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Trends in temperature and rainfall extremes during recent years at different stations of Himachal Pradesh

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ABSTRACT

Daily maximum and minimum temperatures of 4 stations and rainfall of 22 stations of Himachal Pradesh for the period of 1970 to 2014 have been used to work out extreme climate indices and trends. The temperature and rainfall indices for different stations studied showed no uniform trend. The results indicated the increasing trend in minimum of maximum and minimum of minimum temperature. The increased frequency of warm nights and warm spell but decrease in the number of hot days and hot nights were observed at Bajaura and Shimla. The maximum one day rainfall amount, maximum 5-day rainfall during the month and very wet days were found to decrease at most of the stations in the state. Consecutive wet days (CWD) and annual total rainy days (PRCPTOT) showed statistically mixed trends at various stations in the state.

Key words: Extremes, climate indices, precipitation, temperature, rainfall, trend

The term 'Global warming' and 'Climate change' are often used interchangeably, but there is a difference between these two. Global warming is the gradual increase of the earth's average surface temperature due to green-house gases in the atmosphere, whereas the 'Climate change' is a broader term. It refers to long-term changes in climate; including changes in average temperature and rainfall pattern due to climate change. The globally averaged surface temperature data shows a linear warming trend of 0.85 °C (0.65 to 1.06 °C) during the period 1880–2012 (IPCC, 2014). The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 °C (0.72 to 0.85 °C), based on the single longest dataset available (IPCC, 2013). In the context of global warming, the study of extreme weather events has become important due to its impact on socio-economic activities (Karl and Easterling, 1999). Various extreme weather events over the India in the past 100 years have been reviewed and their causes and socio-economic impacts are discussed (De *et al*., 2005). A widespread warming over Indian region through both frequency and intensity indices of temperature extremes has been noticed by Revadekar *et al*. (2012). The significant increasing trends have been observed in fifteen states of India including Himachal Pradesh with the highest (+0.06 ^{o}C/year) increase in winter mean maximum temperature in Himachal Pradesh followed by Goa, Manipur, Mizoram and Tamil Nadu (+0.04 to 0.05 ^{o}C/year) (Rathore *et al*., 2013). A study on the trends in extreme rainfall indices for the period 1901 to 2000 over India showed significant positive trend for most of these indices over the west coast and north-western parts of Indian peninsula (Joshi *et al*., 2006). Increasing frequencies of heat stress, drought and flooding events are also projected for the rest of the century and these are expected to have greater impacts on sectors with closer links to climate, such as water, agriculture and food security (IPCC, 2012). Therefore, keeping in the view, the impact of increasing changes in climate, an attempt has been made in present study to study the trends in temperature and rainfall extremes in Himachal Pradesh (at station level) over past few decades.

MATERIALS AND METHODS

The observed daily data of maximum and minimum temperature of 4 stations and rainfall of 22 stations in Himachal Pradesh during the period 1970 to 2014 has been used to calculate various extreme climate indices. The time period for which data of various stations is used given in Table 1. The RClimDex, a program script written in R language developed at the Meteorological Service of Canada was used for weather data quality assessment and also for working out the indices and their trends (Zhang and Yang, 2004). Station records with more than 25% of the data either missing or recording zero for any particular index was not considered for analysis. The significance of each trend was examined at 95% confidence level.

Table 1: List of stations selected for the study

Stations	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (m)	Data base
Mandi	31.70	76.93	771	1970-2014
Hamirpur	31.70	76.50	782	1971-2014
Kumarsain	31.13	77.44	1693	1971-2014
Dharamshala	32.22	76.31	1246	1972-2013
Kandaghat	30.97	77.10	1484	1972-2014
Keylong	32.57	77.03	3098	1972-2014
Pachhad	30.56	77.30	1567	1972-2014
Rohru	31.20	77.75	1553	1972-2014
Dehra	31.87	76.32	767	1973-2013
Arki	31.15	76.97	1090	1973-2014
Nahan	30.55	77.28	677	1973-2014
Jubbal	31.10	77.70	1927	1974-2014
Karsog	31.38	77.20	1465	1974-2014
Palampur	32.10	76.54	1253	1974-2014
Theog	31.12	77.33	2033	1974-2014
Una	31.48	76.28	389	1974-2014
Kasauli	30.90	76.96	1783	1975-2014
Mashobra	31.13	77.22	2107	1981-2014
Ghumarwin	31.43	76.71	829	1982-2013
Shimla	31.09	77.17	2208	1985-2014
Bajaura	31.84	77.16	1074	1986-2014
Dhaulakuan	30.56	77.30	411	1987-2014
Banjar	31.63	77.34	1419	1988-2014

Table 2: Trends in temperature extreme indices

Index (Station)	Bajaura	Dhaulakuan	Palampur	Shimla
Hot days (SU25)	NS	0.596	0.66	NS
Tropical nights (TR20)	0. 33	0.036	-0.169	-0.089
Hot nights (TR25)	NS	-0.365	-0.021	NS
Warm nights (TN90p)	0.005	NS	NS	-0.203
Warm spell duration (WSDI)	0.197	NS	NS	0.697
Maximum of maximum temperature (TXx)	-0.014	-0.038	0.035	0.051
Minimum of maximum temperature (TXn)	0.018	-0.075	0.019	0.084
Maximum of minimum temperature (TNx)	-0.004	-0.071	-0.021	-0.035
Minimum of minimum temperature (TNn)	0.003	0.004	0.020	-0.058

RESULTS AND DISCUSSION

Trends in temperature extreme indices

The trends in temperature indices for different stations were ascertained following the test of statistical significance for each temperature index. The slope values of the all significant temperature extremes are given in the Table 2. The values of temperature indices showed mixed trends. The

Table 3: Trends in extreme rainfall events

Station	Highest one day rainfall (Rx1day)	Maximum 5-day Precipitation (Rx5day)	Simple daily intensity index (SDII)	Number of heavy precipitation days(R10)	Number of very heavy precipitation days(R20)	Consecutive dry days CDD	Consecutive wet days CWD	Very wet days R95p	Extremely wet days R99p	Annual total rainy days (PRCPTOT)
Arki	-0.165	-1.384	NS	-0.337	-0.238	0.185	-0.024	-2.34	-0.605	NS
Bajaura	-0.409	-0.843	-0.073	-0.23	-0.157	0.052	-0.009	-3.66	-0.902	-5.96
Banjar	-0.917	NS	-0.07	0.059	-0.125	0.269	-0.05	-1.741	-3.568	1.211
Dehra	-0.478	-0.564	-0.209	0.268	0.006	-0.746	0.036	-1.894	-1.182	4.026
Dharamshala	0.228	0.264	0.07	NS	0.193	-0.219	-0.104	3.352	0.043	11.217
Ghumarwin	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139
Hamirpur	-0.065	-0.065	-0.065	-0.065	-0.065	-0.065	NS	-0.065	-0.065	-0.065
Jubbal	-0.336	-0.095	-0.024	-0.238	-0.081	0.351	0.025	0.542	0.574	-4.185
Kandaghat	-0.484	-1.095	-0.026	-0.214	-0.165	0.482	-0.055	-1.996	-1.32	-6.439
Karsog	0.171	-0.318	0.012	-0.103	-0.051	0.069	-0.037	2.058	1.3	-1.059
Kasauli	-1.064	-2.238	-0.236	-0.221	NS	-0.039	-0.083	-10.522	-3.119	-16.307
Keylong	-0.109	-0.042	-0.031	0.014	0.017	NS	0.011	-0.353	-1.041	0.968
Kumarsain	NS	NS	NS	0.345	0.204	0.077	0.001	NS	2.065	8.668
Mandi	-0.703	-1.517	-0.193	-0.114	-0.214	NS	-0.041	-5.14	-2.879	-6.593
Mashobra	-0.187	-0.88	-0.088	-0.272	-0.123	0.095	0.044	-4.977	-1.251	-6.735
Nahan	0.137	-0.744	-0.153	-0.037	-0.121	-0.232	-0.03	-0.609	0.524	-2.935
Pachhad	-1.295	-2.213	-0.063	NS	-0.233	0.323	-0.033	-6.451	-2.727	NS
Rohru	0.261	0.551	0.015	0.128	0.088	-0.653	0.07	3.703	0.682	6.076
Sarkaghat	1.86	3.089	0.095	0.144	0.211	0.36	0.091	6.194	4.003	11.658
Shimla	1.416	1.758	NS	0.521	NS	0.044	0.031	NS	3.282	NS
Theog	-0.749	-0.585	-0.065	-0.19	-0.103	0.146	-0.075	-2.228	-0.969	-5.301
Una	0.45	0.702	0.018	0.118	-0.016	-0.179	0.007	0.476	-0.309	1.927

trend for hot days (SU25) was observed to be significantly increasing at Dhaulakuan and Palampur whereas hot nights (TR25) were decreasing at these stations. Warm nights (TN90p) showed increasing trend at Bajaura and decreasing at Shimla whereas warm spell duration (WSDI) showed increasing trend at both of these stations. The trend of nights with minimum temperature below 20°C (TR20) was observed to be decreasing at Palampur and Shimla whereas it was increasing at Bajaura and Dhaulakuan.

The index of monthly maximum value of maximum of maximum temperature (TXx) indicated increasing trend at Palampur and Shimla whereas decreasing at Bajaura and Dhaulakuan. Events of minimum of maximum temperature (TXn) showed significantly increasing trend at Bajaura, Shimla and Palampur stations whereas decreasing at Dhaulakuan. Events of maximum of minimum temperature (TNx) are showing decreasing trend at all the stations whereas minimum of minimum temperature (TNn) is increasing at all the stations except Shimla. Though annual count of hot days (SU25) and hot nights (TR25) are observed to be non significant at Bajaura but the tendency of the intensity for minimum of maximum and minimum of minimum temperature has shifted for more number of days which might had consequence for not allowing sufficient chilling hours for apple flowering in the Kullu region.

The observations for the extreme temperature indices during past 45 years showed mixed trends. In a similar study conducted by Lunagaria *et al*. (2015) in Gujarat, also found

mixed trends for temperature indices at majority of the stations. Generally increasing trend in mean maximum temperature during winter, summer, post monsoon, annually and during each month has been reported for Himachal Pradesh over the last six decades (Rathore *et al*., 2013). The time period considered for analysis and methodology adopted in present study might be the one of the reasons for non conformity of results with them.

Trend in extreme rainfall events

The trends for rainfall indices were observed to be mostly significant but they were mixed, both increasing and decreasing. The index of maximum one day rainfall amount (RX1day) was observed to be decreasing significantly at 14, increasing at 7 and non significant at one station out of 22 stations studied (Table 3). In case of maximum five day rainfall (RX5day) also, trends were significantly decreasing at 14 and increasing at 6 stations. Very wet days (R95) and extremely wet days (R99) also showed deceasing trends at 13 and 14 stations, respectively. In case of heavy precipitation days (R10), very heavy precipitation days (R20) and consecutive wet days (CWD), trends were again observed to be decreasing at 12, 13, and 11 stations, respectively. Consecutive dry days (CDD) and annual total rainy days (PRCPTOT) showed statistically mixed trends. This observation is contrary to the existing belief that extreme heavy precipitation are on rise in Himachal Pradesh as the most of the indices are observed to be decreasing at more number of stations. Rathore *et al*. (2013) has also reported reduction in rainfall in the order of 2.85 mm/year during southwest monsoon (June to September), 0.21 mm/year during post monsoon (October to December) and 3.26 mm/year annually (January to March) in the state. Mixed trends for RX1, RX5day and R100 indices have been observed by Lunagaria *et al*. (2015) in Gujarat.

CONCLUSION

Mixed trend pattern was observed in the state for most of the temperature and rainfall extreme indices. The trend in hot days was observed to be significantly increasing at Dhaulakuan and Palampur whereas hot nights were decreasing at these stations. The rainfall indices had also no uniform pattern for negative or positive trend throughout the state. The index of maximum one day rainfall amount (RX1day), monthly maximum 5-day rainfall (RX5day) and very wet days (R95p) were observed to be decreasing at more numbers of the stations. The rainfall is the parameter having very high variability, in some of indices i.e., consecutive wet days (CWD) and Annual total rainy days (PRCPTOT) showed statistically mixed trends. The present study, therefore, indicates somewhat ambiguous trends in rainfall in Himachal Pradesh.

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