximum temperature. Both maximum and minimum temperatures were showing a higher rate of increasing during the recent period.

Key words – Rainfall, Temperature, Climatic trend, Analysis, Kullu valley.

1. Introduction

While the earth's own climate has gone through various stages of warming and cooling, the present trend towards warming and the related destabilization of climate systems and weather patterns is human induced and it is human beings who are already suffering the impact of intensification weather vagaries. The climatic change experienced in the last century has been much more drastic and rapid in nature so the analysis of climatic data on regional basis has become more important. The Inter-governmental Panel on Climate Change (IPCC, 2001) has concluded that the global mean surface air temperature has increased by 0.74° C over the last 100 years. Similarly all-India mean annual temperature showed a significant warming by 0.4° C over the past 100 years (Hingane *et al*., 1985). Analysis of long-term rainfall data over different locations of India indicated that monsoon rainfall is trendless (Rupa Kumar *et al*., 1992). The Indian monsoon rainfall shows an inter-annual variability (Kripalani *et al*., 2003). There is a need to quantify regional climatic variability to asses its effect on crop productivity. Variation of rainfall and temperature on regional basis was studied by various workers (Thakur and Sharma, 1993; Rajegoda *et al*., 2000; Hundal and Probhjot-Kaur, 2002; Singh, 2003; Krishna Kumar *et al*., 2008; Singh *et al*., 2009). Nath and Deka (2002) reported decrease in average annual rainfall in north-eastern states. Himalayan region is quite fragile & the attempt in this paper is to use 40 years of meteorological data of two

agricultural stations in Kullu valley to understand trends in temperature & rainfall.

2. Data & methodology

The daily rainfall and temperatures data was collected from two research stations. Katrain (1962-2009) and Bajaura (1973-2009). The climatic data used in the study was recorded in the observatories of IARI Regional Research Station. Katrain (32° N; 77° E and 1550 m amsl) and Hill Agriculture Research Station. Bajaura (31° 10′ N, 77° 6′ E and 1090 m amsl) located on the north and south verge of the valley (Fig. 1). The collected data was compiled on monthly, seasonal, annual basis and divided into three categories: first longer period (1962-1990) and the second decade period (1991-2000) and the third is recent period (2001-2009). The standard analysis was done to calculate arithmetic mean, median, standard deviation, coefficient of variation, correlation & regression and departure from the normal period (1962-2009) during decade and the recent periods. The four seasons considered in the paper are summer (March-May), south west monsoon (June-September), post monsoon (October-November and winter season (December-January).

3. Study area

Kullu which finds a mention in the religious texts, such as Vishnu Purana, Ramayana and Mahabharata as 'Kulantpitha' means 'the end of the habitable world' which seems appropriate as beyond Kullu, there are only the high Himalayas. The Beas River has deposited alluvial terraces, fans and hill slopes have provided an ideal geoenvironment for human activities including agriculture, horticulture, dense settlements and other civil establishment (Sah and Mazari, 2007). Extensive tract of forest exist throughout the valley, which is major concerned now, for maintenance of stability of environment and sustenance of ecology under the rapid land use and climatic changes (Gupta, 1990). Agriculture has been the dominant economic activity in the region for centuries employing ~90% of the population (Singh, 1992). The area is famous for apple & other temperate fruits like pear, plum, apricot, cherry and vegetables like cole crops, tomato, pea, garlic etc. By the early 1990's, agricultural land was being developed or abandoned in favour of tourism-related opportunities now major concern for climatic variability in the valley.

4. Results and discussion

The 'Rain shadow' Kullu valley enjoy salubrious climate with average rainfall varying between 918 mm (Bajaura) to 1124 mm (Katrain). The temperate climate is

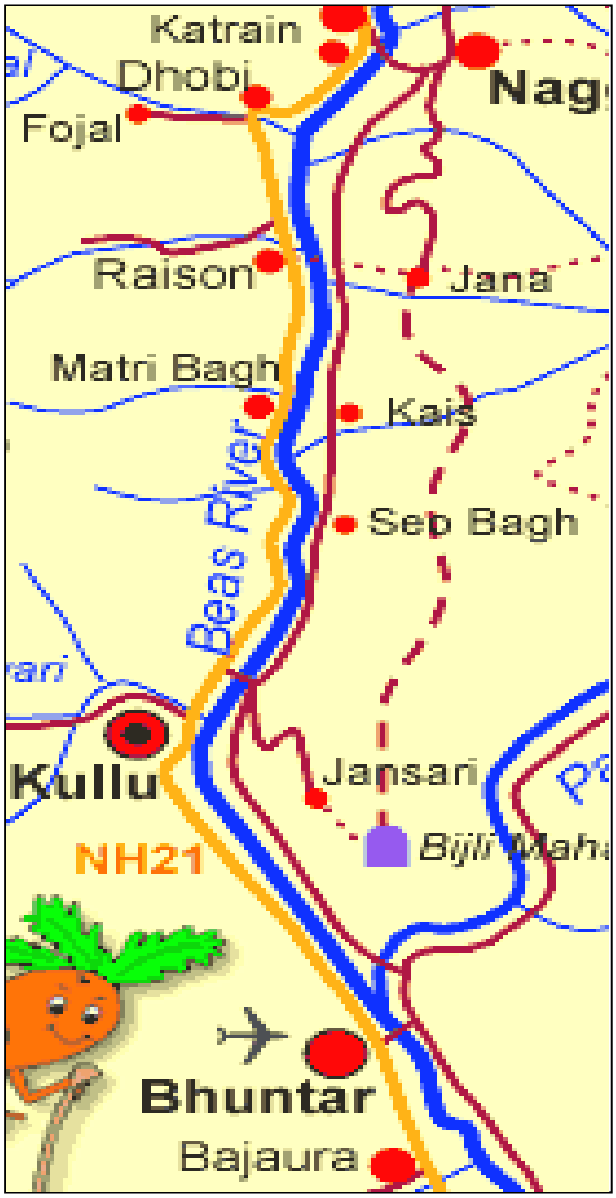

Fig. 1. Map of Kullu valley

characterized here by dry winter with November as the driest month and hot, rainy summer with July as the wettest month. The minimum temperature drops as low as -2° C to -5° C in January as recorded at upstream Katrain, while the maximum temperature rises to 25° C to 37° C during summer in June observed at downstream Bajaura. The season-wise rainfall distribution over Kullu valley indicated that 43 per cent of annual rainfall is received during the south west monsoon season followed by summer (29 %) and winter (23 %). The least rainfall (5 %) in noticed in post monsoon season. The annual rainfall in Kullu valley (Bajaura + Katrain) is dependable as its CV is 18.5 % for Kullu valley 21.7% for Bajaura and 24.2 % for Katrain.

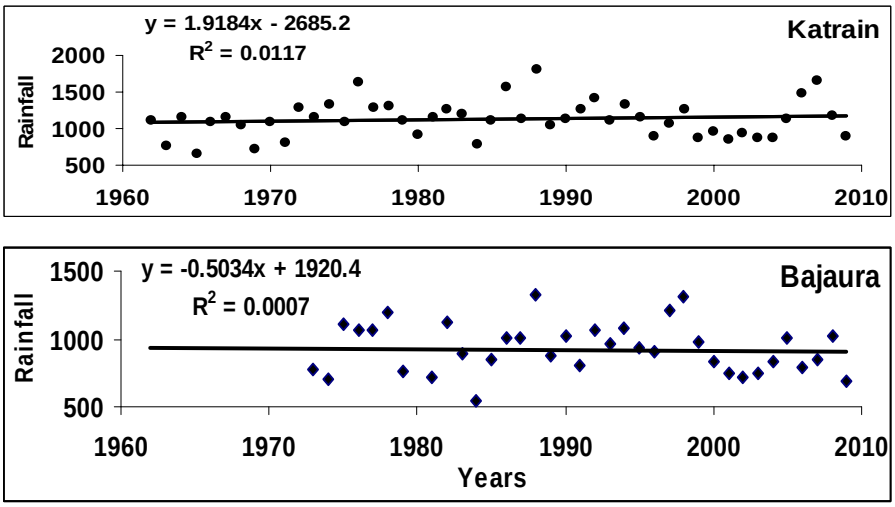

Fig. 2. Variation of annual rainfall in Kullu valley

TABLE 1

Variation of rainfall (mm) at Bajaura (1973-2009)

Month	Mean	Median	SD	CV(%)	Pd(%)	Pr(%)
Jan	80.5	79.3	55.6	69.0	-2.5	-25.3
Feb	91.0	80.6	53.5	58.8	14.3	-9.4
Mar	123.5	121.6	75.8	61.3	10.6	-22.4
Apl	71.3	58.8	44.7	62.7	17.1	-9.1
May	70.1	58.5	51.6	73.7	1.9	-30.7
Jun	64.5	49.8	39.5	61.2	24.1	8.1
Jul	136.3	118.7	74.1	54.4	12.8	-19.2
Aug	126.7	134	66.8	52.8	17.2	15.9
Sep	71.1	48	64.3	90.4	22.9	24.6
Oct	26.3	9.6	40.9	155.3	2.8	-2.0
Nov	23.4	12.4	34.7	148.3	-6.9	-12.1
Dec	33.4	22.5	35.7	107.1	-19.9	-9.5
Summer	264.9	259.6	097.9	036.9	10.9	-22.9
SW Monsoon	398.5	392.5	134.5	033.7	20.8	7.9
Post Monsoon	049.8	031.4	052.6	105.7	-7.6	-25.9
Winter	204.9	194.1	075.0	036.6	-3.7	-20.3
Annual	**918.1**	**907.9**	**199.0**	**021.7**	**10.3**	**-10.0**

SD – Standard Deviation, Pd – Percent departure of decade period from normal,
CV – Coefficient of variation, Pr – Percent departure of recent period from normal

TABLE 2

Variation of temperature (°C) at Bajaura (1973-2009)

	T-max						*T*-min					
Month	Mean	Median	SD	CV(%)	Pd(%)	Pr(%)	Mean	Median	SD	CV(%)	Pd(%)	Pr(%)
Jan	15.2	15.8	2.5	16.3	14.6	22.3	1.2	1.2	1.4	116.1	-35.7	-29.1
Feb	17.0	16.9	3.1	18.3	11.8	20.5	3.1	3.1	1.2	40.1	-10.5	17.3
Mar	20.7	21.0	3.6	17.5	13.3	21.5	6.0	6.1	1.6	25.8	-18.4	-8.7
Apl	25.3	26.1	3.7	14.6	14.2	13.5	9.0	8.9	1.6	17.5	-15.3	-3.9
May	29.5	30.4	3.7	12.5	13.1	13.2	12.8	12.7	1.8	14.1	-12.2	-6.8
Jun	32.2	32.5	1.6	5.0	1.0	1.6	17.6	17.0	1.9	10.6	-12.3	-10.2
Jul	31.1	31.1	1.4	4.4	-1.3	1.7	21.1	20.8	1.3	6.4	-3.7	-2.2
Aug	30.0	30.1	2.0	6.7	3.6	4.4	20.5	20.7	1.4	7.0	0.7	2.0
Sep	29.0	29.7	2.9	9.9	5.4	4.2	16.8	16.8	1.9	11.4	-1.4	-3.5
Oct	27.2	27.6	1.9	6.9	5.9	6.6	9.3	9.2	1.6	16.8	-15.5	-8.0
Nov	23.0	23.5	1.8	8.0	7.8	9.0	3.5	3.2	1.1	32.3	-1.9	-7.0
Dec	17.6	17.5	2.1	11.9	18.2	15.5	1.0	1.1	1.4	142.9	-88.1	11.5
Summer	22.9	24.8	5.0	21.9	13.5	15.5	10.0	9.6	1.9	19.2	-14.6	-6.3
SW Monsoon	30.0	30.8	2.8	9.2	2.1	2.9	19.5	19.5	1.8	9.2	-4.2	-3.4
Post Monsoon	23.9	24.8	2.0	8.5	6.8	7.7	6.9	6.4	1.3	19.4	-11.9	-7.8
Winter	14.8	15.8	2.5	16.9	14.9	19.3	2.0	2.1	0.7	34.4	-34.7	4.0
Annual	**24.8**	**25.2**	**1.9**	**7.6**	**1.8**	**2.2**	**10.1**	**10.2**	**0.9**	**9.1**	**-0.9**	**-0.4**

4.1 *Bajaura*

Rainfall : Bajaura is situated in south verge of the Kullu valley on right bank of the river Beas which a frost affected low rainfall area of the Kullu valley. The annual average rainfall is 918 mm with the 21.7 per cent variability and 199 mm standard deviation. No significant but somewhat decreasing trend was observed (Fig. 2). The mean and the median values are at par which shows the consistency in the annual rainfall. The departure of the normal rainfall was increased by 10.3 percent in the decadal period (1991-2000) and decreased in the recent period (2001 to 2009) by 10.0 per cent. The highest share (43.4 %) of the annual rainfall was received during the south west monsoon season followed by summer (28.9 %) and the lowest (5.4 %) during the post monsoon. The variability of rainfall among the season was lowest during the rainy season and at par during the summer & winter seasons but, highest during the post monsoon season. Only monsoon season was showing an increasing trend and rest are showing a decreasing rainfall trend during the recent period (Table 1). July is the wettest month with annual average rainfall of 136 mm followed by August and March with 127 mm and 124 mm, respectively. The value of mean was higher than median in all the months except August in which it was negative. The rainfall was

TABLE 3

Monthly variation of rainfall (mm) at Katrain (1962-2009)

Month	Mean	Median	SD	CV(%)	Pd(%)	Pr(%)
Jan	95.6	70.5	106.9	111.8	-8.1	0.5
Feb	111.0	93.4	73.9	66.6	-3.9	16.6
Mar	153.8	132.4	96.7	62.9	10.8	-26.6
Apl	94.3	86.2	62.5	66.3	5.6	-10.9
May	79.5	63.9	67.2	84.5	-5.3	41.0
Jun	69.0	60.5	38.7	56.2	13.4	36.2
Jul	159.9	153.3	81.8	51.2	-0.7	-19.5
Aug	155.8	147.7	77.9	50.0	-3.8	-4.7
Sep	96.7	68.6	80.1	82.8	24.9	21.6
Oct	30.6	13.2	43.7	143.1	-4.9	-14.9
Nov	31.2	11.1	41.6	133.2	-10.7	-52.6
Dec	46.7	31.3	48.5	103.8	-46.3	-20.8
Summer	327.6	312.4	136.0	41.5	5.6	-6.6
SW Monsoon	481.5	480.9	158.4	32.9	4.9	0.4
Post Monsoon	61.8	43.5	56.7	91.8	-8.0	-37.7
Winter	46.3	31.3	48.3	104.4	-6.9	4.2
Annual	**1124.1**	**1118**	**247.6**	**22.0**	**-0.1**	**-3.2**

more consistence during July, August, February and March which having low values of coefficient of variation (Table 1). The rainfall has increased during the decade (1991-2000) and decreased during the recent period (2001-2009) in all the months except August.

Temperature : The annual average temperature at Bajaura was calculated 17.5° C with 24.8° C as mean maximum and 10.1° C as mean minimum temperature Table 2). The annual maximum temperature is increasing whereas minimum temperature was declining as the slope of regression line for maximum and mean temperature was positive and that for the minimum temperature was negative. But, the annual average temperature has increased during the last decade earlier it was at par (Table 5). The increasing in maximum and decreasing in minimum temperature is not showing any significant trend (little bit in positive direction) but, widening temperature ranges which indicates the more fluctuation in temperatures. The summer and winter seasons are showing large increasing trend in maximum and mean temperature at Bajaura. The reason for this behaviour cannot be explained as large increase is not noticed in the neighbouring Katrain station.

4.2 *Katrain*

Rainfall : Katrain is situated in north verge of the Kullu valley on right bank upstream of the river Beas. The annual average rainfall was 1124 mm with the 22 per

TABLE 4

Variation of temperature (°C) at Katrain (1962-2009)

	T-max						*T*-min					
Month	Mean	Median	SD	CV(%)	Pd(%)	Pr(%)	Mean	Median	SD	CV(%)	Pd(%)	Pr(%)
Jan	11.0	11.2	1.7	15.3	0.8	5.1	1.6	1.2	1.8	114.7	75.1	306.5
Feb	12.8	12.8	2.2	17.2	6.8	7.1	2.8	2.5	2.0	72.8	54.4	176.9
Mar	16.7	16.3	2.8	16.9	1.9	12.4	5.4	5.0	2.2	40.3	8.4	86.4
Apl	21.6	21.3	2.0	9.0	-0.2	3.8	9.4	8.8	1.9	19.7	8.0	35.2
May	25.3	25.5	2.1	8.2	1.5	1.8	12.2	11.7	2.0	16.0	5.0	25.0
Jun	27.9	28.0	1.3	4.6	1.9	-0.8	16.1	15.8	1.9	11.9	2.4	6.5
Jul	27.1	26.8	1.3	4.7	5.7	5.3	18.3	18.3	2.1	11.5	7.7	19.4
Aug	26.7	26.5	1.4	5.4	5.8	5.2	18.4	18.1	1.7	9.4	6.4	14.3
Sep	26.0	25.9	1.4	5.4	5.5	1.9	14.9	14.6	1.8	12.1	5.3	22.5
Oct	23.0	23.3	1.8	7.8	3.2	3.0	9.5	9.1	1.9	20.2	3.5	25.9
Nov	18.6	18.8	1.6	8.8	7.9	7.7	5.5	4.9	2.0	36.1	24.3	61.9
Dec	14.1	13.7	1.9	13.7	14.0	7.4	3.5	3.1	1.8	52.2	-7.6	79.6
Summer	21.2	21.4	1.6	7.6	1.4	5.3	9.0	8.6	1.7	18.8	6.0	39.8
SW Monsoon	26.9	27.0	1.0	3.7	4.9	3.0	16.9	16.6	1.5	8.8	4.9	15.3
Post Monsoon	20.8	20.8	1.5	7.4	5.4	4.9	7.5	7.1	1.8	24.3	10.1	37.7
Winter	12.6	12.5	1.2	9.5	7.3	6.5	2.6	2.2	1.6	62.2	25.0	140.0
Annual	**20.9**	**20.8**	**0.9**	**4.4**	**4.4**	**4.4**	**9.8**	**9.3**	**1.5**	**15.0**	**7.7**	**30.8**

cent variability and 248 mm standard deviation. No significant but somewhat increasing trend was observed in the annual rainfall as the slope of regression line was positive (Fig. 2). The mean and the median values are almost at par which shows the consistency in the annual raintall. The departure of the normal rainfall of the long period average from the decadal and the recent period is showing a non significant decreasing trend but overall annual rainfall is showing an increasing trend at Katrain. The seasonal share departure of annual rainfall was similar to Bajaura (Table 3). July was the wettest month with annual average rainfall of 160 mm followed by August (156 mm). The value of mean was higher than median in all the months. The value of mean and median was closest during July and August and widest in September and January. Standard deviation (mm) was highest (106.9) in January followed by March (96.7) and lowest during June (38.7) followed by November (41.6). The rainfall was most variable during October, November, January and December with coefficient of variation is 143%, 133% and 112% and 104%, respectively, but it was more consistence during June, July and August.

TABLE 5

Decadal variation of temperatures (°C)

Season/decade		Katrain					Bajaura		
		1961-70	1971-80	1981-90	1991-2000	2001-09	1981-90	1991-2000	2001-09
T-max	Summer	21.0	21.5	20.3	21.2	22.0	24.9	26.0	27.1
	SW Monsoon	26.0	26.3	26.5	27.8	27.3	30.9	30.7	30.9
	Post Monsoon	19.7	21.0	20.4	21.5	21.4	24.2	23.4	23.2
	Winter	12.5	12.2	12.1	13.2	13.1	15.7	17.0	17.8
	Annual	**20.6**	**20.7**	**20.3**	**21.4**	**21.4**	**24.1**	**24.8**	**25.1**
T-min	Summer	7.6	8.8	8.4	8.8	11.6	9.3	8.6	9.6
	SW Monsoon	15.7	16.5	16.5	17.0	18.8	19.8	18.8	18.8
	Post Monsoon	6.5	7.3	6.5	7.6	9.5	6.7	6.0	6.2
	Winter	2.3	1.7	1.9	2.5	4.8	1.9	1.4	1.6
	Annual	**8.8**	**9.3**	**9.2**	**9.7**	**11.7**	**10.9**	**10.1**	**10.2**
T-mean	Summer	14.3	15.1	14.4	15.0	16.8	17.1	17.3	18.3
	SW Monsoon	21.2	21.4	21.5	22.5	23.0	25.3	24.7	24.9
	Post Monsoon	13.1	14.2	13.4	14.5	15.5	15.4	15.8	15.7
	Winter	7.4	7.0	7.0	7.8	8.9	8.8	9.2	9.7
	Annual	**14.7**	**15.0**	**14.8**	**15.6**	**16.7**	**17.5**	**17.5**	**17.7**

Temperature : Standard deviation is higher at Katrain for minimum and at Bajaura for maximum temperature. But, Pd values are higher at Katrain for both of temperatures (Table 4). The annual and seasonal maximum, minimum and mean temperature was increased during all the decades except during 1981-90 at Katrain (Table 5). The increasing trend is more pronounced for minimum than for the maximum temperature also, it was showing a higher rate of increase during the last decade.

5. Conclusion

In Kullu valley the apple belt has moved 30 kilometers northwards (higher altitude) from Bajaura to Raisan (Anonymous, 2007) indicate the impact of global warming the climate of Kullu valley. The valley as a whole (Bajaura + Katrain) is not showing any significant trend in the annual rainfall but an increasing frequency of extremes and inter & intra-annual variability. Monsoon rainfall of wettest months was showing a decreasing but non significant trend. While the annual average temperature was showing an increasing trend but, the difference in decadal means was not significant except in the last decade (2001-09). Particularly the maximum temperature at Bajaura has shown a sharp rise for both summer and winter maximum temperature from 1981-1990 to 2001-2009. The maximum temperature was more variable during summer months and the minimum temperature during winter months in the valley. The frequency of extremes and fluctuations in rainfall and temperatures were higher during the recent period. Such changes may cause variations in weather & crop cycles,

crop rotations. yield attributes, crop development stages, *e.g*., in apple bud break, fruit setting, fruit size, colour development, chilling requirement etc. which further affect the quantity & quality and hence, production of agricultural & horticultural crops in the state.

Acknowledgement

The author is grateful to the Associate Director of Hill Agricultural Research Station, Bajaura and Head, IARI Regional Research Station, Katrain for providing the climatological data and to his parents for encouraging him for the present analysis.

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