

Is summer becoming more uncomfortable over major cities of India?

One of the predicted fallouts of the established global warming is the increase in frequency of extreme events like cyclone, heavy rainfall, flood, heat waves, etc. across different parts of the world on varying scale/intensity. It was also noticed that the nineties were the warmest years over major parts of the world during the last 100 years. Combined with the increased humidity, abnormal high temperatures during summer could create more uncomfortable conditions and may even become lethal at times. Various studies examining the trend in meteorological parameters/extreme events are available¹⁻⁴. However, in spite of the general belief that summer over the mega cities in our country is becoming more uncomfortable/intolerable in recent decades, there are not many studies to either support or discard this belief. The present study aims to examine the same.

We have calculated thermo-hygrometric index (THI) popularly known as discomfort index on the pentad and monthly scales for the months of April, May and June over six major cities of India, viz. Delhi, Kolkata, Chennai, Mumbai, Pune and Bangalore, by using daily data of maximum temperature (T_{max}) and relative humidity (rh) at 1200 h UTC (Universal Time Coordinate), from the year 1969 to the latest available year for the individual station. Daily values of discomfort index (THI) were calculated using the following formula by Besancenot⁵.

$$THI = T_{max} - [(0.55 - 0.0055 rh) (T_{max} - 14.5)]^{\circ}C.$$

From the daily values of discomfort index, running pentad and monthly indices for each individual month for different years of study were calculated. These were subjected to the Mann-Kendall trend analysis to examine the trend if any. It is to be mentioned here that classification of moderate ($26.5^{\circ} \leq THI < 28.5^{\circ}C$) and high ($THI \geq 28.5^{\circ}C$) discomfort situations are valid for extra tropical countries only, as THI values for tropical countries like India are always greater than $28.5^{\circ}C$ over major parts of the country,

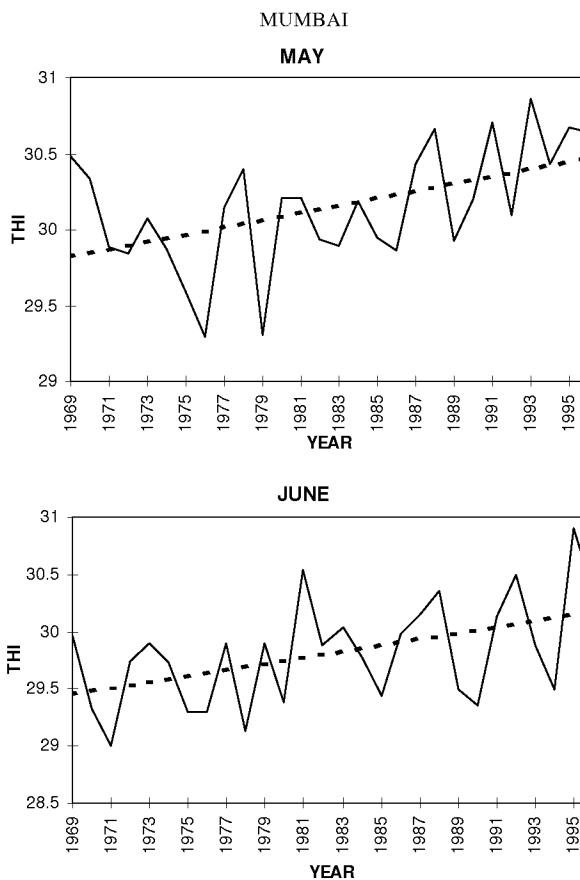


Figure 1. Significant trend noticed in monthly discomfort values over Mumbai for may and June.

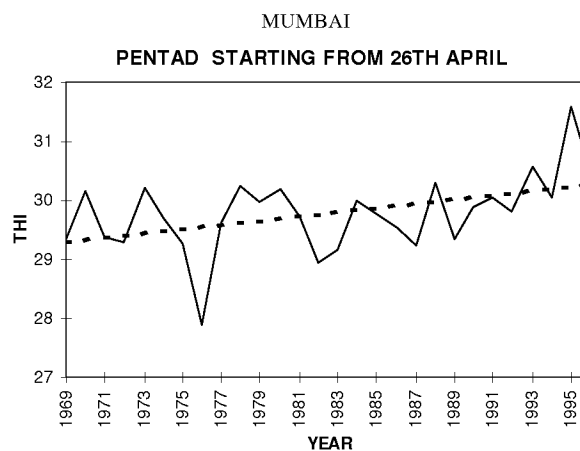


Figure 2. Significant trend noticed in the pentad discomfort indices over Mumbai for April.

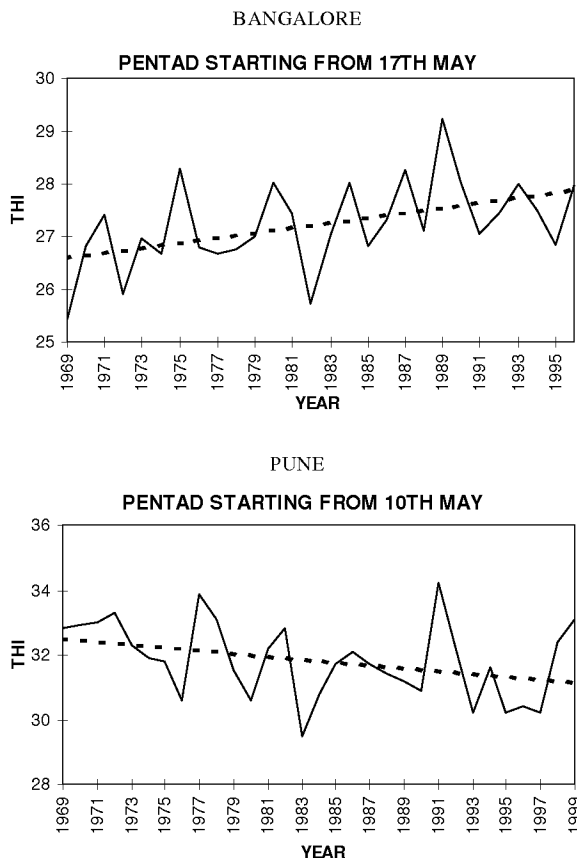


Figure 3. Significant trend noticed in the pentad discomfort indices over Bangalore and Pune for May.

particularly during summer. Therefore, threshold values for different discomfort conditions for tropical countries need to be evaluated. This is beyond the scope of the present study which simply aims to find the trend in discomfort indices only.

For April, most of the monthly discomfort values for different years were found to lie in range of mean monthly value \pm standard deviation and were evenly scattered for all the six stations under study. This indicates that probably no discernible trend exists. Subsequent trend analysis by applying Mann-Kendall test also confirmed that there was no significant trend in the monthly values of discomfort indices for April over all the six stations. The same was found to be true for May and June also, except for Mumbai where monthly values of discomfort indices for recent years often exceeded the range in positive direction, indicating the presence of an increasing trend. Mann-Kendall trend analysis also showed an increase-

ing trend significant at the 1% level in the monthly values of THI for both May and June over Mumbai (Figure 1) indicating that Mumbai is becoming more uncomfortable during May and June.

As we could not find any significant trend in the monthly values of THI over other stations, except Mumbai, trend analysis was carried out for running pentad values of THI for all the three months over all six stations under study. Significant trends found in the pentad values of April, May and June are shown in Figures 2 to 4 respectively. During April, only Mumbai showed significant increasing trend in the pentad values starting from 26 April (Figure 2). During May, significant increasing trend was noticed over Bangalore for pentads starting from 17 to 18 May, while significant decreasing trend was noticed over Pune for pentads starting from 10 to 11 May. These results (one each for Bangalore and Pune) are shown in Figure 3. For June,

significant increasing trend in the pentad THI values starting from 1 June over Bangalore and 3-6 June over Pune was observed. Similarly, significant decreasing trend was noticed in the pentad values starting from 18 to 19 June over Pune. These results (one from each category) are shown in Figure 4. It is also to be mentioned that significant increasing trend was found in most of the pentad values for both May and June over Mumbai and this is already reflected in the trend noticed in the monthly values of THI (Figure 1). It is interesting to note that for Delhi, Kolkata and Chennai, no significant trend was noticed in the pentad values of all the three months. This simply implies that over these stations comfort/discomfort conditions have not changed significantly during the period of study, even on smaller time scale. It is to be mentioned here that the whole study has been made using the data from existing meteorological observatories, which were considered to be representative of the city. But there might be several pockets within these cities itself where in smaller spatial scales, increase in the discomfort due to heat island and other effects may be noticed. To examine the same, simultaneous observations in various parts of the cities, usually by mobile observatories are needed.

We also examined the trend in the temperature and humidity values of different stations for the pentad and monthly scales, corresponding to the periods when THI showed significant trends. Significant increasing trend was found in the monthly values of temperature and humidity over Mumbai for both May and June. For other stations and corresponding pentads, temperature and humidity showed similar qualitative trends as those of THIs, but were not found statistically significant. Therefore, it could be inferred that even though there is no significant trend in temperature and humidity for a particular period, THI may have significant trend for the same period. This is quite possible as THI is a nonlinear function of temperature and humidity. We also found a decreasing trend in the daily rainfall values for the first ten days and the first six days in June for Pune and Bangalore respectively, which may be one of the reasons for increasing trend in the discomfort values for same period over Pune and Bangalore during June.

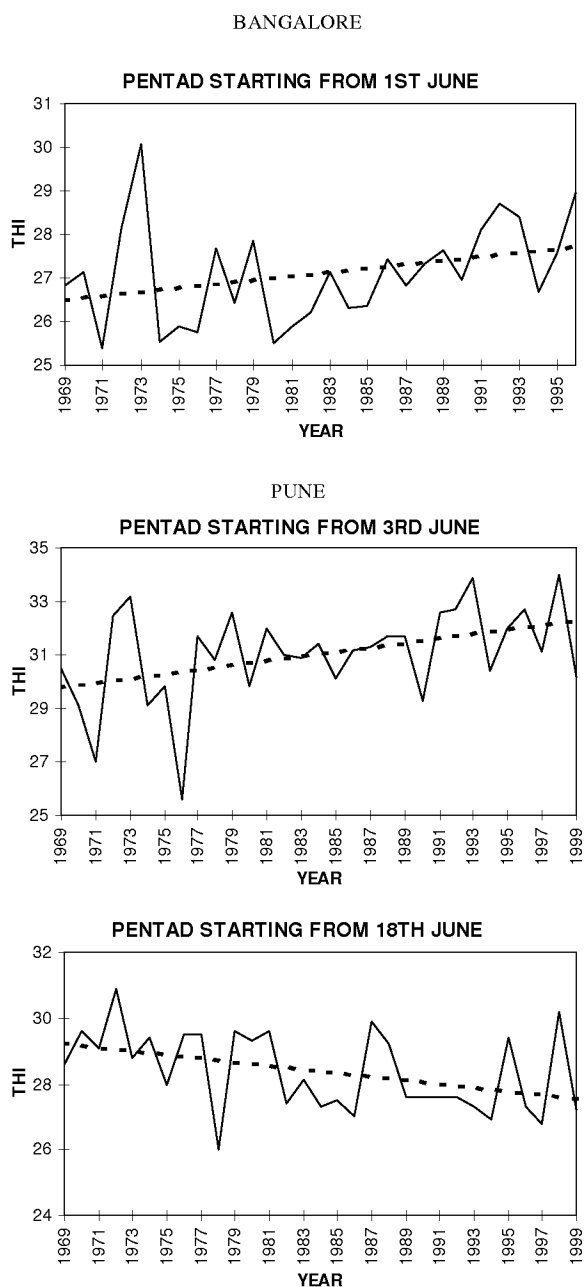


Figure 4. Significant trend noticed in the pentad discomfort indices over Bangalore and Pune for June.

Discomfort indices do not have significant trend on the monthly scale for

all the three months, April, May and June over all the stations under study,

except for Mumbai, where significant increasing trend in monthly values of discomfort indices was noticed. This implies that Mumbai is becoming more uncomfortable during May and June.

However, on pentad scale, significant trends in discomfort values were noticed over Bangalore and Pune during May and June. Other stations did not show any significant trend even on smaller scale.

First ten days of June over Pune and the first five days of June over Bangalore were found to have increasing trend in the discomfort indices, which may partially be due to the decreasing trend in the daily rainfall values for the corresponding period.

1. Srivastava, H. N., Dewan, B. N., Dikshit, S. K., Prakasa Rao, G. S., Singh, S. S. and Rao, K. R., *Mausam*, 1992, **43**, 7–20.
2. Srivastava, A. K., Sinha Ray, K. C. and De, U. S., *Mausam*, 2000, **51**, 115–118.
3. Sinha Ray, K. C. and Srivastava, A. K., *Curr. Sci.*, 2000, **79**, 155–158.
4. Sen, A. K. and Sinha Ray, K. C., Paper presented in INTROMET 1997 held at Indian Institute of Technology, New Delhi during 2–5 December 1997.
5. Besancenot, J. P., *Climate and Tourism*, Paris, Masson, 1990.

ACKNOWLEDGEMENTS. We thank the Director General of Meteorology for providing the necessary facilities. Thanks are also due to Dr U. S. De, Additional Director General of Meteorology (Research) and Shri M. R. Das, DDGM(C) for constant encouragement and valuable suggestions.

Received 26 February 2001; revised accepted 14 May 2001

A. K. SRIVASTAVA*
 K. C. SINHA RAY
 R. V. YADAV

India Meteorological Department,
 Shivajinagar,
 Pune 411 005, India
 *For correspondence. (e-mail: imdpune@pn3.vsnl.net.in)