Analysis of rainfall and temperatures for climatic trend in Kullu valley

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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 climate 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 Intergovernmental 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 assess 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 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

| Month   | Mean (mm) | Median (mm) | SD (mm) | 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 |
| Apr     | 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)

| Month | T-max Mean | Median | SD | CV(%) | Pd(%) | Pr(%) | T-min 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)

| Month   | Mean | Median | SD  | CV(%) | Pd(%) | Pr(%) | Mean  | Median | SD  | CV(%) | Pd(%) | Pr(%) |
|---------|------|--------|-----|-------|-------|-------|-------|--------|-----|-------|-------|-------|
| T-max   |      |        |     |       |       |       |       |        |     |       |       |       |
| 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 rainfall. 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 |
| T-max         | 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         | 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        | 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              | 7.8              | 8.9       | 8.8     | 9.2     | 9.7     | 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.

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