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Is summer becoming more uncomfortable at Indian cities?

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सार – हाल ही के दशकों में भूमंडलीय और क्षेत्रीय दोनों मापक्रमों पर तापमानों में विशेष बढ़ोतरी देखी गई है। उड़ीसा और आंध्रप्रदेश जैसे भारत के कुछ विशेष स्थानों में लू की असामान्य स्थितियाँ पाई गई है जिसके परिणामस्वरूप लू के प्रभाव से बीमारियों और मृत्युदर में बढ़ोतरी हुई है। यह आम धारणा है कि गर्मियों के दौरान, विशेष कर हाल ही के वर्षों में महानगरों का जीवन अधिक तकलीफदेह हो जाता है। इस शोध पत्र में सूचकांक (थर्मोहाइग्रोमीट्रिक इंडेक्स : टी. एच. आई.) से भारत के महानगरों में गर्मी से उत्पन्न तकलीफों की प्रवृति की जाँच करने का प्रयास किया गया है। इस जाँच से प्राप्त हुए परिणामों से यह पता चलता है कि आमतौर पर भारत के अधिकाँश महानगरों में अप्रैल से जून की अवधि के अंतिम 10 दिनों में गर्म मौसम से होने वाली तकलीफों में बढ़ोतरी देखी गई है। इसके अलावा, कुछ स्थानों में गर्मी के मौसम में होने वाली असाधारण तकलीफों के मानों से लगातार बने रहने वाले ऐसे समय की अधिकतम अवधि और बारम्बारता मई और जून के महीनों के दौरान विशेषरूप से लगातार बढ़ी है।

ABSTRACT. The recent decades have witnessed significant increase in temperatures both on global and regional scale. Some specific locations in India like Orissa and Andhra Pradesh have experienced unusually heat wave conditions resulting in increase in heat stress associated illnesses and mortality. There is a general belief that cities have become more uncomfortable during summer, particularly in the recent years. The present study is an attempt to examine the trend in discomfort over the Indian cities measured by an index (Thermo-Hygrometric Index: THI). Results show that in general there is an increasing trend in the discomfort from the last 10 days of April to June over most of the Indian cities. Further, frequency and maximum length of continuous periods exceeding abnormal discomfort values over a number of stations are steadily increasing particularly during May and June.

Key words – Discomfort indices, Uncomfortable condition, Mann-Kendall test, Trend analysis.

1. Introduction

The predicted fallouts of global warming include increase in frequency of extreme events like cyclone, heavy rainfall, flood, heat waves, etc. across different parts of the world on varying scale / Intensity. Therefore, it is desirable that trend in the meteorological parameters be examined. Various studies by *viz*., Sen Roy and Prasad (1991), Srivastava and Sinha Ray (1994), Srivastava *et al.* (1992, 1994), Subrmaniam *et al*. (1992), Sinha Ray *et al.* (1997), De and Rajeevan (1997), Sinha Ray and Srivastava (2000), Srivastava *et al*. (2000, 2002) have examined the trend in meteorological parameters / extreme events. However, inspite of the general belief that summer over cities in our country is becoming more uncomfortable / intolerable in recent decades, there are not many studies to either support or discard this belief. In this context, it may be mentioned that the Intergovernmental Panel on Climate Change (IPCC) in its report of 2001 has concluded that over the twentieth century, there has been a rise of 0.6° C (±0.2° C) in the mean global surface temperature. The rise is very spectacular in recent years and the 1991-2000 decade has been reported as the warmest decade of the twentieth century. Further, 2002 and 2003 were the second and third warmest years on record (the year 1998 was the warmest year). Combined with the increased humidity, abnormal high temperatures during summer could create more uncomfortable conditions and may even become lethal at times.

The present study aims to examine the trend in the discomfort condition over Indian cities during summer, measured by well defined thermo-hygrometric index. There are other discomfort indices developed by Phillips and Crowe (1984) and Giles *et al.* (1990) etc which involve hourly values of temperature and humidity. However, we have used formula used by Besancenot

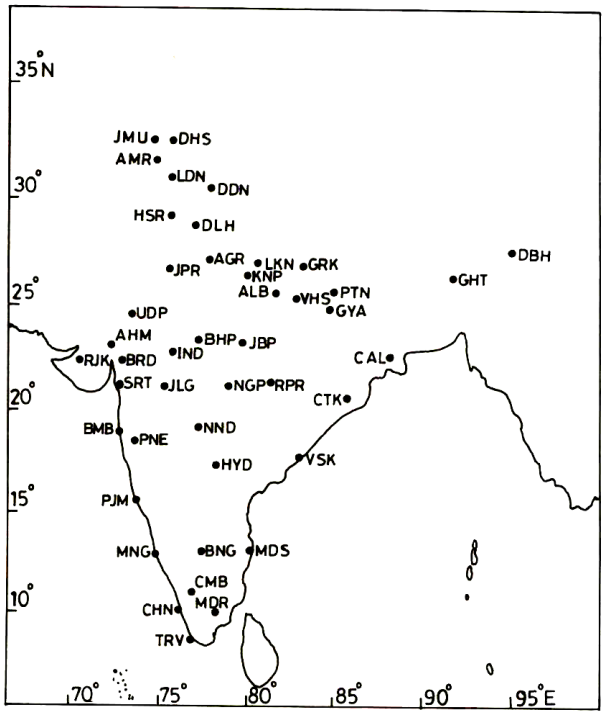


Fig. 1. Stations used in the study

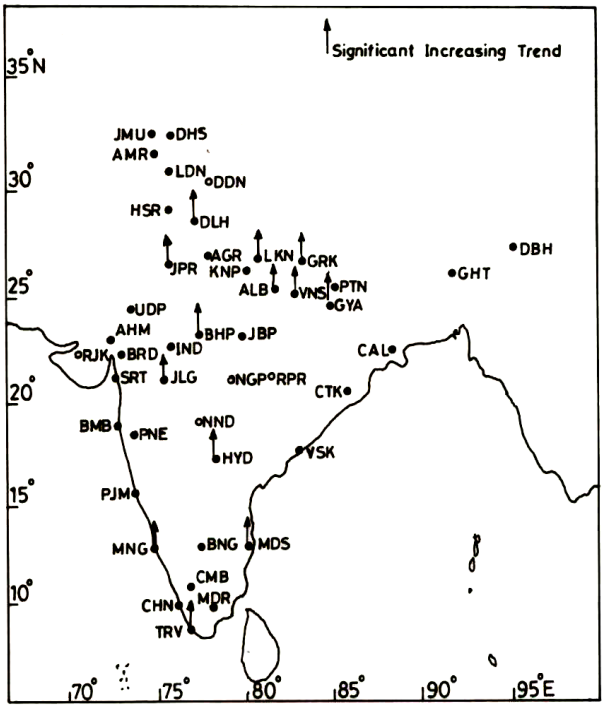


Fig. 2. Significant increasing trend observed in discomfort indices during last ten days of April

(1990), in which only maximum temperature and relative humidity at the time are used to have an idea of the optimum discomfort.

Earlier Srivastava *et al*. (2001) using daily data from the year 1969 to the then latest available year (data for Delhi and Calcutta were available only up to 1990) had calculated discomfort indices for pre-monsoon months for 6 major cities of India *viz*., Delhi, Kolkata, Mumbai, Chennai, Bangalore and Pune and examined trend in the same. On the monthly scale, no significant trend was noticed for stations under study except for Mumbai where an increase in discomfort conditions was observed for May and June months. However, on pentad scale, there was an increasing trend (significant) in the discomfort indices over Pune and Bangalore in one or two pentads. Delhi, Calcutta and Chennai did not show any significant trend on both the scales.

Therefore, the present study is an extension of the above study as it aims to examine the trend in the discomfort during summer over well distributed 44 Indian cities for which regular daily data for more than 25 years from the year 1969 are available.

2. Data and methodology

Daily data of maximum temperature and relative humidity at 1200 UTC for April, May and June months for well distributed 44 major Indian Cities (Fig. 1) for the period 1969-2002 were used for the study.

Discomfort index *viz*., thermo-hygrometric index "THI" for each day from April to June for all the stations, has been calculated by using the following formula given by Besancenot (1990).

$$\text{THI} = T_{\max} - [(0.55 - 0.0055\text{RH})\,(T_{\max} - 14.5)]\ ^\circ\text{C}$$

From the daily values of discomfort index, moving averages for ten days and mean monthly discomfort index values for each year were calculated. These values were subjected to the Mann-Kendall trend analysis (WMO, 1966; Technical Note No. 79) for examining trend, if any.

It may be mentioned that for each city, first, we examined trend on the monthly scale and if mean monthly discomfort indices for a city did not exhibit any significant trend, trend in moving averages of the ten days discomfort index values were examined.

It is to be mentioned here that Besancenot (1990) classified discomfort situations as moderate ($26.5^\circ \leq \text{THI} \leq 28.5^\circ$ C) and severe (THI > 28.5° C), which are valid for extra tropical countries. THI values for tropical countries like India are found to be generally greater than 28.5° C over major parts of the country, particularly during summer. Therefore, threshold values for different

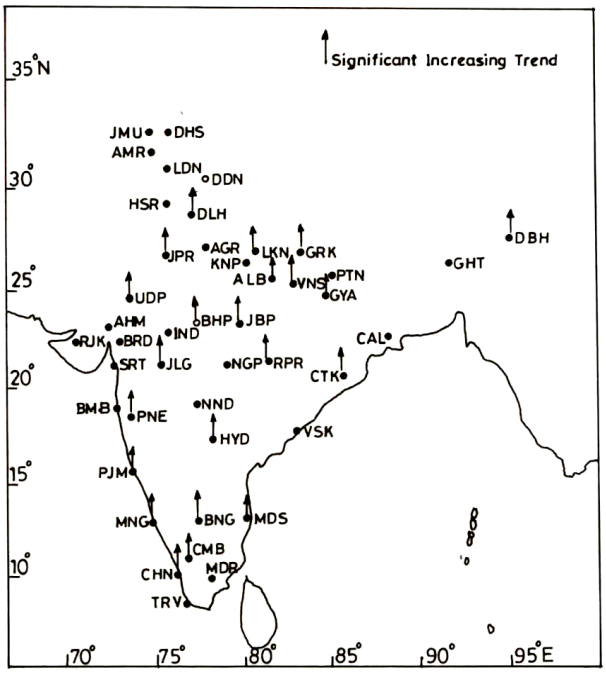


Fig. 3. Significant increasing trend observed in discomfort indices during May

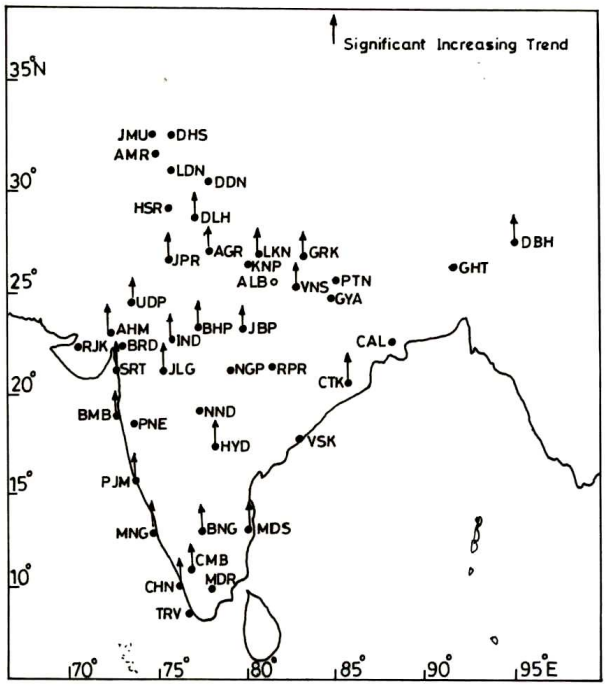


Fig. 4. Significant increasing trend observed in discomfort indices during June

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.

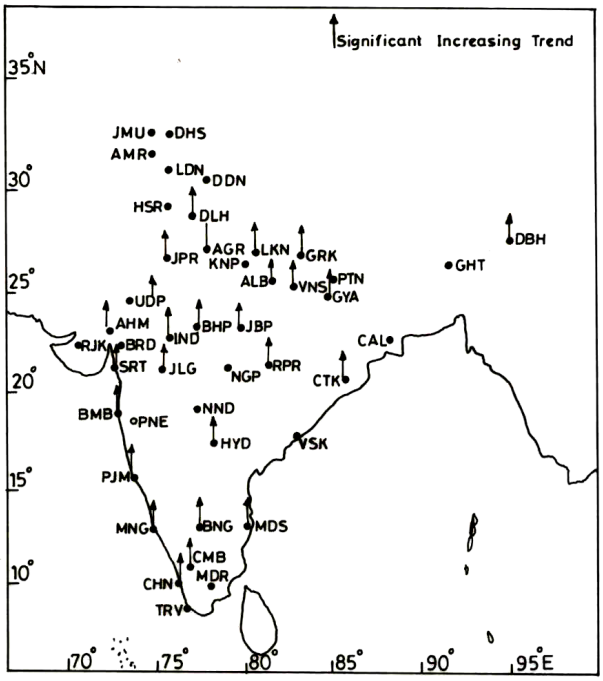


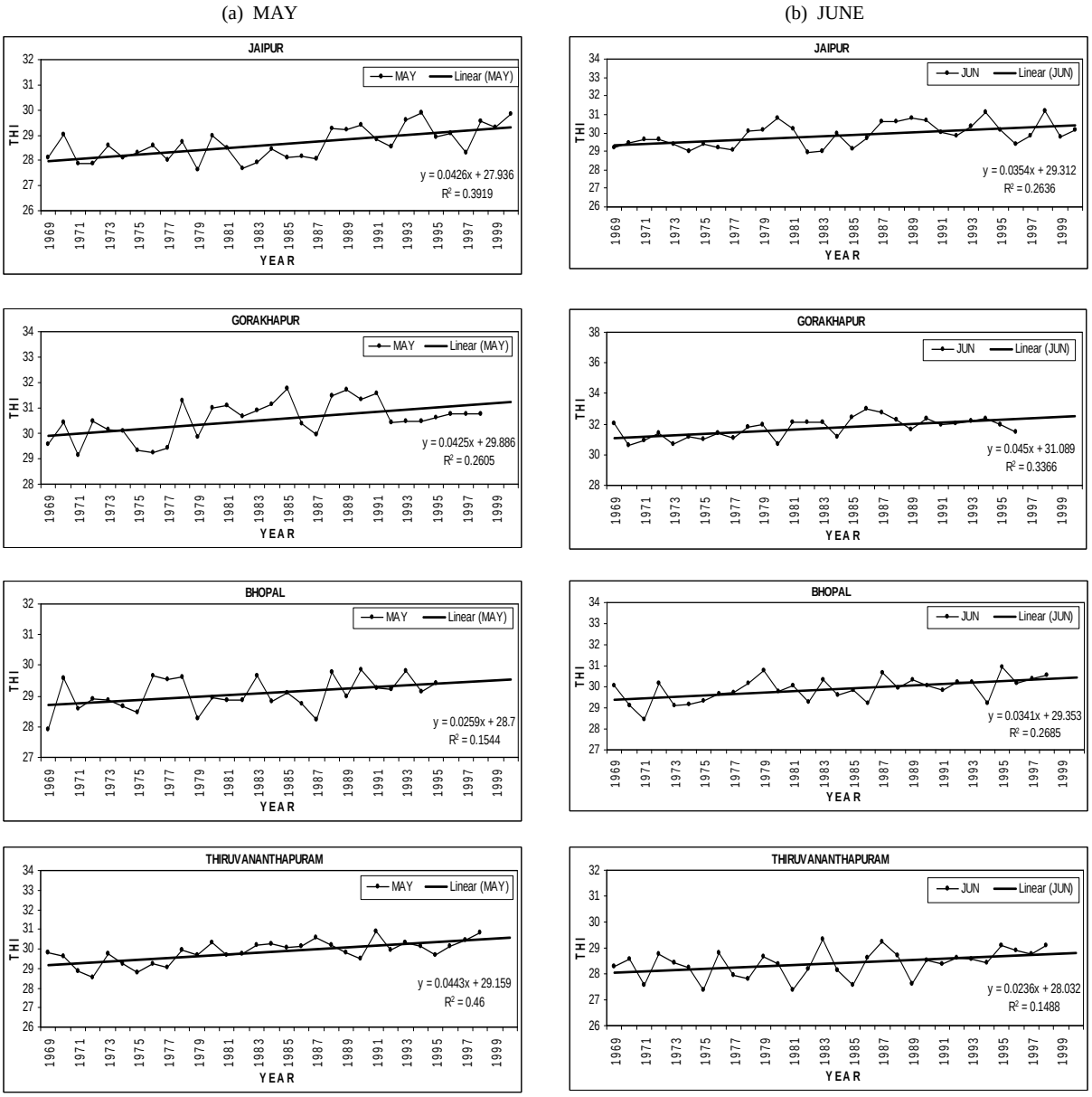
Fig. 5. Significant increasing trend observed during last ten days of May and first ten days of June

3. Results and discussion

(*i*) *Trend in the discomfort indices*

For the month of April, on monthly scale only 3 cities *viz*., Jaipur, Agra and Thiruvananthpuram showed significant increasing trend in the discomfort indices suggesting that April is becoming more uncomfortable for these 3 cities. These stations also showed significant increasing trend in almost all 10 days running average values of discomfort indices. However, a number of cities *viz*., Lucknow, Gorakhpur, Gaya, Allahabad. Varanasi, Bhopal, Jalgaon, Mangalore, Chennai, Thiruvananthapuram and Hyderabad showed an increasing trend in the discomfort in the last 10 days of April (Fig. 2).

For the month of May, a number of cities *viz*. : New Delhi, Hyderabad, Jaipur, Lucknow, Gorakhpur, Bhopal, Allahabad, Varanasi, Gaya, Raipur, Panjim, Chennai, Mumbai, Cochin, Dibrugarh and Cuttack showed significant increasing trend in almost all the ten days running averages of discomfort values. These stations also showed significant increasing trend in mean monthly discomfort indices (Fig. 3) of May. Some more stations



Figs. 6(a&b). Significant trend observed in the discomfort indices for (a) May & (b) June over four selected cities *viz*., Jaipur, Gorakhpur, Bhopal and Thiruvanathapuram

viz., Udaipur, Mangalore, Bangalore and Coimbatore also showed significant increasing trend in running ten days averages since May 20.

For the month of June, significant increasing trend was observed in discomfort indices over New Delhi, Gorakhpur, Varanasi, Panjim, Chennai, Mangalore, Cochin, Mumbai, Bangalore, Dibrugarh, Agra, Bhopal, Jabalpur, Jalgaon, Indore, Surat, Ahmedabad, Udaipur and Cuttack, in first ten days running averages of discomfort values. Further, Mangalore, Coimbatore, Cochin, New Delhi also showed significant increasing trend in the averages of discomfort indices of the last ten days of June also. On monthly scale, significant increasing trend was observed in discomfort indices over New Delhi, Gorakhpur, Varanasi, Panjim, Chennai, Mangalore, Cochin, Mumbai, Bangalore, Dibrugarh, and Agra (Fig. 4).

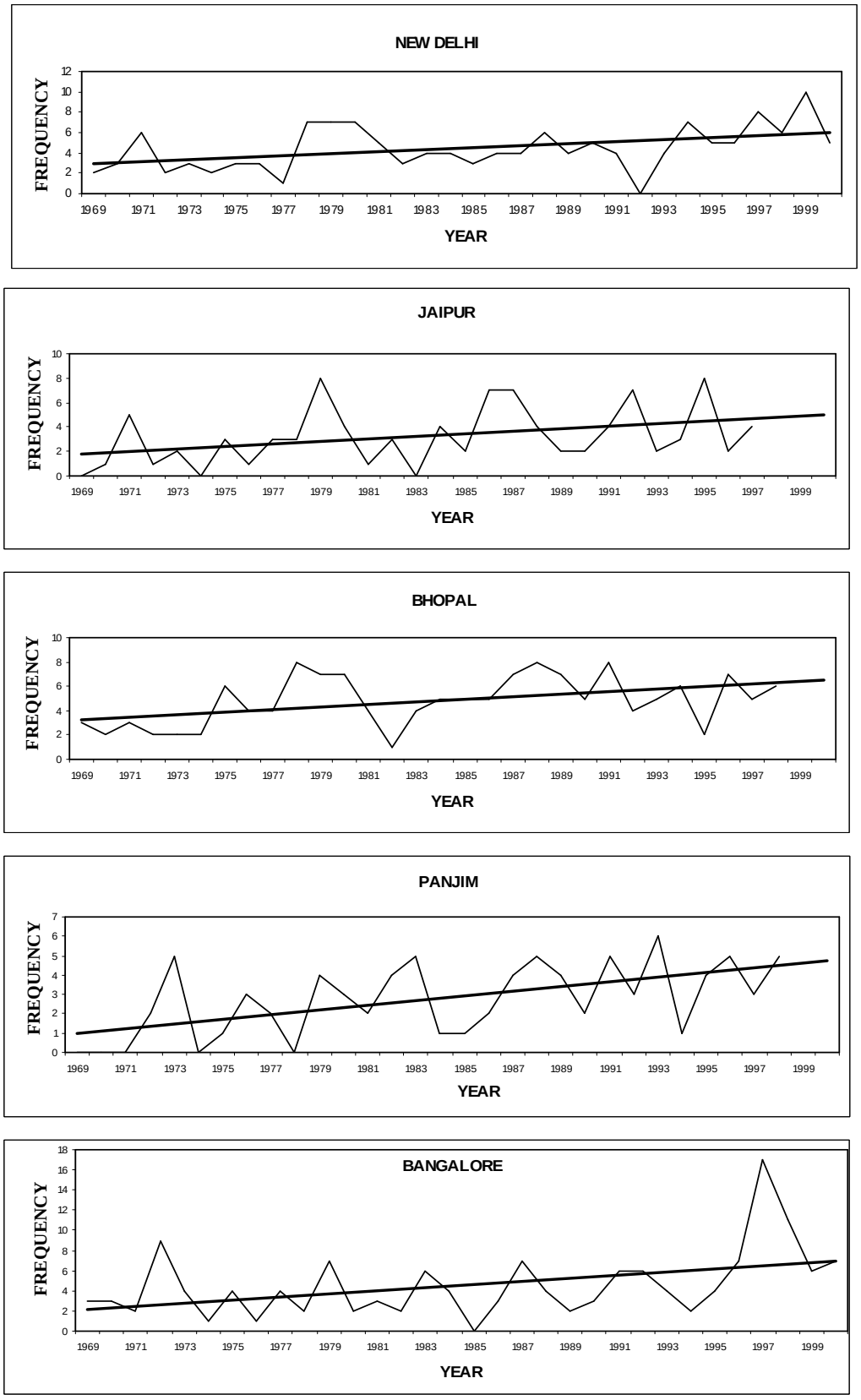


Fig. 7. Significant increasing trend in the frequency of discomfort indices exceeding mean monthly discomfort values +3 standard deviation over some stations during June

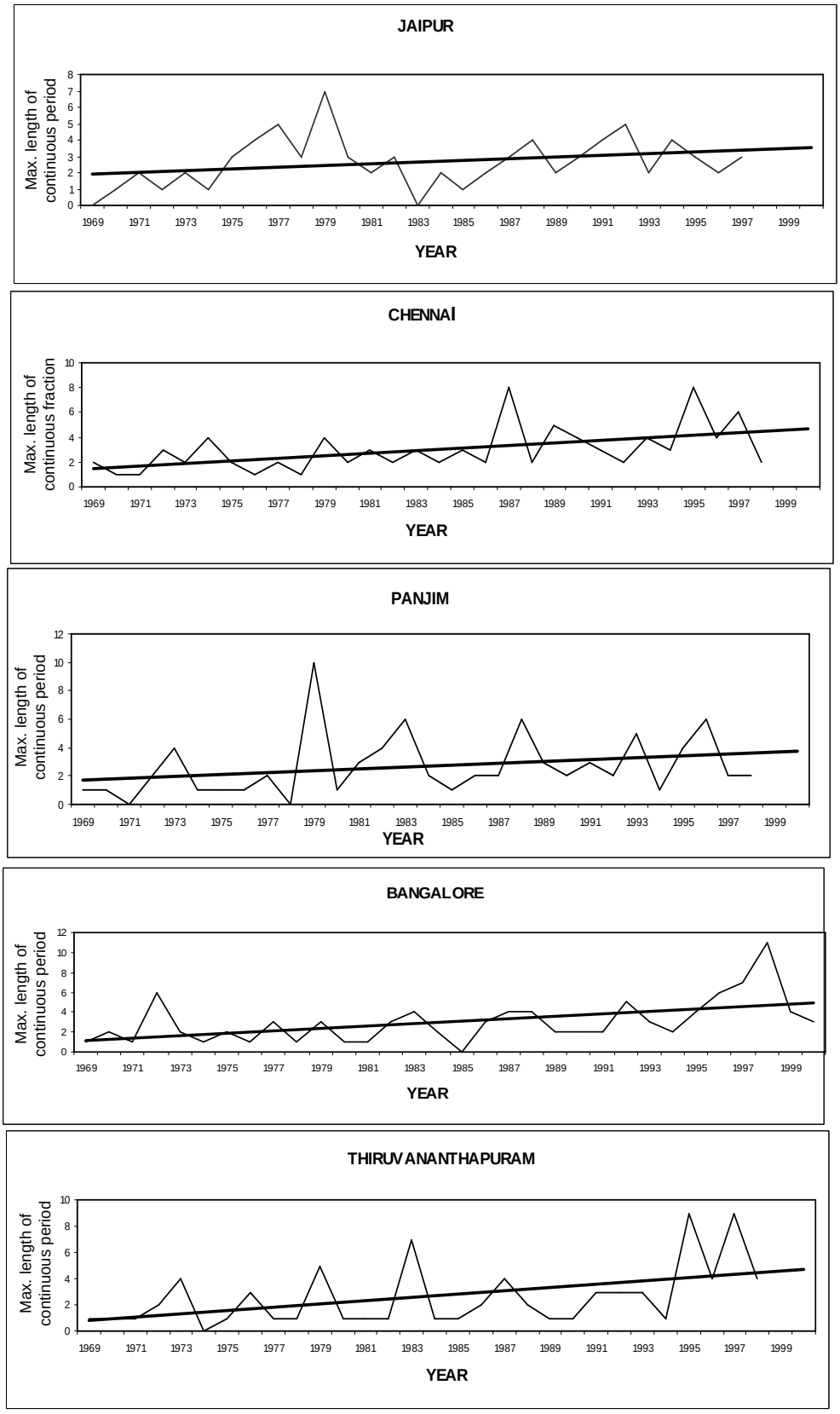


Fig. 8. Significant increasing trend in maximum length of continuous period exceeding mean monthly discomfort values +2 standard deviation over some stations during June

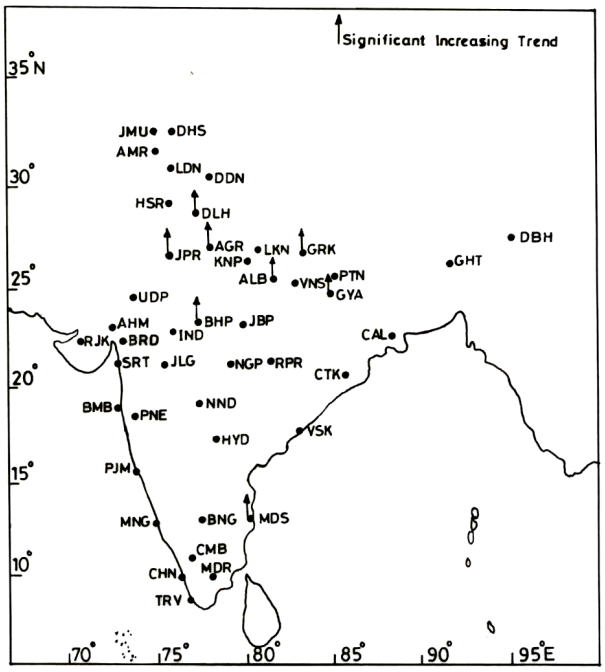


Fig. 9. Significant trend observed in relative humidity during May

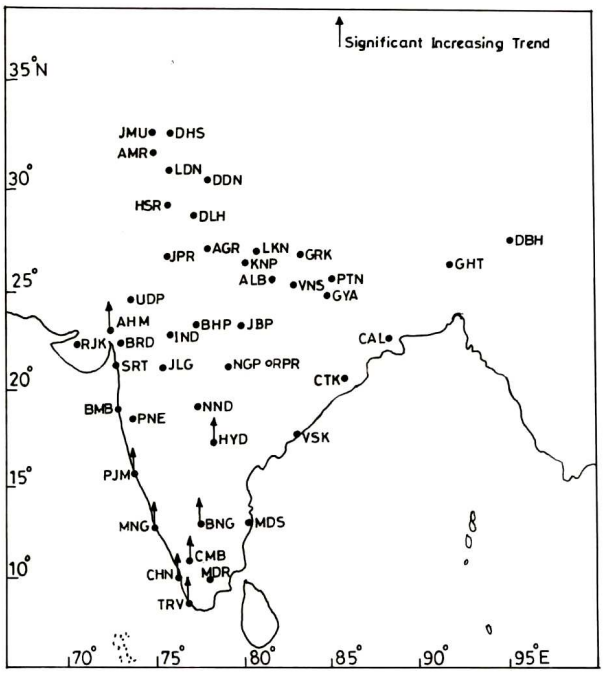


Fig. 10. Significant trend observed in maximum temperature during May

Thus, significant increasing trend in the discomfort indices were observed over as many as 26 cities out of 44 cities under study, for the last 10 days of May and the first 10 days of June (Fig. 5). This suggests that most of the Indian cities are becoming more uncomfortable during the last ten days of May and the first ten days of June. Significant trend in the four selected cities *viz*., Jaipur, Gorakhpur, Bhopal and Thiruvananthapuram during May and June is shown in Figs. 6(a&b).

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 [Daniel & Krishnamurthy (1973) and Mukherjee & Daniel (1976)] and other effects may also be noticed. To examine the same, simultaneous observations in various parts of the cities, usually by mobile observatories are needed.

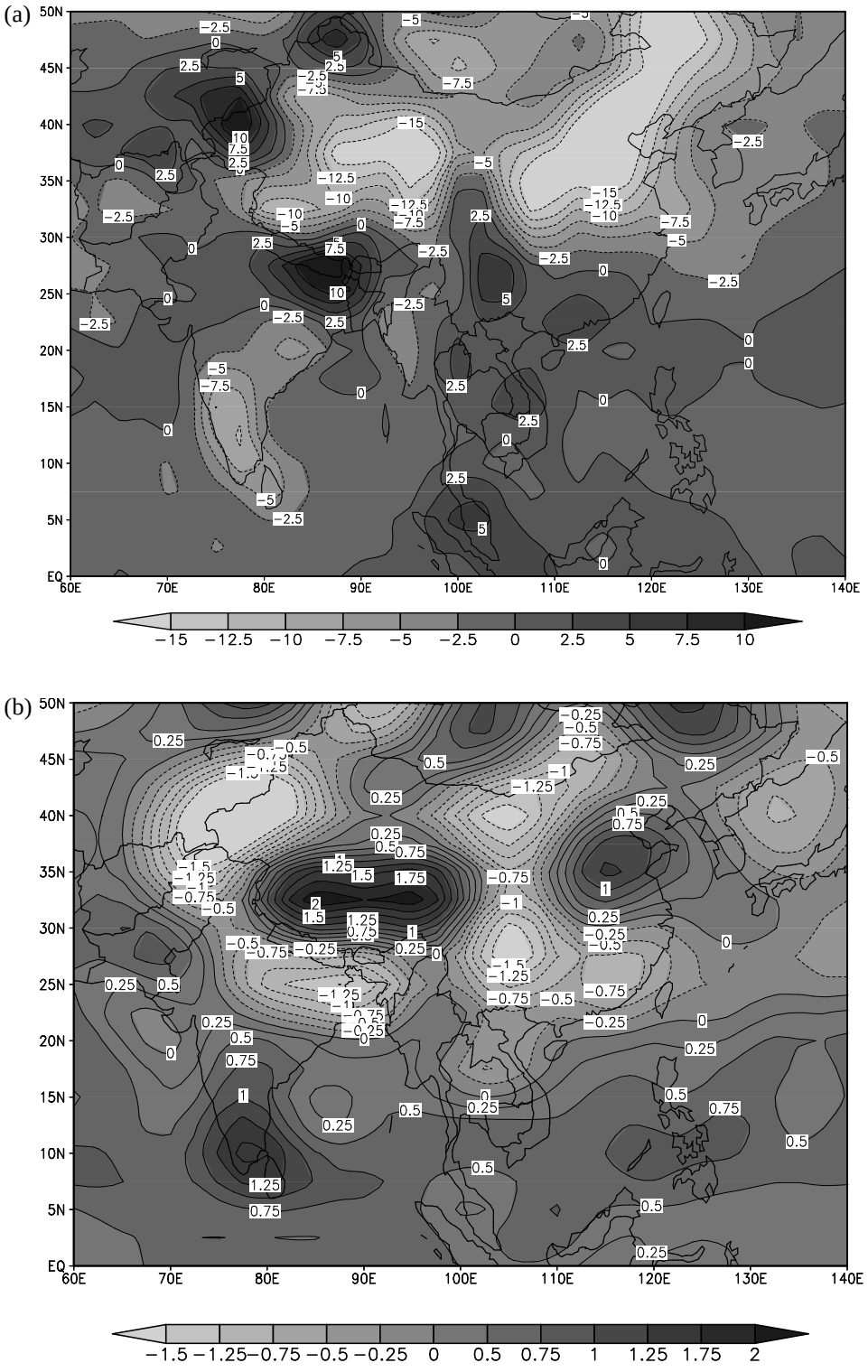
(*ii*) *Trend in the frequency and maximum length of continuous periods exceeding a specified threshold value of discomfort value*

For all the stations under study, we calculated monthly averages and standard deviations of the discomfort indices for all the three months. We further examined trend in the frequency and maximum length of continuous periods exceeding mean monthly discomfort values +1 standard deviation, mean monthly discomfort values +2 standard deviation and mean monthly discomfort values +3 standard deviation, etc. It was found that both the frequency and the maximum length of continuous period exceeding the above said values showed significant increasing trend over a number of stations in all the three months.

For April month, Jaipur, Udaipur, Mangalore, Cochin, Chennai, Thiruvananthapuram showed significant increasing trend in the maximum length and frequency of continuous periods exceeding mean monthly discomfort values +1 standard deviation.

For May month, Amritsar, Hissar, Agra, Jaipur, Lucknow, Udaipur, Kolkata, Hyderabad, Panjim, Mangalore, Coimbatore and Rajkot stations showed significant increasing trend in the maximum length of continuous periods exceeding mean monthly discomfort values +2 standard deviation and more. However a few lesser number of stations *viz*. : Jaipur, Lucknow, Gaya, Panjim, Bhopal and Mangalore stations showed significant increasing trend in the frequency of discomfort indices exceeding mean monthly discomfort values +2 Standard deviation and more.

For June month, Jaipur, Jalgaon, Panjim, Chennai, Mangalore, Bangalore, and Thiruvananthapuram stations



Figs. 11(a&b). Difference in mean monthly (a) Relative humidity and (b) Surface temperature, for the period 1971 to 2000 and 1951 to 1970. NCEP reanalysis data has been used to prepare this diagram

showed significant increasing trend in the maximum length of continuous periods exceeding mean monthly discomfort values +2 standard deviation and more. Similarly Jaipur, Lucknow, Hissar, Hyderabad, Coimbatore, Panjim, Bangalore, Thiruvananthapuram, New Delhi and Bhopal stations showed significant increasing trend in the frequency of discomfort indices exceeding mean monthly discomfort values +2 Standard deviation and more.

It may be mentioned that during June some stations *viz*. : Jaipur, Hissar, Thiruvananthapuram, New Delhi, Bhopal, Panjim, and Bangalore showed significant increasing trend in the frequency of discomfort indices exceeding even more than mean monthly discomfort values +3 standard deviation, indicating increase in the severe discomfort conditions over the stations in the month of June. Fig. 7 shows significant increasing trend in the frequency of discomfort indices exceeding mean monthly discomfort values +3 standard deviation over some stations during June.

Similarly, Fig. 8 shows significant increasing trend in the maximum length of continuous days exceeding mean monthly discomfort values +2 standard deviation over some stations during month of June.

(*iii*) *Trend in the maximum temperature and relative humidity*

As the discomfort is the integral impact of temperature and humidity, we have examined trend in the maximum temperature and relative humidity of the cities under study similar to the trend in discomfort indices, on monthly and ten day scales. This was done to ascertain the specific probable causes (whether temperature or humidity or the both) for the increasing trend in the discomfort conditions.

It was interesting to note that the most of the cities of the northern and central India showed an increasing trend in humidity, while cities of the peninsular and southern India report an increasing trend in the maximum temperature values (earlier also reported by Rupa Kumar *et al*. 1994). Cities showing significant trend in humidity and maximum temperature for the month of May are shown in Fig. 9 and Fig. 10 respectively.

To confirm above results, we examined NCEP reanalysis surface temperature and humidity data for the period 1951 to 2000 down loaded from NCEP website. We simply divided the data into two periods 1951-1970, 1971-2000 and calculated difference in the monthly means of temperature and humidity for two periods. For the month of May, results are shown in Figs. 11(a&b). It may be seen that relative humidity over the northern parts of the country has increased in the later period while temperature has risen over the peninsular and southern parts of the country. Similar results were obtained for the month of June also. This confirms the finding of our study that over the period, humidity has increased in the northern and central parts and maximum temperature has risen over the peninsular and southern parts of the country.

These two factors appear to be probable causes for this increasing trend in the discomfort indices over different cities of India.

We have also examined trend in daily rainfall series of different cities under study for the month of May and June. It was found that most of the stations over central and northern Peninsula *viz*., Nagpur, Ahmedabad, Hyderabad, Bhopal, Patna, Raipur etc. showed a decreasing trend in rainfall in the first ten days of June. This may also be one of the reasons for the observed increasing trend in the values of discomfort indices. However, even when, there is no significant trend either in maximum temperature or humidity for a station, discomfort indices may show an increasing trend as THI is non-linear function of maximum temperature and humidity.

4. Conclusions

This study has found that in general, on ten days scale, there is an increasing trend in the discomfort from the last 10 days of April to the June over most of the Indian cities. On monthly scale, many cities have shown significant increasing trend in the discomfort indices for the month of May and June. Further, the trend was significant over as many as 26 cities (nearly 60% cities under study) for the last ten days of May and first ten days of June. This clearly shows that the last ten days of May and first ten days of June are becoming more uncomfortable for most of the cities of India. Further, frequency and maximum length of continuous periods exceeding abnormal discomfort values over a number of stations are steadily increasing particularly during May and June.

This study has also highlighted that it is increase in the relative humidity which appears to enhance discomfort over the northern Indian cities while it is the rise in the maximum temperature which is mainly responsible for increasing discomfort over the central and southern Indian cities.

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