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Study of trend analysis and extreme events of temperature over Varanasi during summer monsoon season

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सार – इस शोध पत्र में 1971 से 2010 तक के दैनिक तापमानों के 40 वर्षों की समय श्रृंखलाओं के डेटाबेसों के आधार पर वाराणसी जिले में मासिक और मौसमी तापमानों के कालिक परिवर्तनों का विश्लेषण किया गया। तीन दशकों की दो अवधियों 1971-2000 और 1981-2010 तथा 1971 से 2010 से प्रारम्भ हुए चार दशकों के तापमान परिवर्तनों की भी जांच की गई और माध्य अधिकतम तापमान व माध्य न्यूनतम तापमानों की प्रवृत्तियों का पता लगाने के लिए मान-केंडल (MK) प्रवृत्ति जांच और सरल रैखिकीय समाश्रयण विश्लेषण दोनों किए गए। वाराणसी में चरम जलवायु परिवर्तन की प्रवृत्तियों की छानबीन करने के लिए विभिन्न चरम तापमानों के साथ-साथ उनकी अनुवर्ती आवृत्तियों को चुना गया।

मौसमी माध्य तापमान की उष्णता से मुख्यत :न्यूनतम तापमान, विशेषकर पिछले तीन दशकों के दौरान, में परिवर्तन होता है। मॉनसून पूर्व शीतलन और लू के दिनों में वृद्धि सहित इनके संबंध में बड़े पैमाने पर परिसंचरण के साथ, क्षेत्रीय और स्थानीय कारक अध्ययन वाले क्षेत्र में प्रेक्षित जलवायु को प्रभावित करने में महत्वपूर्ण भूमिका निभाते हैं।

ABSTRACT. Temporal changes in the monthly and seasonal temperatures over Varanasi District were analysed, based on the 40 years of time series databases of daily temperatures from 1971 to 2010. The temperature changes during the two tricades of 1971-2000 and 1981-2010 and also for four decades starting from 1971 to 2010 were investigated and both the Mann–Kendall (MK) trend test and simple linear regression analyses were employed to detect trends in the mean maximum temperatures and mean minimum temperatures. Various extreme temperatures criteria, as well as their corresponding frequencies, were chosen to explore the trends of extreme climate change over Varanasi.

The warming of seasonal mean temperature is mainly attributed to changes in the minimum temperature, particularly during the last three decades. A pre-monsoon cooling and its association with increase in heat wave days suggest that, alongwith large-scale circulation, regional and local factors may have played a vital role in influencing the observed climate in the studied area.

Key words – Mann-Kendall (MK), Temperature, Tricades, Heat wave and severe heat wave.

1. Introduction

There are a number of ways extreme climate events can be defined, such as extreme daily temperatures, extreme daily rainfall amounts, large areas experiencing unusually warm monthly temperatures, or even storm events such as hurricanes. Extreme events can also be defined by the impact an event has on society. That impact may involve excessive loss of life, excessive economic or monetary losses, or both. Epstein (2005) studied biologic responses such as casualties and spread of disease, to extreme events, such as heat waves, droughts and floods, which had increasing impacts on human society.

Previous researchers mainly emphasized on the long-term trends in mean temperatures. Liu *et al*. (2004) analyzed daily climate data from 305 weather stations in China for the period from 1955 to 2000 and observed trends in maximum and minimum surface air temperatures and daily temperature range.

Coumou and Rahmstorf (2012) reviewed and argued that for some types of extreme - notably heat waves, but also precipitation extremes - there is now strong evidence linking specific events or an increase in their numbers to the human influence on climate. Karl and Easterling (1999) studied negative effects of weather and climate extremes on society and found that it can harm ecosystem in many obvious ways (*e.g.*, floods, droughts, damaging high winds, extreme heat and cold etc.) resulting into large losses of human life, agriculture, engineering structures such as dams and exponentially increasing costs associated with them. Consequently, in recent years, extreme weather and climate events have received increased attention. Human-induced climate change has the potential to alter the prevalence and severity of extremes such as heat waves, cold waves, storms, floods and droughts. The frequency increase of extreme temperature events reduces yields in warmer regions due to heat stress at key level, quality of life for people and increases water demand, water quality problems, risk of heat-related mortality.

According to Easterling *et al*. (1999) lack of long-term climate data suitable for analysis of extremes is the single biggest obstacle to quantifying whether extreme events have changed over the twentieth century, either worldwide or on a more regional basis.

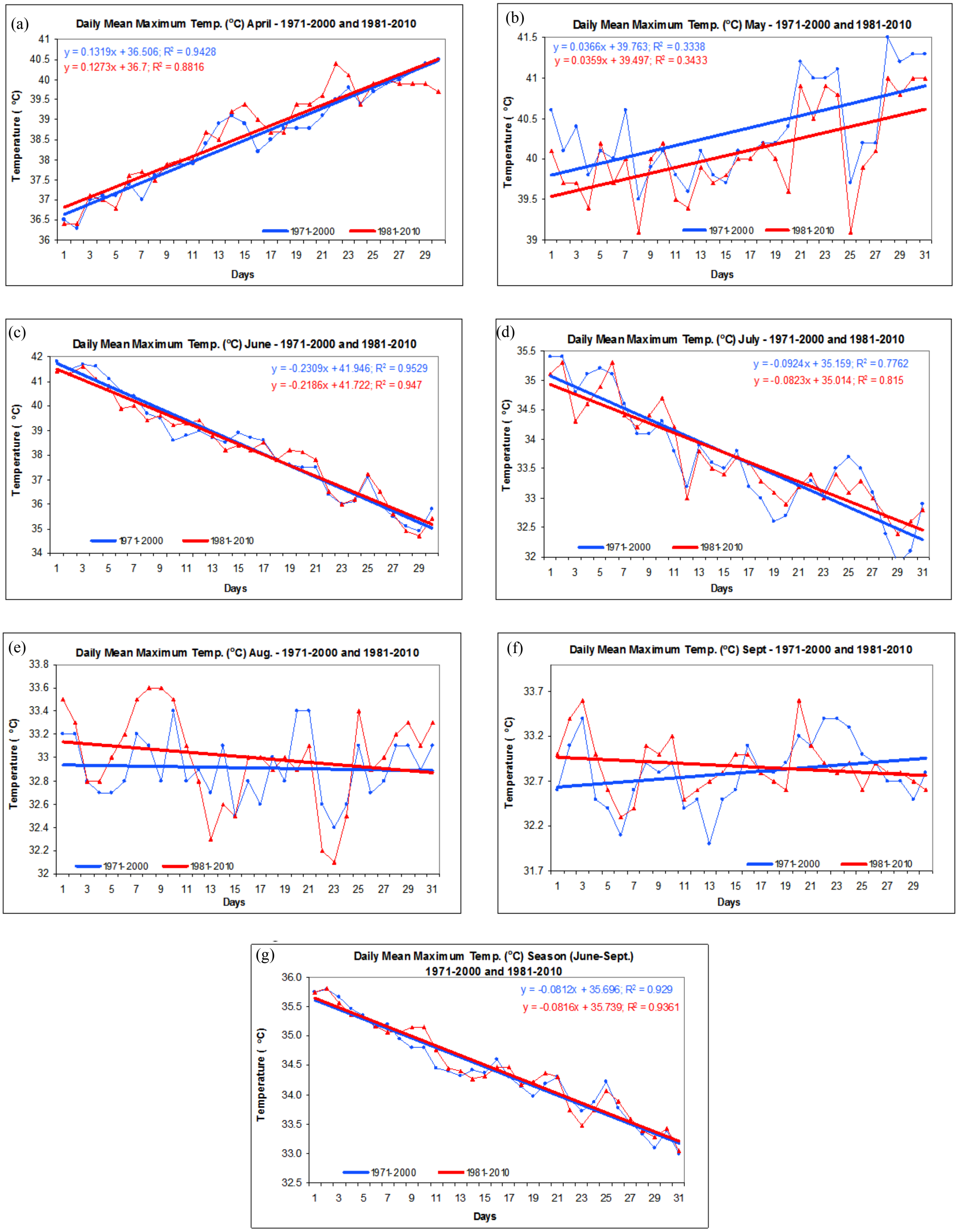
The relationships between changes in mean temperature and the corresponding changes in the probabilities of extreme temperature events are quite nonlinear, with relatively small changes in mean temperature sometimes resulting in relatively large changes in event probabilities (Mearns *et al*., 1984). Mason *et al*. (1999) studied the theoretical, modelling and empirical analysis and suggested that remarkable changes in the frequency and intensity of extreme events, including floods, may occur when there are only small changes in climate. Vyver (2012) applied a variety of efficient trend estimation methods to estimate how temperature extremes are locally changing. He also examined temporal patterns of changes in extreme daily maximum or minimum temperature at homogeneous climate stations located in Belgium and their associations with changes in climate means for the period since 1952/1953. Jones (2000) observed that the frequency of extreme events is more when tropical activity associated with the MJO (Madden - Julian Oscillation) is high. Arora *et al*. (2005) studied the trends in temperature time series of 125 stations distributed over the entire India.

Possible changes in the frequency of rain events in India in terms of their duration and intensity per day was examined using daily gridded (1° × 1°) rainfall data for the period 1951-2004 (Dash *et al*., 2009). They found that the frequencies of moderate and low rain days considered over the entire country have significantly decreased in the last half century. On the basis of the duration of rain events it is inferred that long spells show a significant decreasing trend over India as a whole while short and dry spells indicate an increasing tendency with 5% significance. A significant rise in air temperature is found in the northwest Himalayan region by about 1.6 °C in the last century, with winters warming at a faster rate. The diurnal temperature range (DTR) has also shown a significantly increasing trend. (Bhutiyani *et al*., 2007). Hirsch and Slack (1984) found that trends in data can be identified by using either parametric or non-parametric methods. The nonparametric tests are more suitable for randomly distributed, censored data, including missing values, which are frequently encountered in hydrological time series. Nandintsetseg *et al*. (2007) detected significant increases in the annual number of hot days and warm nights near Lake Hövsgöl, Mongolia. Associated with these changes were concomitant decreases in the annual number of cold days and cold nights. Xia *et al*. (2014) analysed the temporal and spatial changes in the annual and seasonal temperatures in a typical basin of the Qiantang River based on the time series databases of daily temperatures from 14 meteorological stations and found a significant warming trend in cold events both on annual and seasonal basis. He suggested that, in addition to the large-scale circulation, regional factors may have influenced the observed climate change in the studied region. Wilbanks and Kates (1999) emphasized the consideration of a bottom-up approach, *i.e*., how local places contribute to global climate change, instead of top-down approach where global changes accounted for the local variations. It is demonstrated by earlier scientists that daily and extreme temperature changes vary from one region to other. Easterling *et al*. (1997) found that warming trends do not appear simultaneously worldwide and are more pronounced in the northern than in the Southern Hemisphere. It is established that individual extreme climatic events have specific impact areas and durations. Some extreme events are insignificant on a large scale, but can be significant at the sub-regional or small scale.

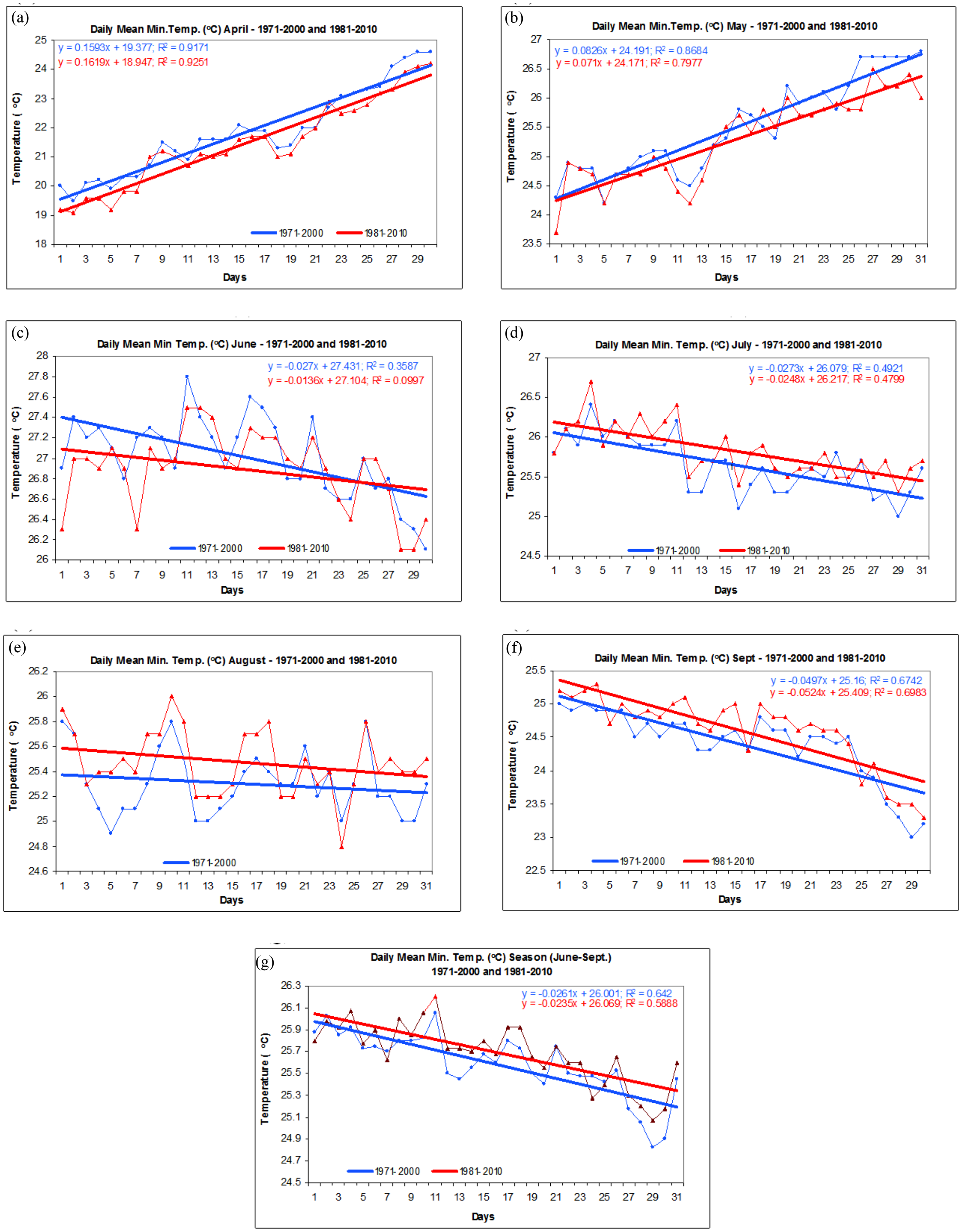
The global temperature has increased by 0.7 °C and Indian temperature by 0.5 °C over the last 100 years (IPCC, 2007). The above changes may further be modified by regional and local factors and hence a station level study of climate change and associated fluctuations in the frequency, duration and severity of extreme temperature events over the study area may provide more meaningful results. The objective of the present study is to examine the trends of mean temperatures and extreme events of maximum and temperature over Varanasi using the daily weather data from 1971-2010.

2. Data and methodology

In the present study, the extreme temperature events and mean temperatures have been analyzed over Varanasi (25°20' N, 83°0' E) using 40 years (1971 to 2010) daily surface data of temperature from April to September. Daily maximum and minimum temperature data are



Figs. 1(a-g). Trend lines for daily mean maximum temperature (°C) for two tricades 1971-2000 and 1981-2010 during April, May, June, July, August, September and monsoon season (June-September)



Figs. 2(a-g). Trend lines for daily mean minimum temperature (°C) for two tricades 1971-2000 and 1981-2010 during April, May, June, July, August, September and monsoon season (June-September) obtained from India Meteorological Department (IMD). The mean temperature changes and fluctuations in the frequencies of extreme temperature events during the two tricadal periods namely 1971-2000 and 1981-2010; also for four decades starting from 1971 to 2010 were investigated.

Frequency of extreme temperature events were calculated for two criteria's namely heat wave days and severe heat wave days as per IMD criteria (http://www.imd.gov.in/doc/termglossary.pdf).

2.1. *Heat wave events*

(a) When normal (mean) maximum temperature of a station is less than or equal to 40 °C and Departure of day's maximum temperature from normal is 5 °C to 6 °C.

(b) When normal maximum temperature of a station is more than 40 °C and Departure of day's maximum temperature from normal is 4 °C to 5 °C.

(c) When actual maximum temperature of the day remains 45 °C or more irrespective of normal maximum temperature.

2.2. *Severe heat wave events*

(a) When normal (mean) maximum temperature of a station is less than or equal to 40 °C and Departure of day's maximum temperature from normal is 7 °C or more.

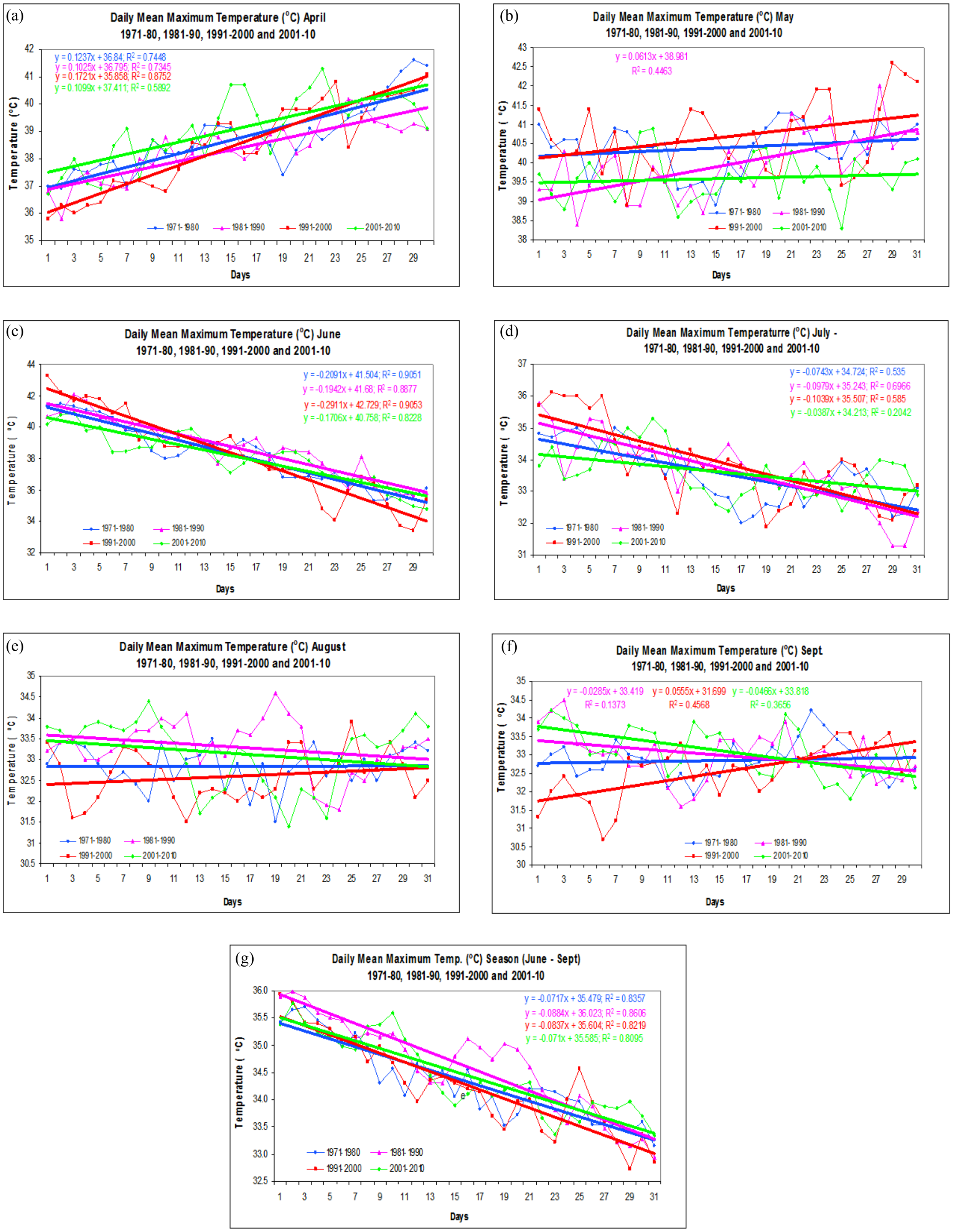
(b) When normal maximum temperature of a station is more than 40 °C and Departure of day's maximum temperature from normal is 6 °C or more.

However, the missing data were not considered while calculation/analysis. Further, the linear trend analysis has been carried out and tested its statistical significance using Mann-Kendall Rank Statistics (WMO, 1966) at 95% significance level. Trend line equation and 'R-squared' value is mentioned at those graphs only which are statistically significant as per Mann-Kendall rank test.

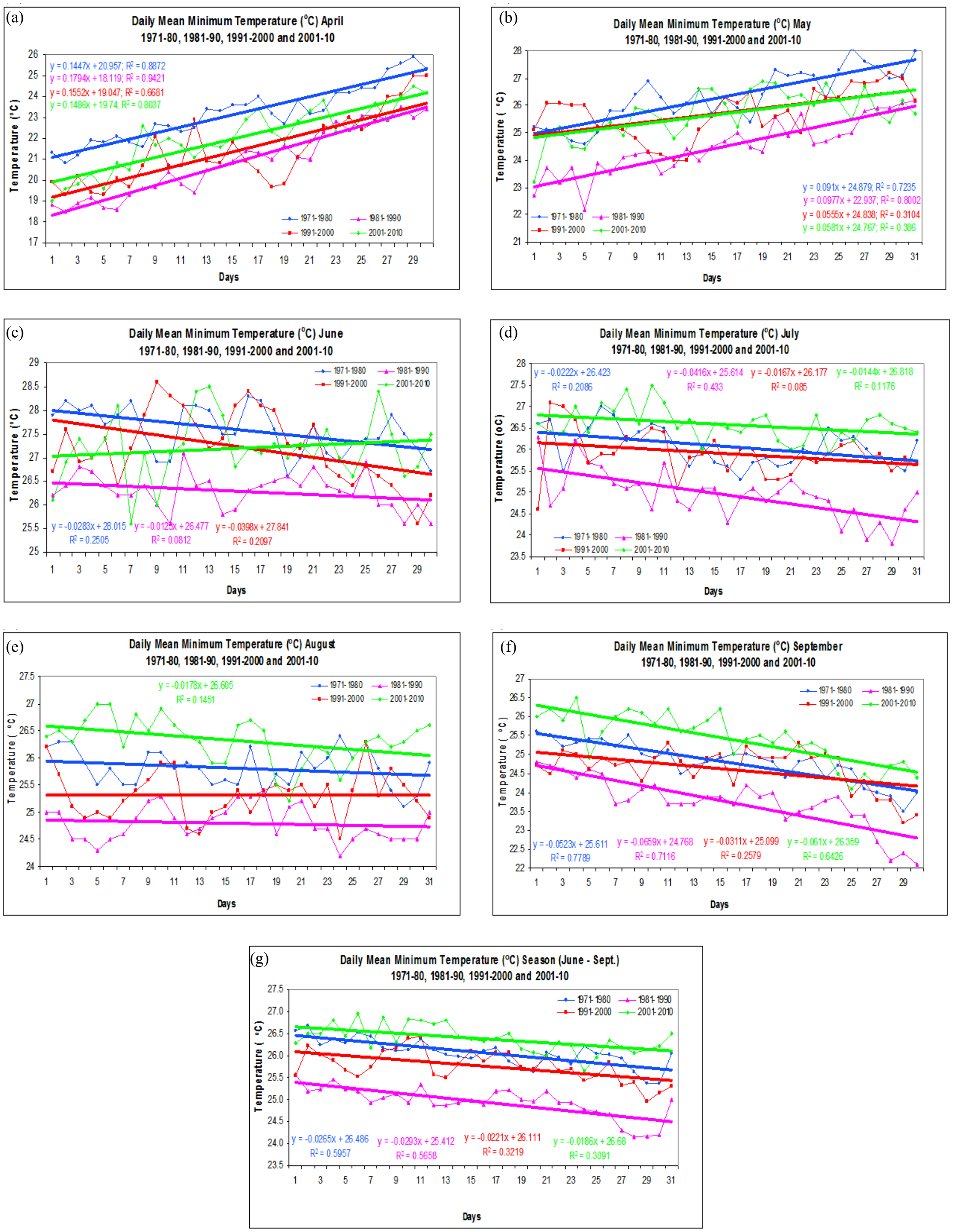
3. Results and discussion

The Figs. 1(a-g) show comparison between trend lines of the variation of daily mean of maximum temperature for two tricades namely 1971-2000 and 1981-2010, *i.e*., the temporal change (change with the progress of the month) for the months of April, May, June, July, August and September separately and also for the monsoon season (June to September) as a whole. During April [Fig. 1(a)], the latest tricade (1980-2010) is warmer than the prior tricade (1971-2000) for first half of the month, whereas for the later half of the month the gap between the two is narrowing down. In comparison to April, during the month of May [Fig. 1(b)] the latest tricade (1980-2010) has become remarkably colder than 1971-2000 and this behaviour continued till end of June [Fig. 1(c)] where both become same. In July tricade 1981-2010 is getting warmer at the end of the month. The magnitude of difference is approximately 0.2 to 0.3 °C [Fig. 1(d)]. In August tricade 1981-2010 is warmer than tricade 1971-2000 by approximately 0.2 °C [Fig. 1(e)]. The magnitude of difference goes on decreasing and both the trend lines coincide at the end of the month. Fig. 1(f) shows that the patterns of two trend lines 1971-2000 and 1981-2010 are quite opposite to other months as 1981-2010 is warmer than 1971-2000 in the first half of the month of September and it is colder than 1971-2000 in later half of the month. In close agreement to the well established fact of pre monsoon heating, both the tricades show the significant warming trend in the month of April and May. After the establishment of monsoon current both the tricades show significant cooling trends in the months of June and July. In August the rate of cooling with advancement of month is very small, whereas, in the month of September both the tricades show the opposite behavior, *i.e*., 1981-2010 shows a decreasing trend, whereas, 1971-2000 shows an increasing trend. Fig. 1(g) shows the daily mean maximum temperature for the whole monsoon season. In this figure trend line for both the tricades are coinciding with each other, and the temporal variation is decreasing significantly.

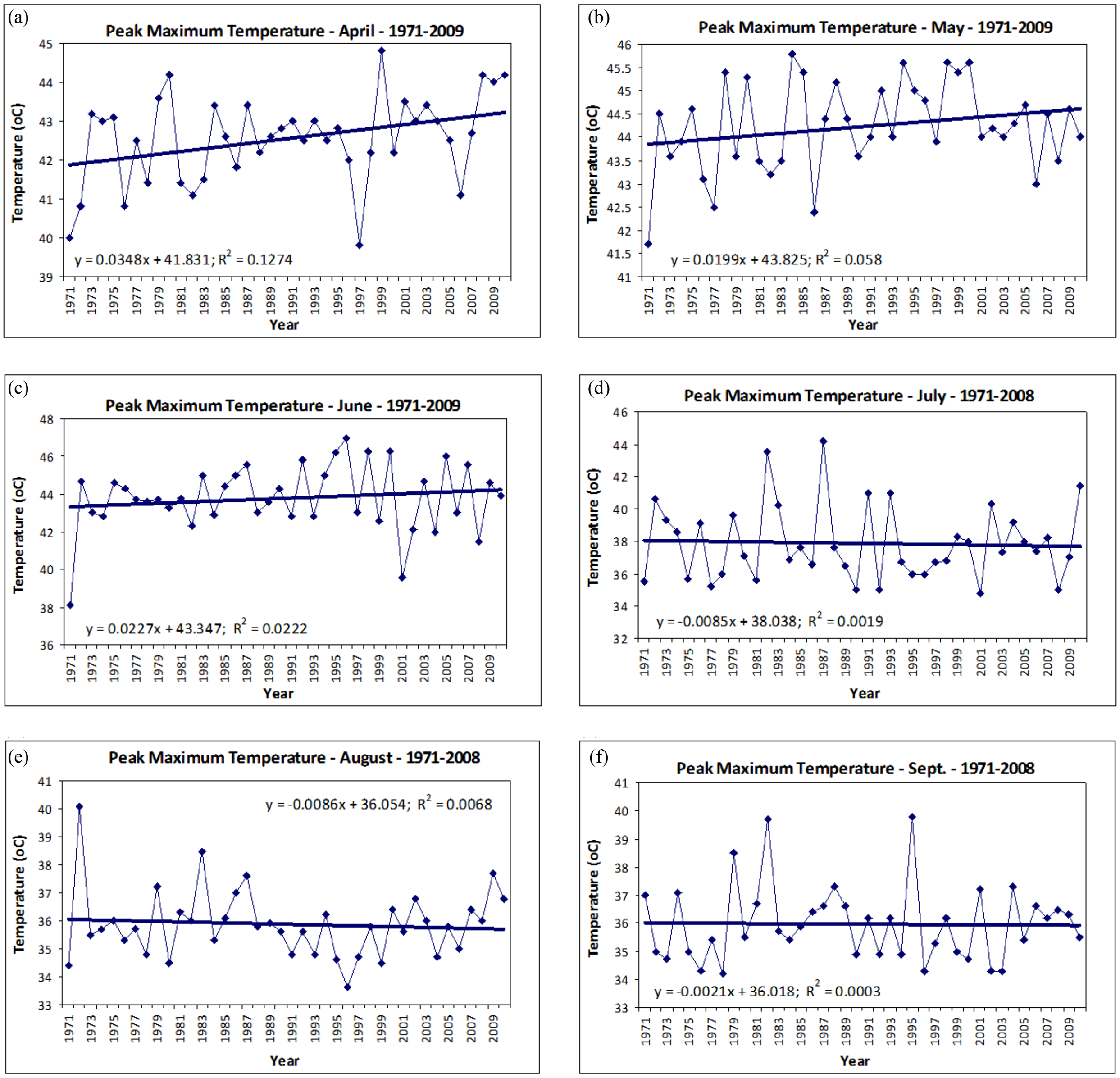
Figs. 2(a-g) shows the comparison of daily mean minimum temperature corresponding to two different tricadal periods, namely 1971-2000 and 1981-2010, over Varanasi for the months of April to September and also for the monsoon season (June to September). Figs. 2(a&b) shows that recent tricadal period (1981-2010) is colder than previous one (1971-2000) during the month of April and May. However, Fig. 2(b) depicts that with the progress of the month the latest tricadal period gets colder and colder as compared to earlier tricade, the maximum difference is being approximately 0.4 °C. Fig. 2(c) represents the changes of daily mean minimum temperature during the month of June and shows that the recent tricade is colder than earlier one but as the decreasing trend is more for earlier tricade; it becomes slightly colder at the end of the month. Fig. 2(d) shows that in July the recent tricade has become warmer than previous tricade throughout the month and the same condition prevailed in August [Fig. 2(e)] and September [Fig. 2(f)]. While considering the temporal variation of daily mean minimum temperature of said months it is clearly seen that both the tricades have significant increasing trend in the month of April and May and have



Figs. 3(a-g). Trend lines for daily mean maximum temperature (°C) for four decades 1971-1980, 1981-1990, 1991-2000 and 2001-2010 during April, May, June, July, August, September and monsoon season (June-September)



Figs. 4(a-g). Trend lines for daily mean minimum temperature (°C) for four decades 1971-1980, 1981-1990, 1991-2000 and 2001-2010 during April, May, June, July, August, September and monsoon season (June - September)



Figs. 5(a-f). Trends for peak maximum temperature (°C) during April, May, June, July, August and September for the period 1971-2010

significant decreasing trend in the months of June, July and September, however, trend for August is decreasing but is tested to be insignificant. This is in good agreement with the usual feature of pre-monsoon and monsoon. Fig. 2(g) shows the seasonal daily mean minimum temperature in which recent tricade is clearly seen to be warmer than earlier tricade whereas both the tricade show a significant decreasing trend. Fig. 1(g) and Fig. 2(g) also reveals that the diurnal temperature is found to be decreasing during the recent tricade.

Figs. 3(a-g) show the daily mean of maximum temperature for four different decades for the months of April to September and for the monsoon season. Fig. 3(a) clearly shows that the recent decade 2001-2010 is warmest in comparison to all other decades for the month of April. However, 1991-2000 is coldest in the beginning of the month and becomes hottest at the end of the month. While, Decade 1981-1990 is found moderate in the beginning of the month and becomes coldest at the end of the month. However, all the decades show significant increasing trend when temporal variation is considered. The recent decade 2001-2010 changed into coldest decade, whereas, 1991-2000 is the warmest decade throughout the month of May [Fig. 3(b)]. Decades 1971-1980 and 1991-2000 have very close values and similar trend. Decade 1981-1990 is showing highest and significant increasing trend in comparison to other decades. Fig. 3(c) results shows that 2001-2010 is the coldest decade, except at the end of the month of June. 1981-1990 is the warmest decade for maximum number of days. All the decades are showing a significant decreasing trend but the maximum rate of decrease is for 1991-2000. During the month of July decade 2001-2010 is coldest in the beginning of the month and becomes warmest at the end of the month, *i.e.*, it shows least decreasing trend during the month [Fig. 3(d)]. Other decades are showing approximately same trend, however, trend lines for all the decades are significantly decreasing. Fig. 3(e) depicts that decade 1981-1990 is the warmest decade and 2001-2010 is the second warmest decade during August. 1991-2000 is the coldest decade and 1971-1980 is the second coldest month. However, no appreciable trend is observed during the month of August. In September [Fig. 3(f)] 2001-2010 and 1981-1990 are warmer up to two third of the month and colder for the rest period. These decades have significant decreasing trend during the month. The decade 1991-2000 shows maximum significant increasing trend being coldest decade in the first two third of the month and being warmest in the rest of the month, however, the decade 1971-1980 shows no variation. Fig. 3(g) shows the variation of daily mean maximum temperature for the monsoon season (June-September), in which 1981-1990 is the warmest decade while 1991-2000 is the coldest decade. Recent decade 2001-2010 and 1971-1980 are cold in the initial days and gradually getting warmer as the month proceeds as compared with other decades. All the trend lines are statistically tested to be significant.

Figs. 4(a-g) show the comparison of daily mean minimum temperature among four decades. In April [Fig. 4(a)] 1971-1980 has the highest daily mean minimum temperature, whereas 1981-1990 has the lowest daily mean minimum temperature. 2001-2010 is the second highest daily mean minimum temperature. Slope of all the trend lines are similar and these are significantly increasing for all the decades. Fig. 4(b) shows the similar results as shown in Fig. 4(a), *i.e.*, all trend lines are significantly increasing, the only difference is that 1991-2000 and 2001-2010 are coinciding to each other. Fig. 4(c) depicts significant decreasing trend for all the decades, except for 2001-2010, which shows an increasing trend. The decade 1971-1980 has the highest daily mean minimum temperature; whereas, 1981-1990 has the lowest daily mean minimum temperature in the month of June. In July, 2001-2010 (recent decade) has the highest daily mean minimum temperature whereas; 1981-1990 has the lowest daily mean minimum temperature [Fig. 4(d)]. Monthly trends are significantly decreasing for all decades. In August [Fig. 4(e)] decade 2001-2010 has the highest daily mean minimum temperature whereas; 1981-1990 has the lowest daily mean minimum temperature. Latest decade 2001-2010 shows significant decreasing trend, whereas other decades do not show any trend. The results for September [Fig. 4(f)] are similar to July [Fig. 4(d)]. Daily mean minimum temperature for the monsoon season [Fig. 4(g)] shows a significant decreasing trend for all the decades. 2001-2010 decade has the highest daily mean minimum temperature, whereas, 1981-1990 has lowest daily mean minimum temperature. 1971-1980 is the second highest daily mean minimum temperature, whereas 1991-2000 is the second lowest daily mean minimum temperature.

Figs. 5(a-f) show peak maximum temperature (highest temperature in a month) for the years 1971-2010 during each month from April to September. Fig. 5(a) shows an increasing trend, which means that peak temperature has a tendency to further increase in future. This increasing trend is maintained in the months of May and June also [Figs. 5(b&c)]. There is no noticeable change or trend is observed for the months of July, August and September [Figs. 5(d-f)]. The trends for all the six months are statistically insignificant.

Table 1(a) shows the composite monthly mean maximum temperature for two tricades 1971-2000 and 1981-2010 for the months of April to September and monsoon season. The analysis reveals that April, August and September has slightly increased temperature, whereas, May and June has decreased temperature in the recent tricade. However, the composite monthly mean maximum temperature for the monsoon season (June-September) shows slight increase of 0.1 °C in recent tricade. Table 1(b) shows the composite monthly mean maximum temperature for four decades viz. 1971-1980, 1981-1990, 1991-2000 and 2001-2010. During the month of April recent decade 2001-2010 has maximum value of mean temperature (39.1 °C) and trend is increasing for the last three decades. For May, June and July decade 2001-2010 is having minimum value as compared to last three decades and trend is decreasing. However, during the month of August and September, in recent decade 2001-2010, the temperature has increased by 0.5 °C as compared to the previous decade 1991-2000. There is increase of 0.2 °C is noticed in the recent decade during monsoon season.

Table 2(a) shows the composite monthly mean minimum temperature for months of April, May, June, July, August, September and for the monsoon season (June- September) as a whole. The composite monthly mean minimum temperature has been calculated over a period of 30 years, one is for 1971-2000 and the other for 1981-2010. Comparison shows that April, May and June are becoming colder in the latest tricade 1981-2010. The

TABLE 1(a)

Composite monthly mean maximum temperature for two tricades 1971-2000 and 1981-2010

Period	Apr	May	Jun	Jul	Aug	Sep	Jun-Sep
1971-2000	38.6	40.3	38.4	33.7	32.9	32.8	34.4
1981-2010	38.7	40.1	38.3	33.7	33.0	32.9	34.5

TABLE 1(b)

Composite monthly mean maximum temperature for four decades 1971-1980, 1981-1990, 1991-2000 and 2001-2010

Period	Apr	May	Jun	Jul	Aug	Sep	Jun-Sep
1971-1980	38.8	40.4	38.3	33.5	32.8	32.8	34.4
1981-1990	38.4	40.0	38.7	33.7	33.3	33.0	34.7
1991-2000	38.5	40.7	38.2	33.8	32.6	32.6	34.3
2001-2010	39.1	39.6	37.7	33.6	33.1	33.1	34.5

TABLE 2(a)

Composite monthly mean minimum temperature for two tricades 1971-2000 and 1981-2010

Period	Apr	May	Jun	Jul	Aug	Sep	Jun-Sep
1971-2000	21.8	25.5	27.0	25.6	25.3	24.4	25.6
1981-2010	21.5	25.3	26.9	25.8	25.5	24.6	25.7

TABLE 2(b)

Composite monthly mean minimum temperature for four decades 1971-1980, 1981-1990, 1991-2000 and 2001-2010

Period	Apr	May	Jun	Jul	Aug	Sep	Jun-Sep
1971-80	23.2	26.3	27.6	26.1	25.8	24.8	26.1
1981-90	20.9	24.5	26.3	24.9	24.8	23.7	24.9
1991-00	21.5	25.7	27.2	25.9	25.3	24.6	25.8
2001-10	22.0	25.7	27.2	26.6	26.3	25.4	26.4

amount of decrease in the temperature is more in the month of April, *i.e.*, of 0.3 °C. The composite monthly mean minimum temperature has increased (0.2 °C) in the latest tricade, *i.e.*, 1981-2010 for the months of July, August and September. When the monsoon season (June-September) is considered, it has also recorded an increase of 0.1 °C in the recent tricade.

Table 2(b) is the comparison of composite monthly mean minimum temperature taken on decadal basis. The composite monthly mean minimum temperature has been computed for the months of April, May, June, July, August, September and also for the monsoon season (June-September), over the decadal periods of 1971-1980, 1981-1990, 1991-2000 and 2001-2010. For the April month, the composite monthly mean minimum temperature has increased by about 0.5 °C in each decade from 1981 onwards. During the months of May and June 1971-1980 has highest composite monthly mean minimum temperature, whereas 1981-1990 has lowest composite monthly mean minimum temperature. From July to September, it observed that 2001-2010 has continuously highest composite monthly mean minimum temperature, whereas 1981-1990 has continuously lowest composite monthly mean minimum temperature. It is also noticed that decade 1981-1990 has lowest composite monthly mean minimum temperature continuously for all the months and season as compared to all the other decades. The temperature trend is found to be increased by about 0.5 °C - 1 °C in latest decade 2001-2010 for all the months except May and June as compared to the previous decade. However, there is no change observed in the month of May and June during the last two decades. The monsoon season (JJAS) shows maximum composite monthly mean minimum temperature for 2001-2010 and minimum composite monthly mean minimum temperature for 1981-1990. One more feature is noticed that composite monthly mean minimum temperature is continuously increasing from 1981-1990 to 2001-2010 for all the months and the monsoon season.

TABLE 3(a)

Frequency of heat wave days for two tricades 1971-2000 and 1981-2010

Period	Apr	May	Jun	Jul	Aug	Sep	Jun-Sep
1971-2000	3	35	38	21	2	1	62
1981-2010	4	30	55	17	1	0	73

TABLE 3(b)

Frequency of heat wave days for four decades 1971-1980, 1981-1990, 1991-2000 and 2001-2010

Period	Apr	May	Jun	Jul	Aug	Sep	Jun-Sep
1971-80	0	10	7	7	1	1	16
1981-90	0	13	17	6	1	0	24
1991-00	3	12	14	8	0	0	22
2001-10	1	5	24	3	0	0	27

The occurrence of heat wave days in the months April to September as well as monsoon season for two tricadal periods of 1971-2000 and 1981-2010 is shown in Table 3(a). The frequency of heat wave days is discussed for May to July only, as other months do not have any significant number of heat wave days. The number of heat wave days has decreased by 14% in the recent tricade 1981-2010 in the month of May, however, the frequency has increased by 44% in June and in July it has decreased by 19% in respect to previous tricade. The analysis of monsoon season make the situation clear, where, the frequency of heat wave days has increased from 62 in tricade 1971-2000 to 73 in recent tricade 1981-2010. Table 3(b) represents the frequency of heat wave days for the months of April to September and monsoon season for four decades, *i.e.*, 1971-1980, 1981-1990, 1991-2000 and 2001-2010. The frequency of heat wave days is discussed for May to July only, as other months do not have any significant number of heat wave days. Here the same kind of changes are found as in Table 3(a), *i.e.*, in May number of heat wave days is decreasing towards the recent decade, being minimum 5 in 2001-2010. The maximum frequency 13 is observed in 1981-1990 followed by the next highest frequency 12 is observed in 1971-1980. In the month of June the maximum frequency (24) is found in the recent decade 2001-2010, whereas 1971-1980 corresponds to minimum frequency (7). In July the heat wave days are gradually decreasing. The analysis of heat wave days in the monsoon season shows an increase towards the recent decade.

The frequency of severe heat wave days is also counted for above discussed months and monsoon season, but the occurrence of these events were limited to few years only therefore the table for severe heat wave days are not presented here.

4. Conclusions

This study identified a clear pattern of climate warming during monsoon season (as tricadal seasonal mean of minimum temperature for 1981-2010 shows a lead over earlier tricade 1971-2000, whereas, tricadal seasonal mean of maximum temperature for both the tricades are coinciding with each other). This also implied the narrowing of mean diurnal temperature for monsoon season for latest tricade, exception being the month of April which shows an increase in diurnal mean temperature. The monthly results for daily mean minimum temperature show a clear cut increase in the months of July, August and September. On the other hand, the pre-monsoon months of April, May and June has shown a decrease in the tricade 1981-2010.

The decadal study of daily mean of maximum temperature reveals that April and August are getting warmer, whereas, May is getting colder in the latest decade 2001-2010. The decadal study of daily mean of minimum temperature, show that 2001-2010 is warmer than 1991-2000 in almost every month and also in monsoon season.

Composite mean maximum and minimum temperature studies over two tricades (1971-2000 and 1981-2010) reveal an increase in diurnal temperature range of April where as an overall cooling in the months of April, May and June. A slight increase in composite mean maximum as well as minimum temperature is observed for August, September and monsoon season. The study of composite mean temperatures (maximum and minimum) with decadal consideration matches with the findings of tricadal mean composite results. It is observed that April, August, September and monsoon season become warmer for both composite minimum and maximum temperature (especially composite minimum temperature has witnessed continuous increase in last three decades). However, composite mean maximum temperature become cooler during the month of May and June.

In recent years an increase in magnitude of peak temperature is observed during April and May. The analysis suggests that more intense heat events are likely to occur in future. It is quite amazing to see a decrease in the mean temperatures and at the same time increase in peak values of temperature. The heat wave days are considerable only in the months of May, June and July. The frequency of heat wave days (both decadal and tricadal) have decreased in the recent period for the month of May and July, whereas increased in month of June.

To brief, the increase in seasonal mean temperature is attributed mainly to months of July, August and September with major contribution from minimum temperature. Contrary to the global observations, pre-monsoon cooling (especially in May) has also been reported. Although there is decrease in mean temperature of May, the extreme temperature events (heat wave days) are increased by 44% whereas magnitude of peak temperature has an increasing trend. Such contrary results suggest a need for micro scale studies. The micro-scale studies are also required for proper mitigation and sustainable development of a given place.

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