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Short Communication

Variability and time series trends of rainfall and temperature in Indian Himalaya

PANKAJ PANWAR[1,*], SHARMISTHA PAL[1], NANCY LORIA[1], MED RAM VERMA[3], N.M. ALAM[2], V.K. BHATT[1], N.K. SHARMA[2] and P.K. MISHRA[2]

[1]*ICAR-Indian Institute of Soil and Water Conservation, Research Center- Chandigarh,*
[2]*ICAR-Indian Institute of Soil and Water Conservation, Dehradun,*
[3]*ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh*
[*]*Corresponding author: dr_pankajp@yahoo.co.in*

India is among the worst affected nations where the changes in temperature and rainfall have been observed (IPCC 2014). Generally reduced rainfall and rising temperature results in drought, whereas high intensity rainfall limits ground water recharge by accelerating runoff thus causes floods. Therefore, strengthening and better understanding of temperature and rainfall trends in the region could provide robust technical information for improving land and water management to enhance crop productivity in the face of climate change. Generally local climate data are limited, assessment methods are usually not uniform and the instrumentation is not sufficiently standardized (Negi *et al*., 2012). Therefore the present study was made to analyse the changes in climatic parameters for understanding vulnerability of north western Himalayan state of India.

Shimla and Dharmshala, the summer and winter capital respectively of Himachal Pradesh were selected for the study. Shimla, representing upper Himachal Pradesh, is situated at an altitude of 2103 m above mean sea level and while situated at an elevation of 1279 m above mean sea level. Average annual temperature is 14.5 °C at Shimla (1969-2015) and 19.2 °C at Dharmshala (1980-2015). Correspondingly annual rainfall is 1365 mm (with snowfall in winter) and 2629 mm.

Meteorological data on monthly temperature (minimum and maximum) and rainfall were obtained from Indian Meteorological Department (IMD) Research Station Shimla, Himachal Pradesh. Data of 46 years (1969 to 2015) for Shimla; and 35 years (1980 to 2015) for Dharmshala were obtained was analysed annually, monthly and season wise for four principal seasons i.e. winter (December, January, February), pre monsoon (March, April, May), monsoon (June, July, August, September) and post monsoon (October, November).

The statistical significance of the trend in monthly, seasonal and annual series was analysed by using the non-parametric Mann-Kendall (MK) test. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend (Mann, 1945; Kendall, 1975).

The Mann–Kendall statistic is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sign}(x_j - x_i)$$

Where n is the number of data points x_j and x_i are two generic sequential data values.

The magnitude of the trend in the annual, seasonal and monthly time series data of temperature and rainfall was determined by using Sen's nonparametric method (Sen, 1968). The Sen's estimator is the median of slopes of all data value pairs calculated as:

$$b = \mathrm{median}\left[\frac{x_j - x_i}{j - i}\right] \text{ for all } i < j$$

where b is the slope between data points x_j and x_i measured at times j and i respectively. Sen's slope b are robust approximation of trend magnitude. A positive estimation of b is likely to show upward trend and negative values is likely to show downward trend.

Monthly trend analysis

Magnitude and significance of the trend for temperature and rainfall using Sen's estimator and Mann Kendall's Z statistics, are given in Table 1. For minimum temperature there is highly significant increasing trend (at 1% probability) as reflected by positive values in all the months except April at Shimla. At Dharamshala trend value were positive and negative, but were not significant. This corroborates the observations of Das *et al*. (2007) who reported both an increase and decrease in the minimum temperatures in the southern and northern regions of India

Table 1: Details of minimum temperature for Shimla and Dharmshala

Month/Season	Sen's estimator of slope		Minimum temp (°C)	
	Shimla	Dharmshala	Shimla	Dharmshala
January	0.06**	-0.01	2.5	5.7
February	0.06**	-0.04	3.4	7.1
March	0.07**	-0.01	7.1	10.5
April	0.03	-0.06	11.5	15.1
May	0.06**	-0.05	14.6	19.0
June	0.05**	-0.03	15.9	20.8
July	0.07**	-0.03	15.6	20.1
August	0.07**	-0.05	15.3	19.4
September	0.06**	-0.02	13.8	18.0
October	0.03**	0.02	11.0	14.7
November	0.05**	0.01	7.7	10.4
December	0.04**	0.00	4.8	7.3
Annual	0.06**	-0.02	10.3	14.3
Winter	0.05**	-0.03	3.5	5.6
Pre-monsoon	0.05**	-0.03	11.1	15.0
Monsoon	0.06**	-0.02	15.1	19.1
Post Monsoon	0.04**	0.015	9.3	12.7

** and * denotes significance of trends at 1% and 5% level of significance respectively based on Mann Kendall's Z statistics (+ for increasing and – for decreasing)

with inter-annual variability caused by deforestation and land degradation at local scale.

Analysis of monthly maximum temperature showed significant rising trend for all the months at Shimla while at Dharamsala it was only for five months (i.e. January, March, October, November and December; Table 2). Rana *et al*. (2012) also indicated higher than average signals of warming in Himachal Pradesh upland than lowland regions. Increasing trend at Palampur and Shimla for monthly maximum temperature was also reported by (Prasad *et. al*., 2017). At Dharmshala, the trend was statistically significant at 1 per cent significance level only for the month of March as indicated by higher values of Sen's slope estimator, 0.12°C. The significant rising trends in maximum temperature are consistent with increasing trends reported by Pal and Tabbaa (2010) in western Himalaya.

Monthly rainfall data had a mixture of rising and falling trends at both Shimla and Dharmshala stations (Table 3). At Shimla the rainfall has a rising trend for seven months with only significant during February (Sen's slope estimator value of 1.27); and declining trend for four months as indicated by positive and negative values of Sen's slope estimator. At Dharmshala values were statistically significant for only two months *i.e.* July (9.83) and August (10.84). The decreasing trends in total rainfall of Shimla and Dharmshala are similar to that over Himachal as reported by Prasad and Rana (2010).

Seasonal trend analysis

At Shimla trend analysis of seasonal minimum temperature (Table 1), maximum temperature (Table 2) showed highly significant rising trend annually as well as during all the seasons. Rainfall also showed increasing trend except during post monsoon (Table 3). At Dharmshala minimum temperature showed declining trend in all seasons except the post-monsoon season, but none of the values were found to be significant (Table 1). Rainfall increased significantly annually and during monsoon (Table 3). Increasing trends in seasonal variability of minimum temperature over the lower Indus basin in the north-western Indian Himalayas were also observed by Singh *et al*., (2008), which may be due to urbanized area and changes in atmospheric circulation that has caused increasing trends in

Table 2: Details of maximum temperature for Shimla and Dharmshala

Month/Season	Sen's estimator of Slope		Maximum temperature (°C)	
	Shimla	Dharmshala	Shimla	Dharmshala
January	0.10**	0.07 *	10.6	15.5
February	0.09**	0.06	11.7	17.1
March	0.11**	0.12 **	16.0	21.4
April	0.06**	0.04	20.8	26.6
May	0.07**	0.04	24.1	30.5
June	0.06**	0.00	24.5	31.1
July	0.06**	0.04	22.5	27.6
August	0.07**	0.00	21.6	26.7
September	0.08**	0.02	21.7	26.7
October	0.06**	0.04 *	20.1	25.2
November	0.08**	0.05 *	16.6	21.6
December	0.08**	0.07 *	13.3	17.6
Annual	-0.07**	-0.05 **	18.6	24.0
Winter	0.09**	-0.07 **	11.6	15.2
Pre-monsoon	-0.07**	-0.08 **	20.3	26.1
Monsoon	-0.07**	0.01	22.5	28.1
Post Monsoon	-0.07**	0.04	18.4	23.5

** and * denotes significance of trends at 1% and 5% level of significance respectively based on Mann Kendall's Z statistics (+ for increasing and – for decreasing)

air temperature series. Sontakke *et al*. (2009) also observed declining trend in rainfall of the western Indian Himalaya region for the period 1960–2006 without mentioning statistical significance.

Significant rising trends in minimum and maximum temperature for almost all months and all seasons at Shimla suggests introduction of low chilling cultivars of apple at Shimla. Increasing trend in rainfall during monsoon and increased rainfall intensity (I30) at 0.95 mm $hour^{-1}$ $year^{-1}$ could result in more soil loss and runoff. Thus more efforts should be diverted toward soil and water conservation in Dharmshala, which represents lower Himachal.

Thus, better understanding the trends of temperature and precipitation based on statistical analysis can be of help to identify the suitable thermal and drought tolerant cultivars and such agronomic management practices in western Himalayan region which optimise the agricultural production in changed climate.

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Table 3: Details of rainfall for Shimla and Dharmshala

Month/Season	Sen's estimator of Slope		Rainfall (mm)	
	Shimla	Dharmshala	Shimla	Dharmshala
January	0.67	-0.38	54.1	85.7
February	1.27 *	1.21	70.1	121.5
March	1.09	-0.04	74.4	124.2
April	0.45	0.11	55.0	69.2
May	-0.23	-0.16	76.5	76.7
June	-0.05	2.80	190.2	235.9
July	0.36	9.83 *	323.0	714.5
August	0.75	10.84 **	300.1	768.0
September	-0.06	4.95	150.7	310.7
October	-0.08	0.83	32.5	57.4
November	0.00	-0.04	17.3	24.6
December	0.27	-0.53	24.8	54.6
Annual	0.43	2.98 **	114.0	221.8
Winter	0.93 **	0.24	49.6	82.9
Pre-monsoon	0.43	-0.18	68.6	90.0
Monsoon	0.19	8.78 **	241.0	507.3
Post Monsoon	-0.22	0.28	25.4	43.5

** and * denotes significance of trends at 1% and 5% level of significance respectively based on Mann Kendall's Z statistics (+ for increasing and – for decreasing)

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