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ORIGINAL PAPER

Extreme temperature and rainfall events in National Capital Region of India (New Delhi) in the recent decades and its possible impacts

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Abstract

Intergovernmental Panel on Climate Change (IPCC) promulgated a clear message that there have been many extreme weather and climate events observed globally since 1950, and these changes occurred mainly due to anthropogenic causes and emission of greenhouse gases. A computation study was carried out to assess the extreme temperature and rainfall events for the period 1984–2015 at the Indian Agricultural Research Institute, New Delhi by using ETCCDI indices through RClimDex software. The statistical significance of time series data and various calculated indices was done by linear regression as well as by Mann-Kendall test. Results indicated that annual mean maximum temperature decreased significantly at 0.019 °C/year and annual mean minimum temperature showed an increasing trend but without statistical significance. Alteration has happened in atmospheric properties, both physical and chemical over Delhi region during the period because of rapid urbanization and, increased concentration of aerosol. Fossil fuel/biomass waste burning, transportation of sand dust from Thar Desert, and reduction in incoming solar radiation have contributed both for fall in daytime temperature and rise in nighttime temperature. The changes in temperature would affect agricultural production through reduction in the rate of photosynthesis and excessive nocturnal respiration. Frequency and magnitude of coolest day (maximum temperature < 15 °C) and night (minimum temperature < 5 °C) have been rising at IARI, New Delhi. In the case of rainfall-based indices, annual rainfall (PRCPTOT), consecutive wet days (CWD), and number of days with rainfall ≥ 20 mm (R20) showed significant increasing tendency. Increasing trend in simple daily intensity index (SDII), rainy days (R2.5), and declining trend of consecutive dry days (CDD) indicates better distribution of rainfall. Nevertheless, increasing tendency in RX1day, RX5day, and R99p indicates possibilities of heavy rainfall events although the trend has been found insignificant.

1 Introduction

Occurrence of extreme weather events is common in any climatic region, but its frequent occurrence would wreak havoc to the ecosystem as well as the socio-economic condition of the region. For instance, recent raging floods induced by heavy rainfall in Chennai (more than 300 mm on 1st December 2015) and in some coastal districts of Tamil Nadu, India during November–December 2015 affected normal life of millions of people beside agriculture, marine, education, health, and aviation sectors (WMO 2015). Similarly, flash floods about a decade back due to very heavy rainfall events damaged properties and affected normal life severely in three major cities in India (Mumbai in July 2005, Chennai and Bengaluru in October 2005, and again Chennai in December 2005) (Guhathakurta et al. 2010). Since then, there has been growing importance for information on the occurrence of extreme weather events and/or natural hazards from Government as well as from private sectors and also from bureaucrats during these days for effective management. Intergovernmental Panel on Climate Change (IPCC) asserted that since 1950, many changes have been observed in extreme weather and climate events like increase in day temperature during summer, heavy precipitation events, and decrease in night

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temperature during winter in many parts of the world (IPCC 2014). It has been reported that recent climate changes impacted human and natural ecosystem on a wide-spread scale, and these are mainly due to anthropogenic emission of greenhouse gases. Therefore, study on changes in extreme weather events is highly important for better disaster management plan. Many studies (Sinha Ray and Srivastava 2000; Sen Roy and Balling 2004; Goswami et al. 2006; Khaladkar et al. 2009; Pal and Al-Tabbaa 2010; Revadekar et al. 2012; Taxak et al. 2014; Singh and Mal 2014) have been reported on time series analyses of extreme rainfall and temperature events using grid data and surface observatory data at regional, state and nation level in India. De et al. (2005) presented a review report on occurrence of various extreme events over India. However, these studies were not based on appropriate or recognized indices for comparison. World Meteorological Organization (WMO) constituted an Expert Team on Climate Change Detection and Indices (ETCCDI) (Collaboration of Commission for Climatology (CCl), World Climate Research Program (WCRP), and Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM)) after the workshops conducted in the year 1997 and 1999 (Karl and Easterling 1999; Zhang et al. 2011). The team proposed a standard set of globally accepted indices for climate extremes to facilitate comparison in changes in any part of world. In the recent past, many studies (New et al. 2006; Wong et al. 2011; Hasib and Saiful Islam 2012; Keggenhoff et al. 2014; Gbode et al. 2015) were undertaken using these indices globally. However, few of them (Joshi and Rajeevan 2006; Rao et al. 2013; Lunagaria et al. 2015; Jayasooryan et al. 2015) have been carried out in India and mostly on rainfall. Keeping in view the importance of extreme weather events, this study aimed to analyze extreme events related to temperature and rainfall at Indian Agricultural Research Institute (ICAR), New Delhi for the period 1984–2015 by using ETCCDI indices.

2 Materials and methods

2.1 Study area

Indian Agricultural Research Institute (IARI), New Delhi (28.63° N; 77.15° E; 229 m AMSL) is located in the National Capital Region and Capital city of India (Fig. 1). The area lies in a semi-arid climate and receives an average annual rainfall of 728 mm (1984–2015). Almost 600 mm of rainfall (82% of annual rainfall) is received through summer monsoon (June to September). The average date of onset of southwest monsoon over New Delhi is 29th June. Wide variation is observed in thermal regime during summer and winter months. Mean maximum temperature of the hottest month (May) is 39.5 °C, and mean minimum temperature of the coldest month (January) is 6.3 °C. Monthly variation of temperature (maximum and minimum) and rainfall is presented in Fig. 2.

2.2 Weather data

Daily weather data (maximum and minimum temperature and rainfall) was collected for the period 1984–2015 from the Agrometeorological Observatory which is being maintained by the Division of Agricultural Physics, Indian Council of Agricultural Research-Indian Agricultural Research Institute (ICAR-IARI).

2.3 RClimDex software

Weather data was analyzed using RClimDex software which was developed and maintained at Climate Research Branch of Meteorological Service of Canada. The FORTRAN program source for calculating different indices was written in R statistical software by Xuebin Zhang and Feng Yang of Meteorological Service of Canada. Before this, ClimDex, a MS-Excel-based program was used to compute the indices was developed by Byron Gleason of the National Climate Data Centre (NCDC) of the National Oceanic and Atmospheric Administration (NOAA), USA. The entire information regarding input file preparation, installation of R, and running the program was available in RClimDex user manual (Zhang and Yang 2004).

2.4 Indices

Data quality checking was done through RClimDex software which was the first step before computation of indices. The data was checked for invalid data (negative rainfall, maximum temperature which was less than or equal to minimum temperature) and removal of outliers by threshold values defined by user in the form of standard deviation. In the present investigation, outliers in temperature were identified using 3-sigma level. Sheikh et al. (2009) also used 3-sigma for their Asia Pacific Network Project. However, New et al. (2006) used 3.5-sigma level for computation of weather extreme indices over southern and west Africa. After quality checking, 27 indices were computed out of which 16 are related to temperature and 11 to rainfall (Table 1). According to India Meteorological Department (IMD), rainy day means a day with rainfall equal or more than 2.5 mm and rainfall of 64.5 mm or more in a day denotes heavy rainfall under Indian condition. Hence, these two indices viz., R2.5 and R64.5 were

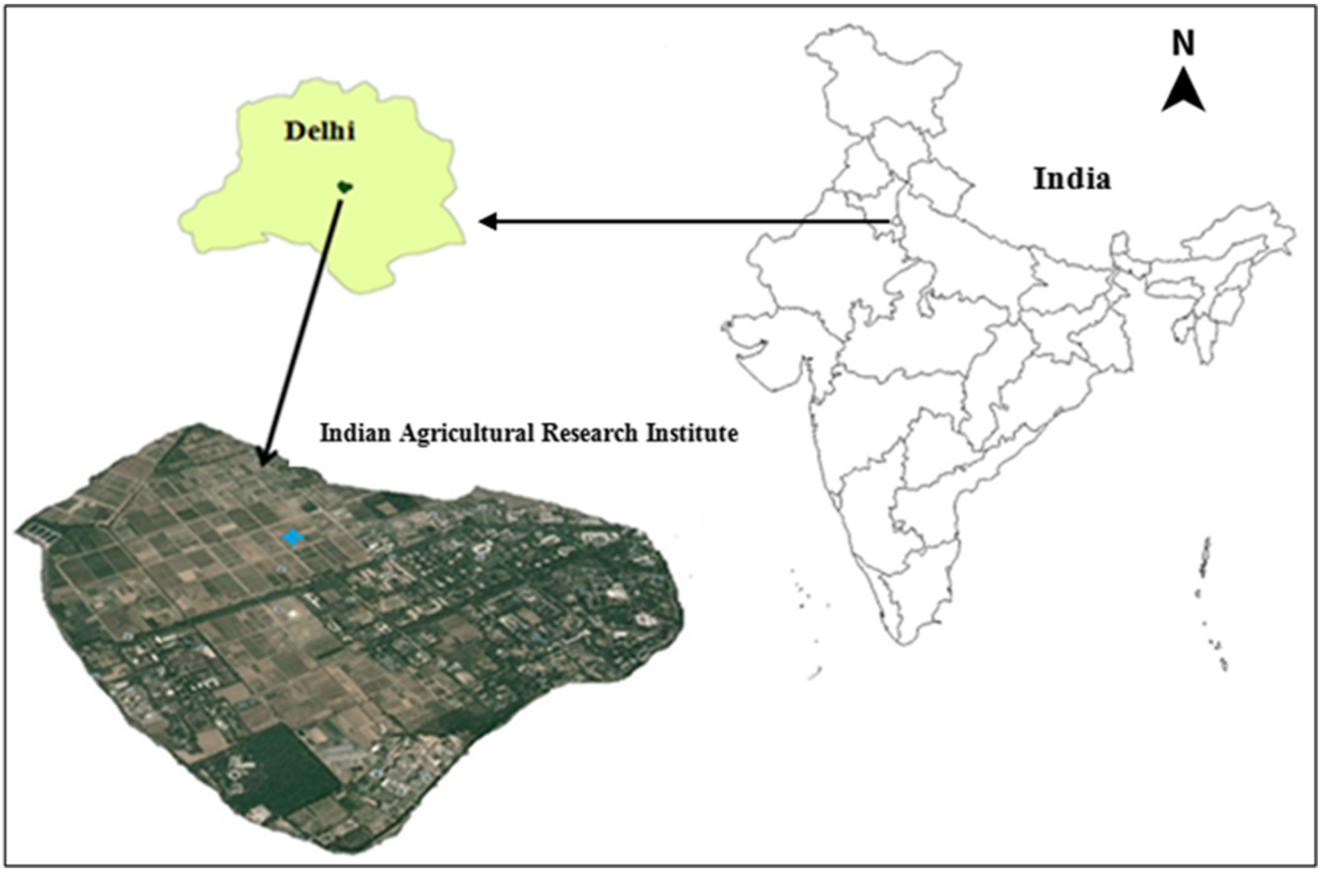


Fig. 1 Location of ICAR - Indian Agricultural Research Institute, New Delhi

included specifically for finding out the trend in rainy days and heavy rainfall events at the study area.

2.5 Statistics

Trend analysis of various indices was carried out by linear regression method. According to Helsel and Hirsch (1992), hypothesis of constant variance and normality of residuals are required for linear regression. Simple linear regression model was used which is described by the following equation as:

$$Y = ax + b \tag{1}$$

where Y is variable of interest (rainfall or temperature); t is year; a is slope, indicating the rate of change per year for variable in question; and b isintercept.

Non-parametric test like Mann-Kendall test (MK test) was opted to find statistical significance of the climatic indices computed based on frequency of occurrence, and it was carried out using Trend Toolkit software (Chiew et al. 2005). This test has widely been employed for time series analysis of weather data (Mirza et al. 1998; Lazaro et al. 2001; Libiseller and Grimvall 2002). If the time series values (X_1, X_2, X_3, … , X_n) are replaced by their relative ranks (R_1, R_2, R_3, … , R_n), then according to Salas (1993), test statistic S is:

$$S = \sum_{i-1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}\left(R_j - R_i\right) \tag{ii}$$

where:

$$\operatorname{sgn}(X) = \begin{cases} +1 \text{ for } (X) > 0 \\ 0 \text{ for } (X) = \quad 0 \\ -1 \text{ for } (X) < 0 \end{cases} \tag{iii}$$

If the null hypothesis Ho is true, then S is approximately normally distributed with:

$$E(S) = 0$$

$$\operatorname{var}(\mathrm{S}) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \tag{iv}$$

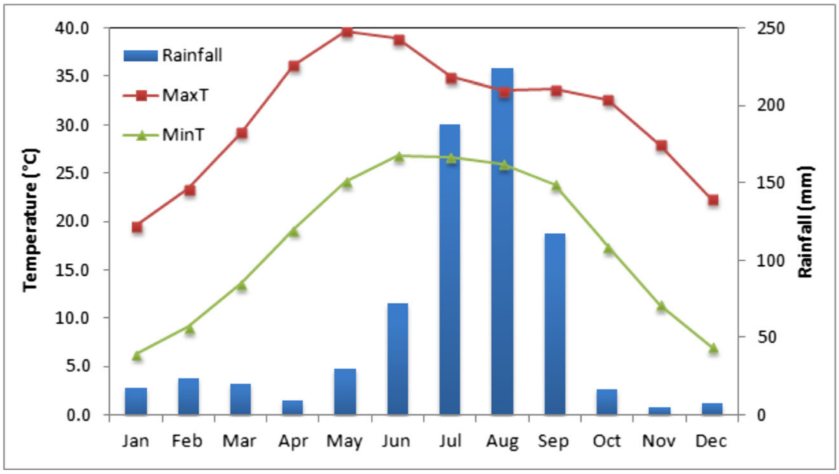


Fig. 2 Monthly mean values (1984–2015) of temperature and rainfall at ICAR-IARI, New Delhi

The z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):

$$Z = \frac{|S|}{\sigma^{0.5}} \qquad \text{(v)}$$

A positive value of S indicates that there is an increasing trend and vice versa.

3 Results and discussion

3.1 Temperature indices

Slope, p value for linear regression, Z value, and significance level for MK test of temperature and rainfall indices are furnished in Table 2. Annual mean maximum temperature at IARI showed a decreasing trend significantly (at 10% level) at the rate of 0.019 °C/year during the period 1984–2015. However, annual mean minimum temperature was increasing at 0.011 °C/year in the last 32 years though it was not significant. Dhorde et al. (2009) also indicated a significant decreasing and rising trend in annual mean maximum and minimum temperature, respectively, over Delhi for the period 1901–1990. The fall in annual mean maximum temperature over the years could be attributed to increase in cloudiness and alteration in optical properties of atmosphere. Wild et al. (2005) draws attention on popular theory of solar dimming, and they found that amount of insolation was declining over land surface until 1990 and thereafter increment was noticed. However, they opined that Atmospheric Brown Cloud (ABCs) dimming was continued over Indian stations. Some studies also revealed that amount of solar radiation (Padma Kumari et al. 2007; Singh et al. 2012) and bright sunshine hours (Rao et al. 2004) were declined significantly at New Delhi.

The increase in minimum temperature over the period under study at Delhi could be explained as increased concentration of greenhouse gases as well as aerosol amount which were capable of absorbing outgoing nocturnal radiation. Urbanization due to population explosion especially after 1940 is also one of the major reasons for the rise in minimum temperature (Dhorde et al. 2009). Study on spatial variations in land surface temperature over Delhi using Advanced Spaceborne Thermal Emission and Reflection (ASTER) satellite data showed strong positive correlation between population density and surface temperature with a logarithmic regression coefficient of 0.748 (Mallick and Rahman 2012). Nevertheless, Bartolini et al. (2012) and Almazroui et al. (2013) reported that temperature increment was not only related to population growth and urbanization, and it might be explained by global climate change and large-scale circulations.

Rise in nighttime temperature, although found to be not significant in this study, is a cause of concern as it affects agricultural crop growth and yield. Many studies were undertaken to understand the effect of increased nighttime temperature on performance of different crops. Investigation of global climate projections (Meehl et al. 2007) indicated that minimum temperature will shoot up faster than maximum temperature, and there would be greater consequences on food grain production. In general, a rise in minimum temperature increases nocturnal respiration in plants, and extra energy required for this process is obtained from stored food material which in turn affects crop yields. Cooper et al. (2008) opined that night temperature during grain development has the key role in deciding grain quality also. In the case of rice which is a very important cereal crop in India, increase in night temperature has led to high amylase content in rice grains (Resurreccion et al. 1977), decreasing the head rice yield (Counce et al. 2005). Wheat, another key cereal crop during winter season in India, is highly susceptible to high

Table 1 Temperature and rainfall indices

Index	Description of Index	Definition	Unit
$T_{\max}$ mean	Annual mean maximum temperature	Annual mean maximum temperature	°C
$T_{\min}$ mean	Annual mean minimum temperature	Annual mean minimum temperature	°C
TXx	Maximum of maximum temperature	Monthly maximum value of daily maximum temperature	°C
TNx	Maximum of minimum temperature	Monthly maximum value of daily minimum temperature	°C
TX*n*	Minimum of maximum temperature	Monthly minimum value of daily maximum temperature	°C
TN*n*	Minimum of minimum temperature	Monthly minimum value of daily minimum temperature	°C
DTR	Diurnal temperature range	Monthly mean difference between maximum and minimum temperature	°C
SU35	Hot days	Annual count when daily maximum temperature > 35 °C	Days
SU40	Very hot days	Annual count when daily maximum temperature > 40 °C	Days
FD5	Cold nights	Annual count when daily minimum temperature < 5 °C	Days
ID 15	Cool days	Annual count when daily maximum temperature < 15 °C	Days
TR 30	Tropical nights	Annual count when daily minimum temperature > 30 °C	Days
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
PRCPTOT	Annual total wet-day precipitation	Annual total rainfall in wet days (RR > =1 mm)	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as rainfall > = 1.0 mm) in the year	mm/day
CDD	Consecutive dry days	Maximum number of consecutive days with Rainfall<1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with Rainfall > = 1 mm	Days
R20	Number of precipitation days	Annual count of days when rainfall > = 20 mm	Days
R64.5	Number of heavy rainfall days	Annual count of days when rainfall > = 64.5 mm	Days
R2.5	Number of rainy days	Annual count of days when rainfall > = 2.5 mm	Days
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5 day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
R95p	Very wet days	Annual total PRCP when RR > 95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	mm

night temperature, and according to Lobell et al. (2011), there would be yield reduction by about 10% with the increase in minimum temperature by 1 °C.

Diurnal temperature range, difference between maximum and minimum temperatures showed a significant (at 5% level) decreasing tendency (0.03 °C/year) during the study period. This is ascribed to the observed opposite trend of both decrease in maximum and increase in minimum temperature. Rathore et al. (2013) also reported that diurnal temperature range over Delhi decreased significantly (at 5% level) by 0.01 °C/year during 1951–2010. In Haryana, border state to Delhi, significant declining trend in diurnal temperature range

Table 2 Trend and statistical significance level of climatic indices by linear regression and MK test

Index name	Linear regression		MK test	
	Slope	*P* value	*Z* value	Sig. level
Temperature-related indices				
T_{max} mean	−0.019	0.086*	−1.849	*
T_{min} mean	0.011	0.242	0.568	NS
TXx	0.032	0.184	1.427	NS
TNx	−0.039	0.161	−1.038	NS
TX*n*	−0.117	0.001***	−3	***
TN*n*	−0.054	0.011**	−2.287	**
DTR	−0.03	0.011**	−2.157	**
SU35	−0.12	0.738	0.162	NS
SU40	−0.167	0.489	−0.778	NS
FD5	0.287	0.047**	2.238	**
ID 15	0.211	0.006***	3.308	***
TR 30	−0.09	0.415	−1.443	NS
TN10p	−0.128	0.2	−0.13	NS
TN90p	0.04	0.576	0.795	NS
TX10p	0.11	0.197	2.189	**
TX90p	−0.111	0.258	−0.632	NS
Rainfall-related indices				
PRCPTOT	7.904	0.083*	1.216	NS
SDII	0.032	0.596	0.0	NS
CDD	−0.359	0.589	−0.032	NS
CWD	0.093	0.028**	1.849	*
R2.5	0.213	0.167	1.492	NS
R20	0.183	0.061*	1.541	NS
R64.5	0.025	0.37	−0.049	NS
RX1day	0.66	0.308	0.6	NS
RX5 day	1.346	0.192	0.778	NS
R95p	2.047	0.408	−0.178	NS
R99p	1.51	0.277	0.681	NS

NS, non-significant

*Significant at 10% level; **significant at 5% level; ***significant at 1% level

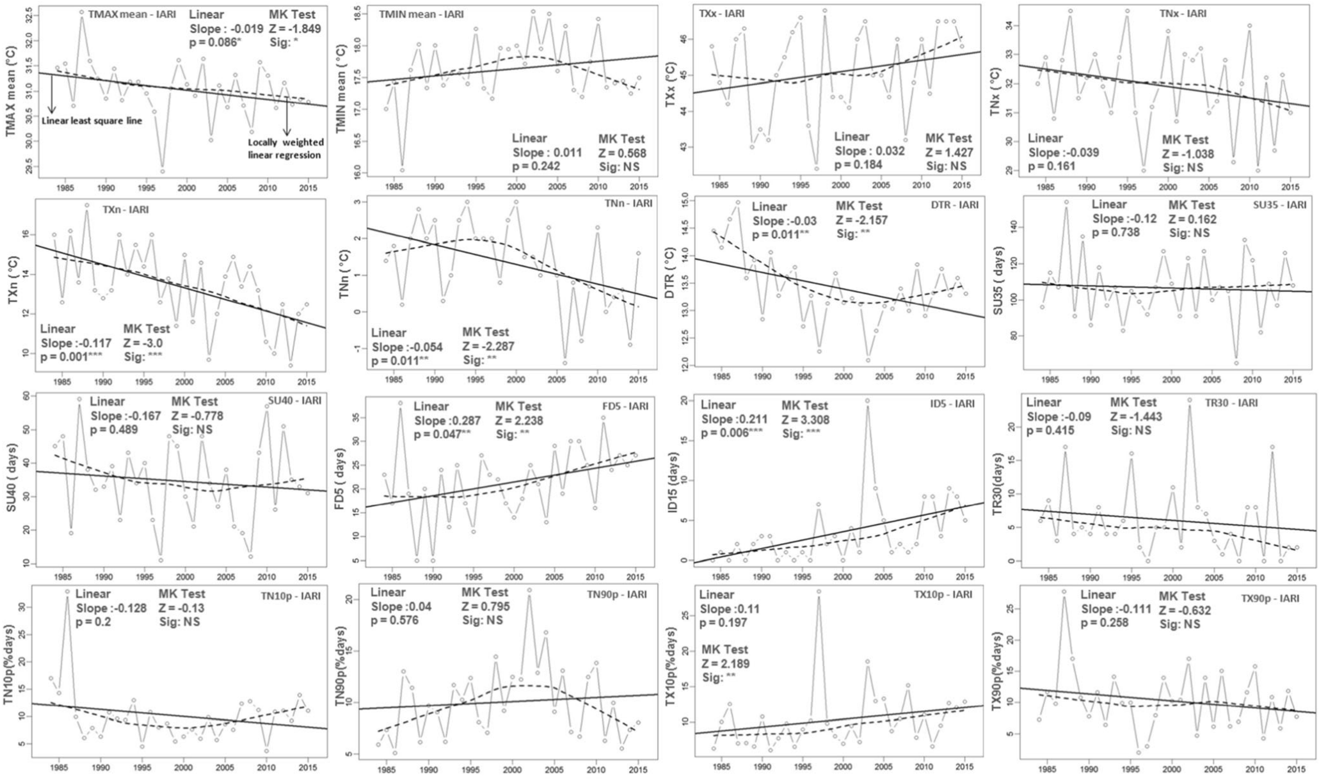
was observed at Bawal, Hisar, Karnal, and Sirsa stations at −2.39, −2.50, −2.09, and −3.16 °C, respectively during study period 1985–2014 (Mamta 2016). Wang et al. (2012) reported a decline in maximum temperature due to solar dimming, was observed both in urban and rural stations in China whereas increased minimum temperature was noticed more in urban stations than rural stations, indicating the role of urbanization on reduction in diurnal temperature range during the period 1960–2009.

Changes in atmospheric physical and chemical properties over Delhi region have been observed and reported because of fossil fuel burning by industries and vehicular pollution (Tiwari et al. 2009; Ram et al. 2012) and incineration of biofuels like wood, dung cake, and crop waste (Habib et al. 2006). According to Singh et al. (2005), Delhi Municipal Corporation alone shares 7% of vehicles in India, and they further added that solar energy cut by 10% over ocean and 10–20% over land due to brown cloud formation have led to cooling of land and ocean and heating of atmosphere. The significance of locality of Delhi which is in western part of Indo-Gangetic Basin (IGB), one of the highly polluted regions of the world has led to major contribution of aerosol (Ramanathan and Ramana 2005; Tare et al. 2006; Rengarajan et al. 2007; Singh et al. 2010). Srivastava et al. (2012) analyzed some chemical properties of aerosol samples collected at Delhi for 7 months except monsoon period in the year 2007 and reported that 71% aerosol surface forcing was caused by anthropogenic activities. Besides anthropogenic activities, aerosols have been added in the atmosphere over Delhi due to transportation of sand dust from neighboring Thar Desert during summer months (Prasad and Singh 2007; Pandithurai et al. 2004; Gautam et al. 2009; Srivastava et al. 2011). Simulation study on the consequences of rising greenhouse gases and sulfate aerosol forcing on diurnal temperature over Indian subcontinent using ECHAM3 and LSG coupled model indicated decline in diurnal temperature range on an annual scale, and it is more prominent during winter (−0.6 °C) during the decade 2040 (Lal et al. 1996). Further, they cautioned that there would be significant ill effect on the agricultural productivity over India due to projected changes in maximum, minimum, and diurnal temperature range. Declining tendency of differences between day- and nighttime temperatures affected crop yield through excessive usage of photosynthates to compensate energy expenditure due to more respiration (Das et al. 2014).

There are many studies dealing with temporal and spatial variations of aerosol loads over India using satellite-derived data (Badarinath et al. 2007; Sheshu Kumar et al. 2012; Narasimhan and Satheesh 2013; Srivastava et al. 2016; Midhuna et al. 2017; Jethva et al. 2018). The analysis of MODIS, CERES, and AIRS satellite data between May and June months during 2009–2011 at Kanpur revealed that high aerosol loads caused significant cooling of around 2–3 °C in lower troposphere (Sarangi et al. 2016). Soni et al. (2018) studied aerosol optical depth using MODIS Terra satellite data during a dust storm event that occurred between 20 and 23 March 2012 and found that the average daily aerosol optical depth (AOD) and particulate matter 10 concentration (PM10) were as high as 0.956 and 1800 µg/m at Delhi on 21 March 2012. This resulted in reduced radiative flux at surface level which in turn reduced the surface temperature by 2–10 °C at Delhi.

Our study indicated that yearly lowest values of maximum (TX*n*) and minimum (TN*n*) temperature was declining significantly. Mamta (2016) also found a decreasing trend in the case of TX*n* and TN*n* for Bawal station located in Haryana state during the period 1985–2015. Jenamani (2007) studied the relationship between fog hours and maximum temperature during the month of January using the data from Indira Gandhi International airport and Safdarjung airport of New Delhi and found that average maximum temperature fell by 2–3 °C since 1989 with the rise in fog hours per day. The lowest values of day- and nighttime temperature were observed in the month of January and December at IARI station. It varied from 9.4 °C (2013) to 17.5 °C (1988) in the case of maximum temperature and from − 1.4 °C (2006) to 3.0 °C (1994) in the case of minimum temperature. To support this fall in lowest maximum and minimum temperatures, trend values of FD5 and ID 15 also showed an increasing tendency (Fig. 3). It means the number of days are increasing when minimum temperature is less than 5 °C and maximum temperature is less than 15 °C. In regard to similar index, TX10p (percentage of days when maximum temperature is < 10th percentile value) also increased significantly (at 5% level) at the rate 0.11%/year during 1984–2015. Our observation and analyzed values indicate that the frequency and magnitude of coolest day and night are increasing at IARI, New Delhi. The increased frequency and extent of low values of day- and nighttime temperatures may prolong the vegetative period of winter crops, and germination of wheat seeds get affected under low-temperature (< 5 °C) condition.

It is interesting and respite to residents of Delhi to note that indices like number of days with maximum temperature ≥ 35 and ≥ 40 °C (SU35 and SU40), percentage of days when maximum temperature > 90th percentile (TX90p), and frequency of days with nighttime temperature > 30 °C (TR30) were plummeting, although the trend was not found to be significant. Rao et al. (2004) also reported that frequency of maximum temperature > 35 °C at New Delhi was less. On the other hand, non-significant increasing trend was noticed in extreme value of maximum temperature (TXx), and non-significant increasing trend in days when minimum temperature is at the > 90th percentile (TN90p) at IARI. Singh et al.'s (2016) study on extreme temperature events using WMO/CLIVAR indices for the northwest Himalaya during the period 1970–2005 also indicated a decreasing trend or no change in hot extreme events like warm days, tropical nights, and TNx and an increase in frequency of cool days. Nonetheless, they found declining trend in TXx (warm nights) and increasing trend in cool nights which is not true with our study. It has been observed that during the months of May and June, the highest value of maximum temperature rose by 1 °C (44.5 to 45.6 °C) in the last 32 years. Despite that extreme values of maximum temperature were experienced for a few days, as heat wave condition, the impact on public health is tremendous. Recently, Dholakia et al. (2015) have reported the heat-wave-related mortality



*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level; NS – Non significant

Fig. 3 Linear trend line of different temperature indices with statistical significance (linear regression and MK test) in urban India under present and future climate scenarios. They cautioned that human mortality rate due to extreme daytime temperature/heat-wave condition would increase by two or more times in the cities with million plus population over India; especially, Delhi is going to witness the highest rise in heat mortality rate in 2080 under RCP 8.5 scenario. However, they also mentioned that mortality due to cold wave would reduce in the future since night temperature will increase in the coming years. According to Kovats and Hajat (2008), withstanding capacity of human being reduced with the increase in maximum temperature in hot- and dry-zone climates owing to breaking of physiological threshold level of temperature tolerance. This prompts the Government/Municipal Corporations to give emphasis on public health and for preparation of adaptation/contingency measures in urban areas to cope up with heat-wave condition like heat health warning system initiated by the Ahmedabad (Gujarat State, India) Municipal Corporation since 2013 (AMC 2015).

3.2 Rainfall indices

Trend analysis of rainfall-related climate indices revealed that annual rainfall (PRCPTOT), consecutive wet days (CWD), and number of days with rainfall ≥ 20 mm (R20) showed a significant increasing tendency under linear regression method. Yet, under MK test, only CWD showed a significant rising trend. The increasing trend (non-significant under MK test) in annual rainfall at IARI is mainly attributed to excess rainfall received during monsoon season in the past 3 years. Results of Rao et al. (2004) is in agreement with the results of our study, and they found that annual rainfall increased by 33% at New Delhi during 1901–2000. Our results are also comparable with the analysis on extreme rainfall using WMO/ETCCDI indices at Bawal station located in Haryana state, and a significant increasing tendency was noticed in indices like PRCPTOT, RX1day, RX5day, R2.5mm, R20mm, R95p, and R9p for the period 1985–2014 (Mamta 2016). Increased availability of cloud condensation nuclei might be the reason for the increase in rainfall. Further, the increased cloud condensation might be the consequence of the addition of aerosols in the atmosphere. Padmanabamurty and Bahal (1984) interpreted that enhanced rainfall amount due to urbanization has led to increased buoyancy and convection. Many other studies around the globe are also supporting this argument that atmospheric aerosols are the main reason for the augmentation of rainfall (Teller and Levin 2006; Tao et al. 2007, 2012).

It is interesting that consecutive wet day (≥ 1 mm) is significantly rising. This is obvious from the increasing trend of simple daily intensity index (SDII), rainy days (R2.5), and declining trend of consecutive dry days (CDD) though there is no statistical significance which signifies better distribution of rainfall (Fig. 4). In the case of rainfall indices like RX1day, RX5day, and R99p, increasing trend was not found significant; this has indicated the possibilities of heavy rainfall events. The results of Joshi and Rajeevan's (2006) study are also in accordance with our results that the moderate wet days (with rainfall more than 75% of the long period average) are significantly increasing (0.4 days per decade) at New Delhi (Safdarjung station) for the period 1901–2000. Study on extreme rainfall events over the Himalayas between 1871 and 2007 also indicated the increase in the 1-day extreme rainfall events in the Himalayas during the decades 1951–1960 to 1991–2000 (Nandargi and Dhar 2011). Nonetheless, they also found a declining trend in 1-day extreme rainfall during 2001–2007 period and attributed to weak monsoon conditions. On the other hand, from our study, it is evident that the highest 1-day rainfall was noticed in IARI to the tune of more than 100 mm (126 mm in July 2013, 121 mm in July 2014, and 162 mm in July 2015) which was during the last 3 years. Goswami et al. (2006) analyzed occurrence of extreme rainfall events over India and opined that rainfall events (> 120 mm/day) were increasing especially during summer monsoon (June–Sept) in the last 50 years.

4 Conclusions

Analysis of extreme temperature events at the Indian Agricultural Research Institute, New Delhi showed a significant falling trend in annual mean maximum temperature (0.019 °C/year) and increasing trend in annual mean minimum temperature. Because of this, diurnal temperature range is narrowing down significantly. These temperature changes will have an implication on crop production especially food grain crops like rice and wheat. There would be a decrease in the rate of photosynthesis and increase in nocturnal respiration. TX*n* and TN*n* temperatures are falling (during the months of December and January), and the number of days with maximum temperature < 15 °C and minimum temperature < 5 °C are increasing significantly. This implies that the frequency and magnitude of coolest day and night have been increasing at the IARI, New Delhi. It is also noticed that extreme value of maximum temperature (TX*x*) and days when minimum temperature > 90th percentile (TN90p) during the months of May and June are causing discomfort and affecting public health, which necessitates action from the Government/Municipal Corporations for preparation of contingency measures in urban areas. In the case of rainfall-based indices, annual rainfall (PRCPTOT), CWD, and number of days with rainfall ≥ 20 mm (R20) showed increasing trend significantly. The study indicates that better distribution of rainfall may be expected as there

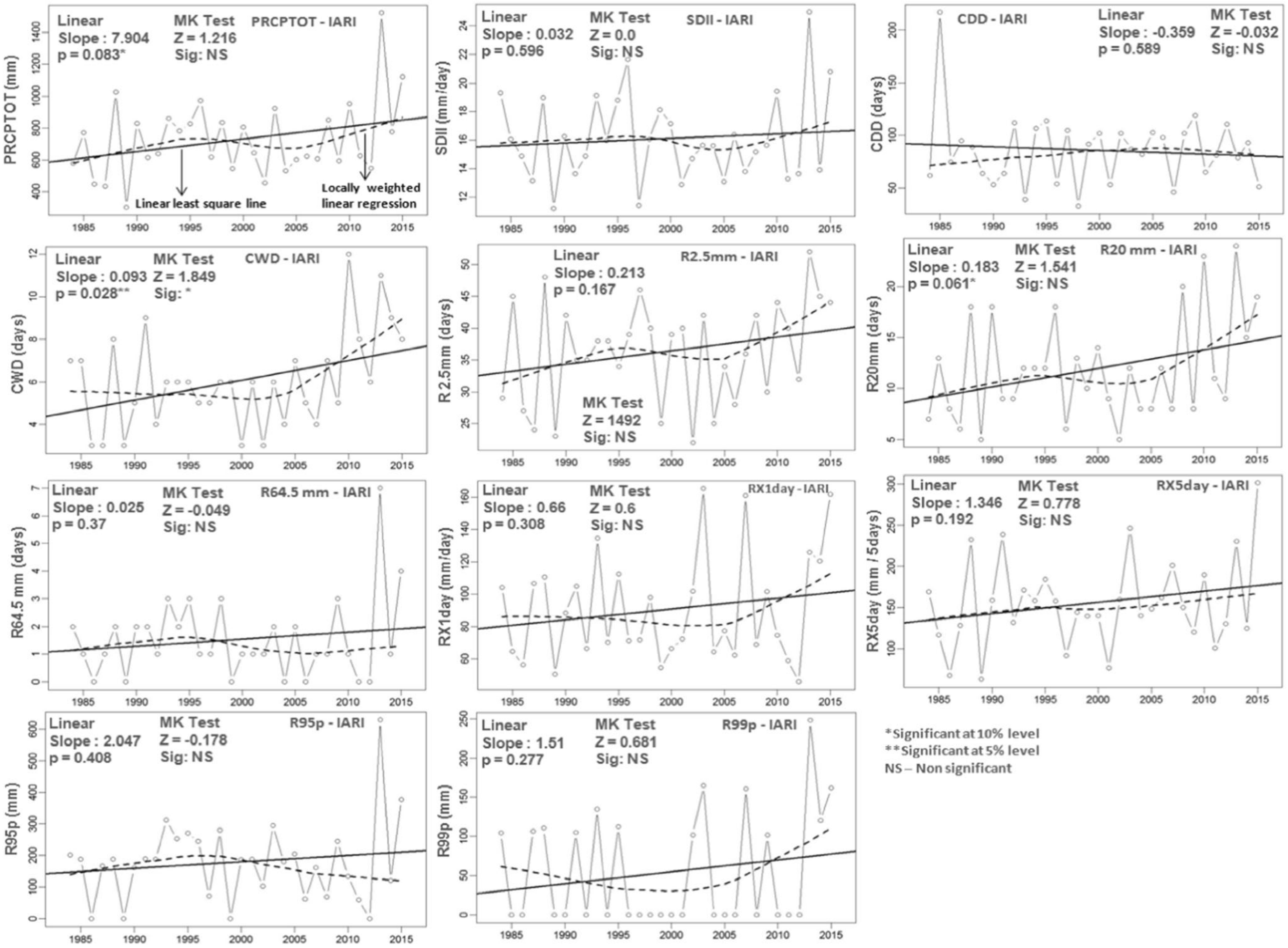


Fig. 4 Linear trend line of different rainfall indices with statistical significance (linear regression and MK test)

was increasing trend in SDII, rainy days (R2.5), and declining trend of CDD. Yet, increasing tendency of indices like RX1day, RX5day, and R99p denotes for possibilities of heavy rainfall events though the trend is insignificant.

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