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Short Communication

Detection of heat wave trends in semi-arid climate of Udaipur, Rajasthan

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The number, duration and area of spread of heat waves in India increased sharply during 1991-2000 in comparison to the earlier two decades, according to a study by the Indian Meteorological Department (Bhatta, 2009). Predictive studies indicate that an accelerated rise in stream and river water temperatures will occur during the next century because of global warming (Webb, 1996). Udaipur district (study area), situated in the hard-rock hilly terrains of Aravalli Range in Rajasthan (the largest and driest state of India) suffers from frequent droughts due to abnormally high summer-temperature and inadequate water resources (Bhuiyan *et al.,* 2006).

The study area (Udaipur, 24°35' N; 73°42' E, 582.17 m MSL) comes under agro-climatic zone IV-A of Rajasthan. The climate of the study area is tropical, semi-arid and hot. May is the warmest month of the year, with mean daily maximum and minimum temperatures of 38°C and 24°C, respectively. January is the coldest month with mean daily maximum and minimum temperatures of 24°C and 7.8°C, respectively. The mean annual rainfall is 624 mm (1901-2008) and the principal crops are maize, sorghum, groundnut, cotton, black gram, wheat, barley, gram and mustard.

The monthly mean maximum air temperature time series along with 3-year moving average time series were plotted on time scale of more than three decades (1977-2009) and are shown in Figs. 1(a-f) as an example for six months, i.e., January, February, March, April, November and December which clearly depict an increasing trend. However, the present trend is not statistically significant as indicated by the low R^2 value.

Difference in the mean annual maximum and minimum temperature over three decades, i.e., 1977-1986, 1987-1996 and 1997-2006 is compared in Table 1. There has been a significant increase of about 1°C indicating a gradual increase in the maximum air temperature. The annual difference in the maximum and minimum temperature also show increasing trend.

Heat waves as defined by the India Meteorological Department (IMD), Pune, India (IMD, 2009) i.e. if daily maximum air temperature is more than 5 °C above normal, then it is said to be affected by heat waves. Firstly, the total number of days affected by heat waves was counted for individual months of the year for a period of 33 years (1977-2009) and for individual three decades.

Annual heat waves' affected days are shown as barcharts in Fig. 2. Annual frequency of the heat waves over the last three decades showed a rise of 5 days in the heat waves' affected days. Furthermore, it is seen that the last decade had a significant rise in the duration of heat waves as compared to the earlier two decades. The mean annual duration of heat waves in the decade 1977-86 and 1987-96 was 67 and 62 respectively, whereas, the last decade (1997-2009) had 70 days. Thus the annual frequency of the heat waves' affected

Table 1: Comparison of minimum and maximum temperature over three decades

Period (Decade)	Maximum	Minimum	Difference
1977-86	30.6	16.4	14.1
1987-96	30.8	16.2	14.6
1997-06	31.2	16.4	14.9

Table 2: Results of Mann-Kendall trend test

S. No.	Period	Computed Test-Statistic	Critical Test-Statistic	Remark
1	1977-2009	-0.05	±1.96	Not Significant
2	1977-1986	-0.89	±1.96	Not Significant
3	1987-1996	-1.79	±1.96	Not Significant
4	1997-2009	2.62	±1.96	Significant

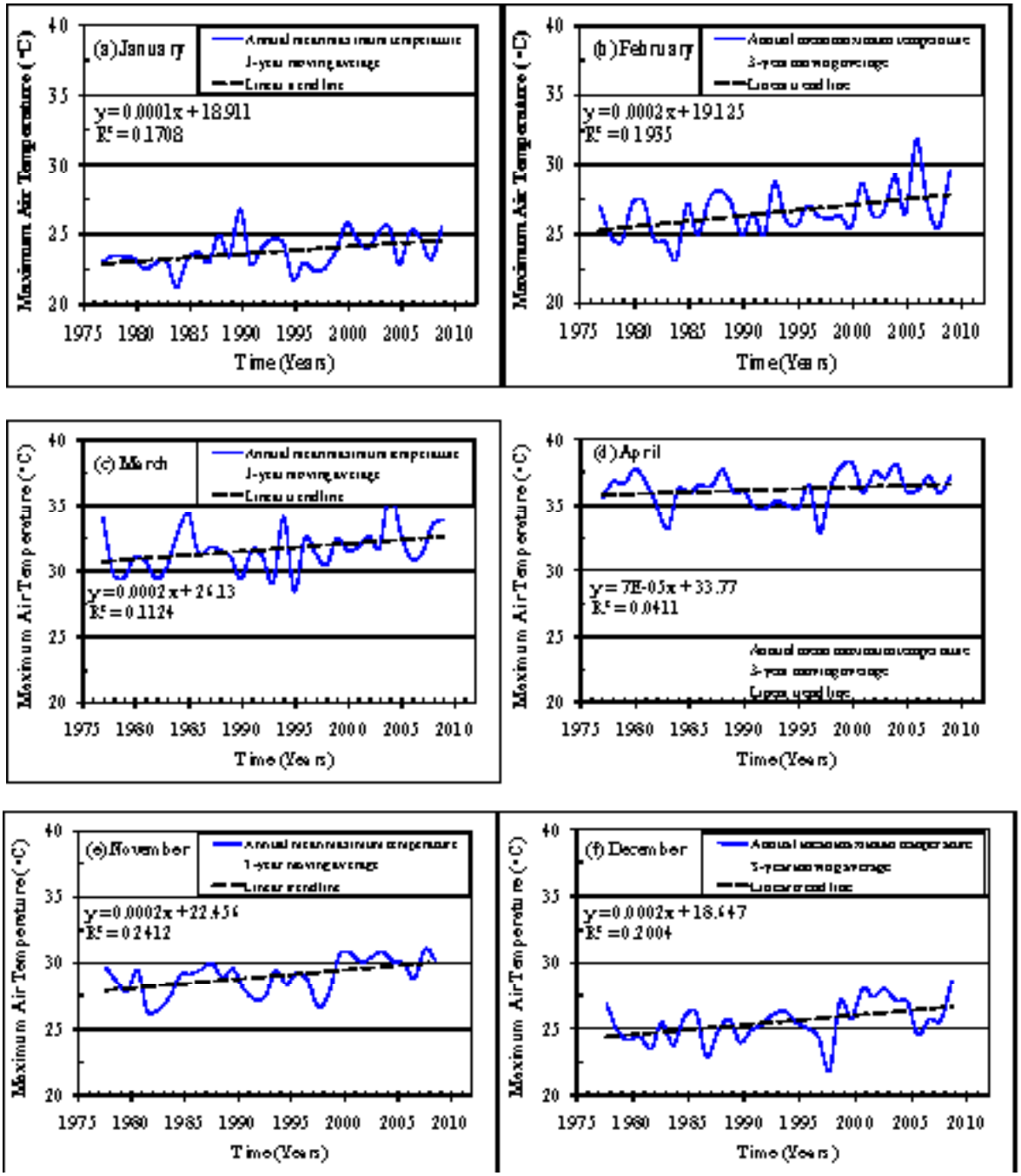

Fig. 1(a-f) : Time plots of maximum temperature and 3-year moving average time series

days has an increasing linear trend. It is apparent that number of heat waves' affected days was more than 70 in 5 years during 23-year period (1977-1999), whereas, this happened in 8 of the past decade (2000-2009).

A time series of annual heat wave index was generated and then trend was detected by applying Mann-Kendall Test. The definition of the annual heat wave index involves computation of apparent body temperature that describes the combined effect of maximum air temperature and mean relative humidity. The analyses of heat wave index followed the approach used by Meehl and Tebaldi (2004). Daily maximum air temperatures and mean relative humidity were converted to apparent body temperature (T_a) using

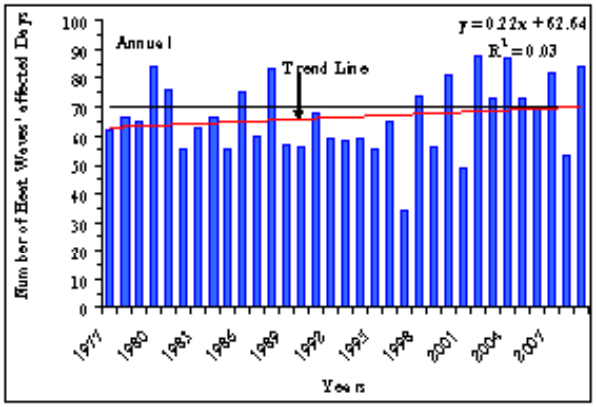

Fig. 2: Annual frequency of heat waves' affected days

the approximated non-linear expression . The time series of annual heat wave index was subjected to univariate Mann-Kendall (MK) test in order to detect monotonic trends (Hirsch and Slack, 1984). Results of the Mann-Kendall test are presented in Table 2. The computed test-statistic value (-0.05) is within its critical value (±1.96) in case of entire 33-year period time series of annual heat wave index and similarly, for earlier two decades (1977-1986 and 1987-1996) indicating that they are free from any trends. However, the computed test-statistic value (2.62) for the last decade (1997-2009) is not within the critical limits (±1.96). Thus, a significant increasing trend is present (p>0.05) in heat wave index series of the last decade at 5% significance level.

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