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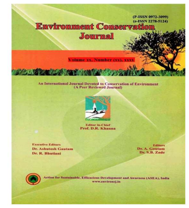

Analysis of climate variability and influence of climate variables on major crop yields in Nalgonda District of Telangana State, India

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ABSTRACT

Climate change has become a major concern globally, demanding immediate attention and action. In view of the extreme climatic uncertainties, it is obvious that Indian agriculture is highly vulnerable to climate change as climate is the direct input for production. This scenario emphasizes the dire need to understand the patterns of climate change and thus prepare agricultural systems for future climatic uncertainties. Therefore, the present study was conferred to analyse the climatic variability of Nalgonda district in Telangana State, considering 30 years (1988 to 2017) of historical weather data pertaining to rainfall and temperature (maximum and minimum). Climatic variability of the district was systematically analysed using box-and-whisker plot, Coefficient of Variation (CV), and trend analysis. The association between climatic variables (rainfall, maximum and minimum temperatures) and the major *Kharif* crop yields was calculated using Pearson's correlation coefficient. The results revealed that the recent decade (2008-2017) had a stable increase in seasonal rainfall in almost all the months compared to the earlier two decades but with the least consistency in rainfall (CV 29.03 %) and higher fluctuations in the maximum temperature (CV 2.38%). September month had shown the higher risk of recording low rainfall conditions compared to July and August months in the district. The rice crop yields during the recent decade (2008-2017) were found to have significant positive and negative associations with the rainfall in September and October months, respectively. Similarly, the lint yields of cotton crops were found to have a significant negative association with the maximum temperatures of the October and November months of the district. The major finding of the study realized was that climate variability and change exist in Nalgonda district, and the climate variables had significant effects on the crop yields of the district.

Introduction

The importance of earth is apodictic, as it is the only known planet suitable for the sustenance of living organisms due to the favorable climatic conditions that prevail on this blue planet. The atmosphere on earth protects the life forms from lethal ultraviolet radiations, maintains moderate temperatures, transports water vapour, and provides all kinds of useful gases. The climate and weather on earth are dependent on the atmosphere. Intergovernmental Panel on Climate Change (IPCC) defined climate in simple terms as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to many years.

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Climate change has become a major concern globally, necessitating immediate attention and action due to the rise in global temperatures, extensive melting of ice, changes in precipitation patterns as well as intensity and frequency of occurrence of uncertain events. The effects of climate change are more detrimental in a densely populated country like India, considering its highly vulnerable nature. The IPCC projections for the Indian region (South Asia) have revealed that the temperature rise would be 0.88-3.16°C by 2050 and 1.56-5.44°C by 2080, subject to the scenario of future development (IPCC, 2007a). The projected change in climate for 2100 indicated an increase in the temperature and rainfall between 2.5- 4.4°C and 15 and 24%, respectively (Bal *et al.,* 2016). The erratic and extreme rainfall events could result in drought and floods. These evidences are escalating to suggest the importance of building resilience into the system in order to sustain the vital ecosystem.

In the present context, the Government of India has conferred high priority for research and development to cope up with climate change in the agriculture sector. Accordingly, the Indian Council of Agricultural Research (ICAR) initiated a major network project, *i.e.,* National Innovations in Climate Resilient Agriculture (NICRA) in February 2011 to address the development needs of extremely vulnerable populations of the country. Nalgonda district of Telangana State was one among the 100 vulnerable districts which were selected for the Climate Resilient Agricultural (CRA) technology demonstration and dissemination to the farmers. Hence, the present study was undertaken with an objective to analyse the climate variability of the Nalgonda district, which may aid in providing advisory services to the farmers towards improving their preparedness for climatic aberrations.

Material and Methods

Climate variability is a regular phenomenon that occurs within a shorter time span, such as a month, season, or a year whereas climate change considers changes that occur over a longer period of time, typically over decades or even longer. For the present study, erstwhile Nalgonda district of Telangana state was purposively selected as it was one among the 100 vulnerable districts selected for the National Innovations in Climate Resilient Agriculture (NICRA) project implementation across India. The important climatic vulnerabilities of the district are higher drought proneness, mid and terminal dry spells, extreme heat stress, *etc*.

The 'in season' climate variability and change, which occurred at the decadal scale was analysed by considering 30 years (1988 to 2017) historical weather data of Nalgonda District. The secondary data of climate variables *viz.,* rainfall and temperature (maximum and minimum), and yields of major crops (rice and cotton) were acquired from the Directorate of Economics and Statistics (DES) of Telangana State for analysis.

Climatic variability of the Nalgonda district was analysed by calculating the coefficient of variations (CV) and Box-and-whisker plot. Trend analysis of the climatic variables was done, and the association between climatic variables and the *Kharif* crop yields was calculated using Pearson's correlation coefficient.

Results and Discussion

Rainfall

Annual Rainfall trend

The annual rainfall data were summed for each year from 1988 to 2017 and plotted as a line graph (Figure 1). The trend line shows that there was a slight increase in annual rainfall over 30 years. However, the year-to-year variability was more in the recent decade (2008 to 2017). The annual rainfall deviation from normal was plotted in figure 2 conformed that the year to year deviations in annual rainfall was very high during the recent decade.

Decadal rainfall trend

To get more detailed information on rainfall trend, the historical rainfall (30 years) data was divided into three decades, and the mean was computed for each decade separately and presented in table 1. The obtained results indicated that the annual rainfall of the third decade (788.7 mm) was higher than the first (707 mm) and second (688.3 mm) decades, as well as 30 years' annual mean rainfall (717.1 mm). However, the rainfall variability of the third decade was very high (29.03%) as compared to the first (19.7%), second (13.1%) decade, and 30 years' variability (21.9%). Among the three

Table 1: Annual and decadal rainfall (mm) trends of Nalgonda district during 1988-2017

Annual/Decade		Average rainfall (mm)	Range		CV (%)
			Min (mm)	Max (mm)	
Annual rainfall		717.10	505.30	1267.40	21.86
First decade	1988-1997	707.20	523.00	945.40	19.72
Second decade	1998-2007	688.27	559.90	870.90	13.10
Third decade	2008-2017	788.71	505.30	1267.40	29.03

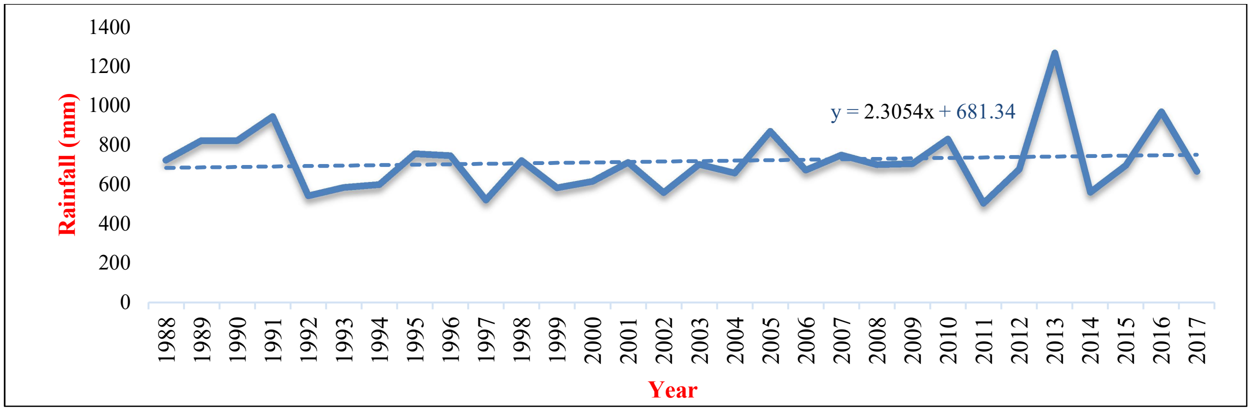

Figure 1: Annual rainfall (mm) trend of Nalgonda district from 1988 to 2017

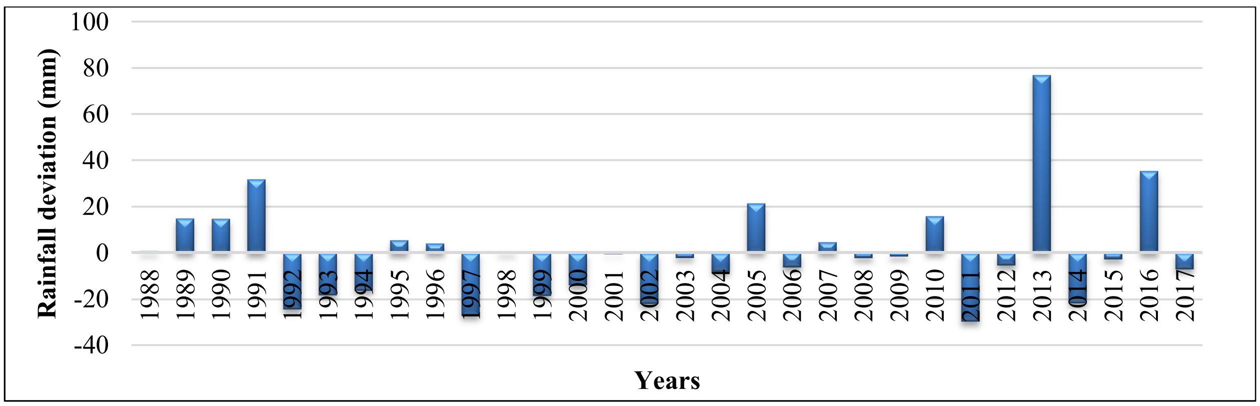

Figure 2: Mean annual rainfall deviation of Nalgonda district during 1988-2017

decades, the second decade had low rainfall. However, there was more consistency in receiving rainfall with the lowest coefficient of variation (CV 13.10%) as compared to its preceding (19.72%) and succeeding (29.03%) decade as well as the historical 30 years (21.86%) data. The present investigation clearly designated that there was an apparent decadal change in the trend of rainfall. In the recent (third) decade, though the annual rainfall increased, this beneficial effect is being nullified due to increased variability in annual rainfall. The results are similar to the findings of Chanapathi *et al.* (2020), wherein they reported an increase in fluctuations in the annual rainfall.

Decadal change in monthly rainfall pattern

Drawing a conclusion on the impact of rainfall on crop growth and yield based on annual rainfall doesn't make more sense as the crops selected (rice & lint cotton) for the study were season bound. Therefore, an attempt was made to understand the shift in rainfall pattern on a monthly scale from June to November among three decades, as shown in figure 3. On perusal of data, it was noticed that there was a clear and consistent increase in rainfall of August month from the first to the third decade. This trend was also reflected in June and September

Table 2: Monthly rainfall (mm) distribution of Nalgonda district during 1988-2017

Month	Average rainfall (mm)	Range		CV (%)
		Min (mm)	Max (mm)	
June	85.40	30.05	204.14	54.50
July	119.07	47.58	314.70	47.03
August	143.88	76.99	247.45	31.86
September	163.45	43.57	357.76	44.03
October	101.04	15.00	456.15	84.48
November	20.59	0.00	64.44	100.82
Season (June-November)	630.14	408.89	1546.50	22.18

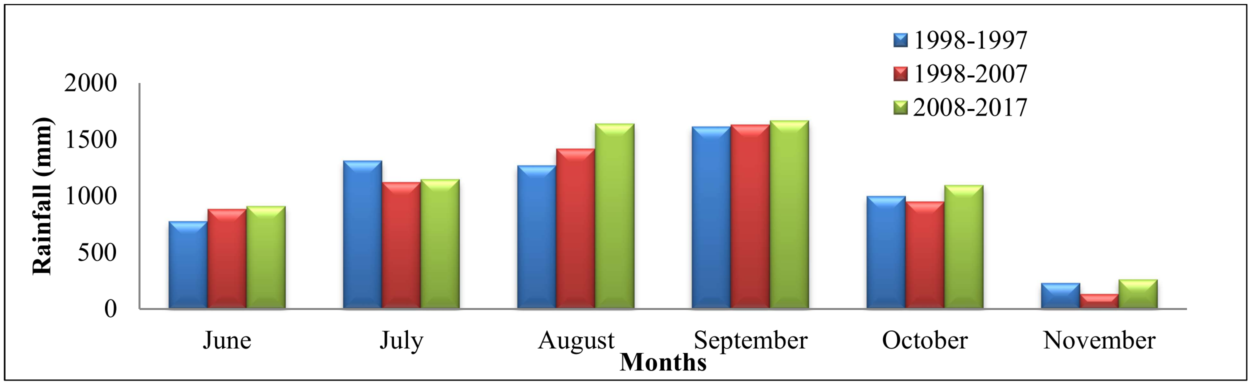

Figure 3: Monthly decennial seasonal rainfall (mm) variability in Nalgonda district

rainfall. However, the decadal change was meagre. In contrast to this, there was a decrease in rainfall of July month during the third decade as compared to the first decade. The decrease in July month rainfall may hamper the establishment and growth at an early stage of the rainfed cotton crop and delay the rice nursery in Nalgonda district. Hence, farmers may be advised not to go for early sowing or prepare a contingency plan in order to face the risk of aberrant rainfall during July month. The increase in rainfall during the October months in the recent decade may be beneficial for rainfed cotton as it coincides with the boll development stage. But, it is inevitable for rice crops as it coincides with the flowering stage during October month, and the rains may result in the aborted ovary and chaffy grains.

Monthly rainfall variability

On perusal of 30 years (1988 to 2017) historical monthly rainfall data from June to November, it was noticed that the rainfall ranged from 409 mm to 1547 mm with a mean of 630 mm (Table 2.). The highest average monthly rainfall was observed during the month of September (163.45 mm), followed by August (143.88 mm) and the least in the month of November (20.6 mm). Based on the coefficient of variation in monthly rainfall, it was observed that August month was more consistent in receiving rainfall with the lowest CV of 31.90% followed by September with CV of 44.00% whereas November and October months were found to be highly variable in rainfall with CV 100 % and 84.50%, respectively. The highest variability during these two months could be due to low influence of the North-East monsoon on the Nalgonda District. Therefore, the probability of occurrence of rainfall events during the October and November months was very low.

Monthly rainfall distribution

The detailed analysis on the deviation of rainfall was further deepened in every month under investigation and summarised in a box plot which was depicted in figure 4. The results revealed that September month had received the highest rainfall with reference to its median value. However, the lengthier lower side whisker indicates a higher risk of recording lower rainfall compared to the July and August months. As rainfall in September month is crucial for crop growth and development, farmers may be advised to prepare with supplemental irrigation to face the events of low rainfall during September month. In the case of

August month, though the median rainfall value is slightly lower than September month, the lengthier upper side whisker shows that the chance of receiving high rainfall is more in comparison to all the other months under investigation. Similarly, the lengthier upper side-whiskers in June, July, October, and November months indicated that the chance of receiving higher side rainfall events with respect to their corresponding median values was more.

Maximum Temperature

Annual maximum temperature trend

The annual mean maximum temperature data were averaged for each year from 1988 to 2017 and plotted as a line graph as depicted in figure 5. The trend line shows a conspicuous increase in the annual mean maximum temperatures over the years. It can be observed that the year-to-year variability was more during the first decade (1988-1997) and the recent third decade (2008-2017).

Decadal maximum temperature pattern

In order to obtain further information on the maximum temperature trend, the historical maximum temperature (30 years) data was divided into three decades, and the mean was computed for each decade separately and presented in table 3. The results showed that the third and second decades had the mean maximum temperature of 33.9°C, which was 0.3°C higher than the first (33.6°C) decade and 0.1°C more than the 30 years' annual mean maximum temperature (33.8°C). The results are in concordance with the findings of Chettri *et al.* (2020), where they reported an increased rate of maximum temperature. The mean maximum temperature of the third decade (2008-2017) had the higher coefficient of variation (2.38%) as compared to the first (2.24%), second (0.99%) decades, and 30 years mean maximum temperature (1.96%) which indicates that the recent decade (2008-2017) had higher fluctuations in maximum temperatures compared to the earlier two decades. The second decade was found to have the least fluctuations in maximum temperature with the lowest coefficient of variation (0.99%) as compared to its preceding (2.24%) and succeeding (2.38%) decade as well as the historical 30 years (1.96%) data. This detailed investigation clearly showed that there was a change in the decadal maximum temperature pattern. The results are in line with the report of IPCC (2007b), wherein it was mentioned that there would be constant warming of 0.2°C per decade during the future decades.

Further, Sreenivas and Raji Reddy (2010) also revealed that, in Andhra Pradesh, the temperatures are projected to increase by at least 3°C throughout the state due to climate change from 2041 to 2060. In the context of climate change, temperature is one of the major environmental factors which influence the growth, development, and yields of rice crops. Vaghefi *et al.* (2011) projected a decline of 0.36 t/ha in rice crop yields when there is an increase in temperature of 2°C at a CO_2 concentration of 383 ppm.

Decadal change in the monthly maximum temperature pattern

A shift in maximum temperature pattern on a monthly scale from June to November between the three decades was depicted in figure 6. On perusal of data, it was observed that there was a slight increase in the maximum temperature in June, July, and August months from the first to the third decade, while the September month had shown consistent maximum temperatures during the three decades. Further, in October, there was an increase in the maximum temperature of 0.6°C and 0.3°C during the second and third decades, respectively, compared to the first decade. A Similar trend was also observed in November month.

Monthly maximum temperature variability

On perusal of 30 years (1988 to 2017) historical monthly maximum temperature data from June to November, it was noticed that the maximum temperatures ranged from 31.5°C to 34.6°C with a mean of 32.9°C (Table 4). The highest average monthly maximum temperature was observed during the month of June (36.6°C), followed by July (33.1°C) and the least in the month of November (30.8°C). It can be inferred that July month has highly variable maximum temperatures (CV 5.59%) followed by June month (4.97%), which may increase the risk of germination during the early stages of crop growth.

Monthly maximum temperature pattern

The detailed analysis on the deviation of maximum temperature was further expanded every month under investigation and summarised in a box plot which was depicted in figure 7. The results indicated that June month had the highest

Table 3: Annual and decadal maximum temperature in Nalgonda district during 1988-2017

Annual/Decade		Mean MaxT (°C)	Range		CV (%)
			Min (°C)	Max (°C)	
Annual mean maximum temperature		33.8	32.6	35.4	1.96
First decade	1988-1997	33.6	32.6	34.8	2.24
Second decade	1998-2007	33.9	33.4	34.4	0.99
Third decade	2008-2017	33.9	33.0	35.4	2.38

Table 4: Monthly and seasonal mean maximum temperature in Nalgonda district during 1988-2017

Month	Mean MaxT (°C)	Range		CV (%)
		Min (°C)	Max (°C)	
June	36.6	32.2	40.0	4.97
July	33.1	29.8	37.0	5.59
August	32.3	29.6	35.2	4.96
September	32.3	30.6	34.7	3.41
October	32.4	29.7	35.7	3.90
November	30.8	28.8	32.6	3.11

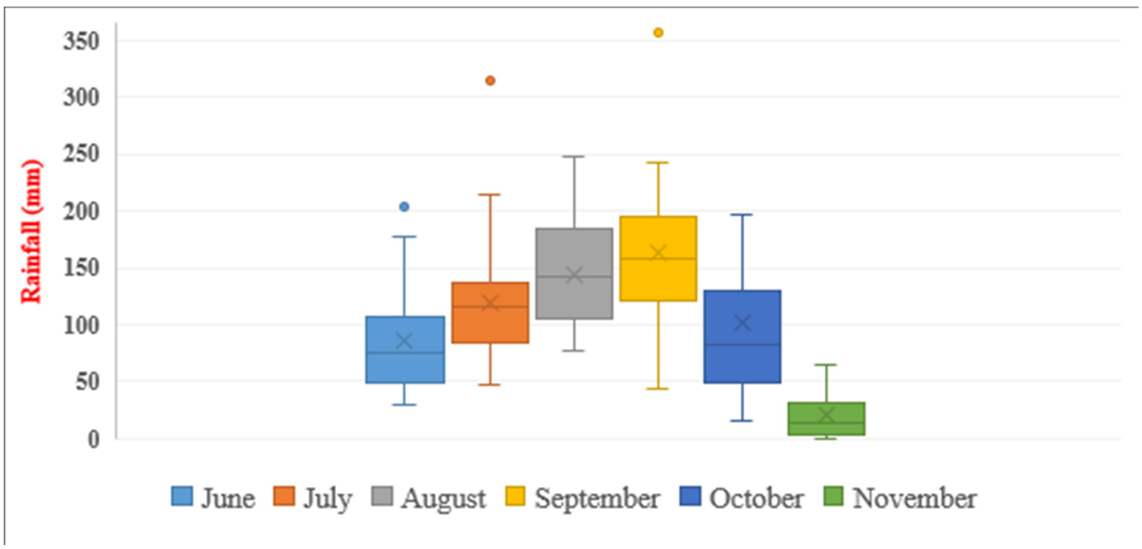

Figure 4: Box whisker plot of rainfall (mm) grouped by months

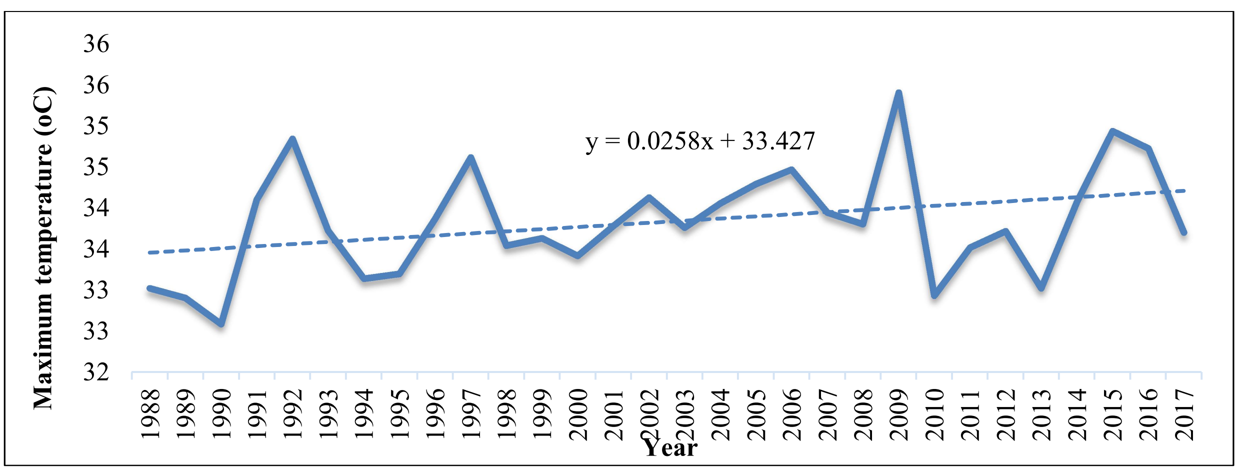

Figure 5: Linear trend of annual maximum temperature in Nalgonda district during 1988-2017

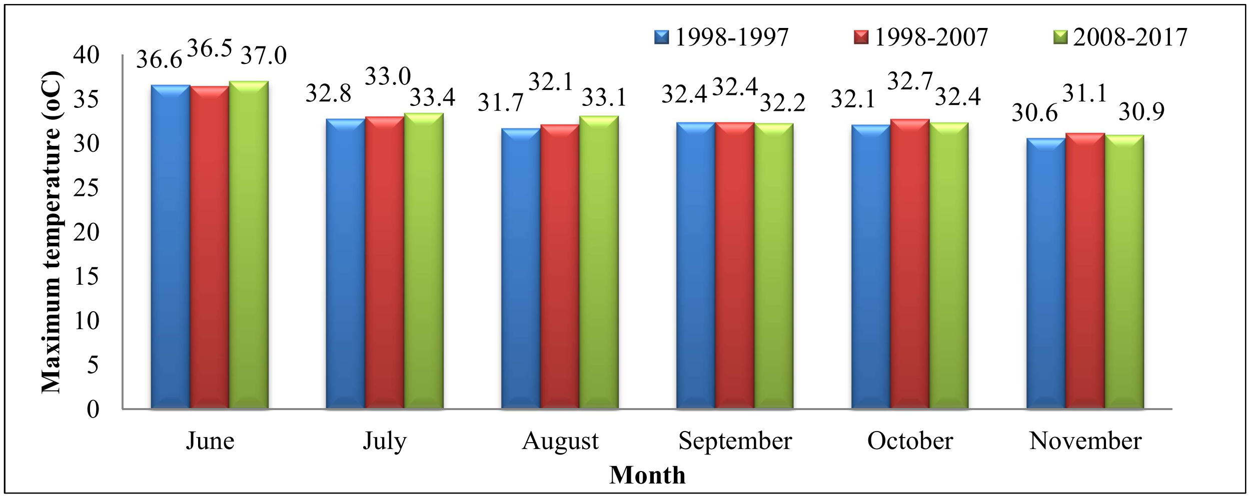

Figure 6: Monthly decennial seasonal maximum temperature variability in Nalgonda district

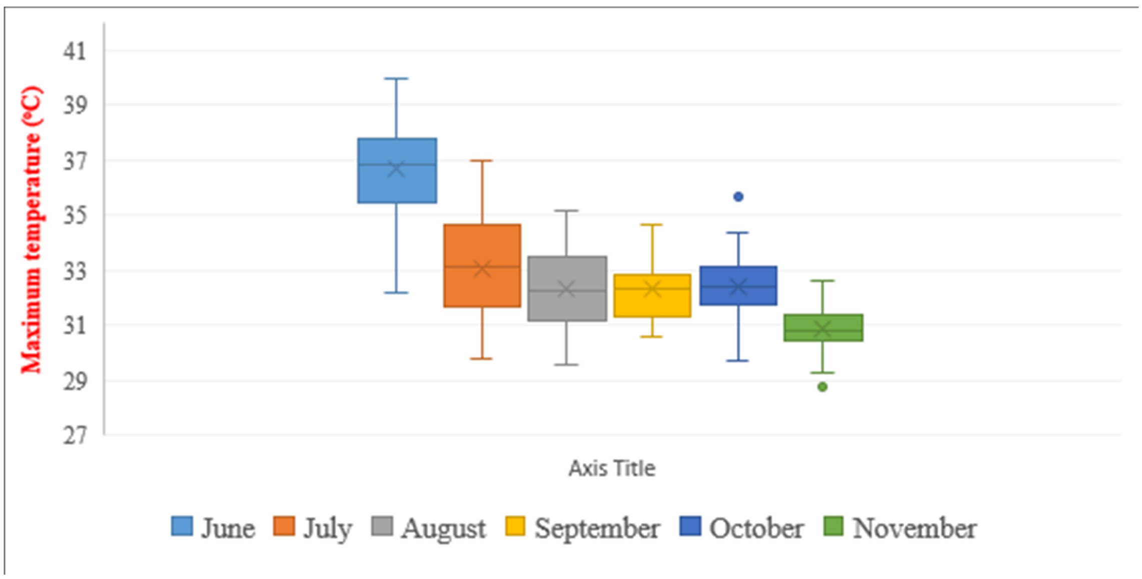

Figure 7: Box whisker plot of maximum temperature (^{o}C) grouped by months

maximum temperatures with reference to its median value, followed by July month. However, the lengthier upper side whisker of July and September months shows that the events of recording higher maximum temperatures over its median value were more frequent as compared to June month. Whereas, in the case of October month, the lengthier lower side whisker shows that the chance of recording maximum temperatures below its median value is more. Similarly, it can be inferred that the November and August months have equal chances of recording high or low maximum temperatures with respect to their corresponding median values.

Minimum temperature

Annual minimum temperature trend

The annual mean minimum temperature data from 1988 to 2017 was plotted as a line graph as depicted in figure 8. The trend line shows a slight increase in the annual mean minimum temperature over the years. It can be observed that the year-to-year variability was very high during the first decade (1988-1997) compared to the second (1998-2007) and third decade (2008-2017).

Decadal minimum temperature pattern

For further investigation on the minimum temperature trend, the historical minimum temperature (30 years) data was divided into 3 decades, for which the mean was computed separately for each decade and presented in table 5. The results indicated that there was a 0.5^{o}C fall in mean minimum temperature during the second decade as compared to its preceding as well as succeeding decades. The results are similar to the findings of Chettri *et al.* (2020). The coefficient of variation of the first decade (3.41%) was very higher than the second (1.68%) and third (1.69%) decades, as well as 30 years, mean minimum temperature (2.54%) specifying the higher degree of instabilities in the minimum temperatures during the first decade. The second decade was found to have the least fluctuations in minimum temperature with the lowest coefficient of variation (1.68%). This detailed investigation clearly showed that there was a change in the decadal minimum temperature pattern.

Decadal change in monthly minimum temperature pattern

A shift in minimum temperature pattern on a monthly scale from June to November between the three decades was depicted in figure 9. On perusal of data, it was noticed that there was an increase in mean monthly minimum temperature in the third decade (2008 - 2017) when compared to a second decade (1998 - 2007) in all the months under investigation. This analysis is clear evidence of a change in mean minimum temperature. These results are in line with the prediction of IPCC (2007b) wherein, it was mentioned that there would be constant warming of 0.2°C per decade in the next few decades.

Monthly minimum temperature variability

On perusal of 30 years (1988 to 2017) historical monthly minimum temperature data from June to November, it was noticed that the minimum temperatures ranged from 21.8^{o}C to 25.6^{o}C with a mean of 23.8^{o}C (Table 6.). The highest average monthly minimum temperature was observed during the month of June (26.5^{o}C), followed by July (24.8^{o}C) and the least in the month of November (20.3^{o}C). It can be inferred that November month has shown high variability in minimum temperatures (CV 7.5%) followed by October month (5.69%). The September month has shown more consistency in the minimum temperatures followed by August month with the coefficient of variation values 3.52 % and 3.98 %, respectively.

Monthly minimum temperature pattern

The detailed analysis on the deviation of minimum temperature was further extended in every month under investigation and summarised in a box plot, which was depicted in figure 10. The results indicated that June month was found to have the highest minimum temperatures with respect to its median value, followed by July month. However, the lengthier lower side whisker of July, August, and October months shows that the events of recording lower minimum temperatures were more frequent when compared to their corresponding medians. Whereas the months of June, September and November have equal chances of recording high or low minimum temperatures with respect to their corresponding median values.

Historical yields of rice and cotton (kg/ha) during *Kharif* season

The district-level yield data of rice and cotton pertinent to *the Kharif* season was collected from DES, Govt. of Telangana to analyse the yield trend and correlate with climate data. The yield data were grouped into decadal yields and presented in figure 11 and figure 12 of rice and cotton, respectively. The mean grain yield of rice during the first, second and third decades were found to be 2870, 2800, 3120 kg, ha^{-1} respectively (Figure 11). Similarly, the historical yields (kg/ha) of lint cotton (kg/ha) were presented in figure 12. The mean yields of lint cotton during the first, second and third decades were found to be 1130, 1430, 1820 kg/ha, respectively.

Effect of climate variability on rice and cotton yields during *Kharif* season

Rice and lint cotton crops are the major crops grown in terms of their area in the Nalgonda district. The relationship between the climate variables during the crop period (June to November) and yields of rice and lint cotton were studied by considering 30 years (1988-2017) rainfall and temperature data of the Nalgonda district. The data sets were divided into three decades, and Pearson's correlation analysis was performed separately for each decade, keeping in view of decadal variability in climatic variables and technological advancement in crop management. The correlations between weather parameters and yields of rice and lint cotton crop yields were presented in table 7 and table 8, respectively.

Table 5: Annual and decadal minimum temperature in Nalgonda district during 1988-2017

Annual/Decade		Mean MinT (°C)	Range		CV (%)
			Min (°C)	Max (°C)	
Annual mean minimum temperature		22.6	21.4	23.9	2.54
First decade	1988-1997	22.8	21.4	23.9	3.41
Second decade	1998-2007	22.3	21.6	22.9	1.68
Third decade	2008-2017	22.8	22.2	23.4	1.69

Table 6: Monthly and seasonal mean minimum temperature in Nalgonda district during 1988-2017

Month	Mean MinT (°C)	Range		CV (%)
		Min (°C)	Max (°C)	
June	26.5	23.0	29.1	5.13
July	24.8	22.0	26.8	4.53
August	24.4	22.5	25.9	3.98
September	24.1	22.4	25.6	3.52
October	22.8	21.0	27.7	5.69
November	20.3	18.2	25.3	7.50
Season (June-November)	23.8	21.8	25.6	3.72

Table 7: Association of climatic variables and *kharif* rice crop yields (kg/ha) of Nalgonda district (1988-2017)

Decade	Kharif crop Season months					
	June	July	August	September	October	November
Rainfall (mm)						
1988-1997	-0.34	0.15	0.51	-0.42	0.02	0.04
1998-2007	0.36	0.25	0.43	0.12	-0.01	-0.11
2008-2017	0.23	0.00	-0.41	0.76***	-0.53**	0.09
Minimum temperature (°C)						
1988-1997	0.03	-0.32	-0.55	-0.77	-0.32	-0.63
1998-2007	0.25	-0.31	0.29	0	-0.32	0
2008-2017	0.29	0.33	0.54	0.08	-0.55*	0
Maximum temperature (°C)						
1988-1997	0.03	-0.08	-0.53	-0.1	0.02	0.06
1998-2007	0.08	-0.64**	-0.16	-0.43	-0.12	0.1
2008-2017	0.09	0.24	0.52	-0.52	0.15	0.24

***- 1 % level of significance **- 5% level of significance *- 10 % level of significance

Correlational analysis of Rice crop yields with rainfall

The correlation between rainfall and rice crop yield was found to be positive and highly significant in September month and negatively correlated in October month during the third decade (2008-2017). The negative effect of rainfall on crop yield during October month may be due to increased rainfall (Table 1) that might have coincided with the flowering stage leading to aborted ovaries and a higher percentage of chaffy grains. Rice crop needs a clear sky and bright sunshine during the flowering stage. Some studies (Alam *et al*., 2013., Alam *et al*., 2012) showed that a 1 % increase in rainfall causes a 0.12 % decline in current paddy yield and 0.21 % decline in the subsequent season. Low light and cloudy weather during the heading stage evidently resulted in sterile panicles in rice crops, while shading after the heading stage leads to loss of photosynthesis. Consequently, relocation of photosynthates, sink capacity, and dry matter accumulation are reduced, which further leads to a significant reduction in the yield contributing characters, *viz.,* spikelet fertility which leads to poorer grain yields (Liu *et al*., 2013).

Table 8: Association of climatic variables and *kharif* lint cotton crop yields (kg/ha) of Nalgonda district (1988-2017)

Decade	Crop Season months					
	June	July	August	September	October	November
Rainfall (mm)						
1988-1997	0.03	-0.59*	-0.48	-0.32	0.57	0.24
1998-2007	-0.43	0.13	-0.49	0.74***	0.19	0.64**
2008-2017	0.39	0.02	0.28	0.11	0.54	0.26
Minimum temperature (^oC)						
1988-1997	0.25	0.46	0.22	0.02	0.92***	0.39
1998-2007	0.29	0.38	0.43	0.43	0.25	-0.04
2008-2017	0.2	0.03	-0.13	-0.18	-0.07	0.06
Maximum temperature (^oC)						
1988-1997	0.11	0.47	0.36	0.64**	-0.49	-0.3
1998-2007	0.29	0.14	0.46	-0.21	-0.26	-0.25
2008-2017	-0.26	-0.29	-0.36	-0.19	-0.64**	-0.72**

***- 1 % level of significance **- 5% level of significance *- 10 % level of significance

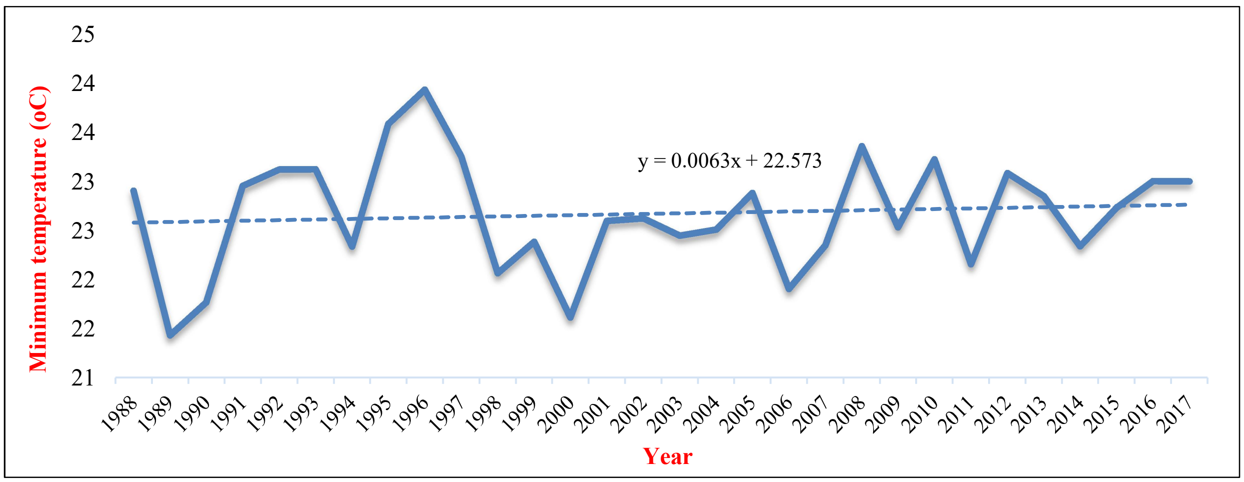

Figure 8: Annual minimum temperature trend in Nalgonda district during 1988-2017

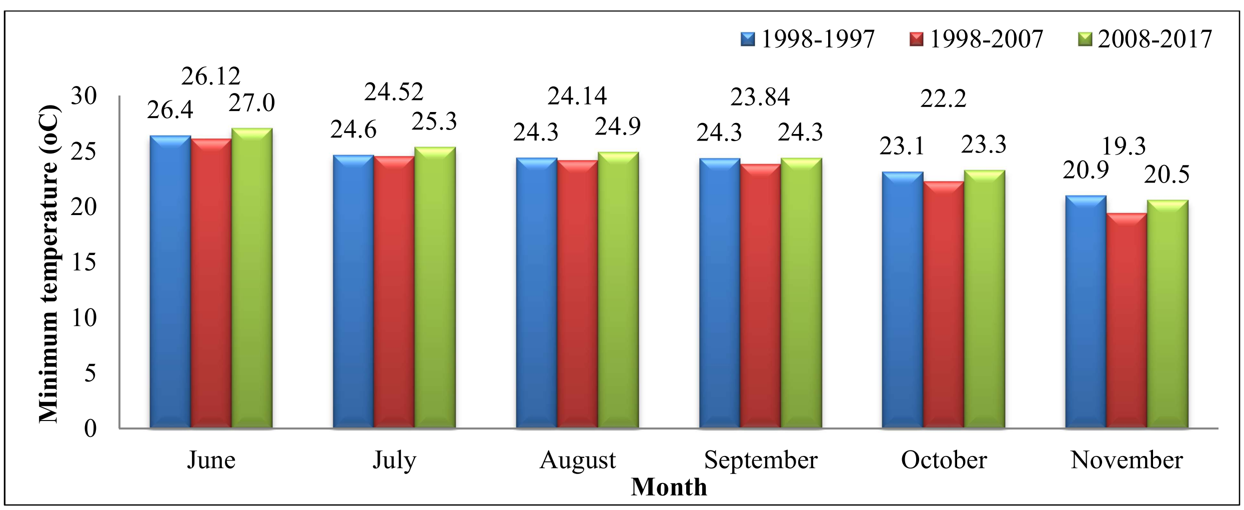

Figure 9: Monthly decennial seasonal minimum temperature variability in Nalgonda district

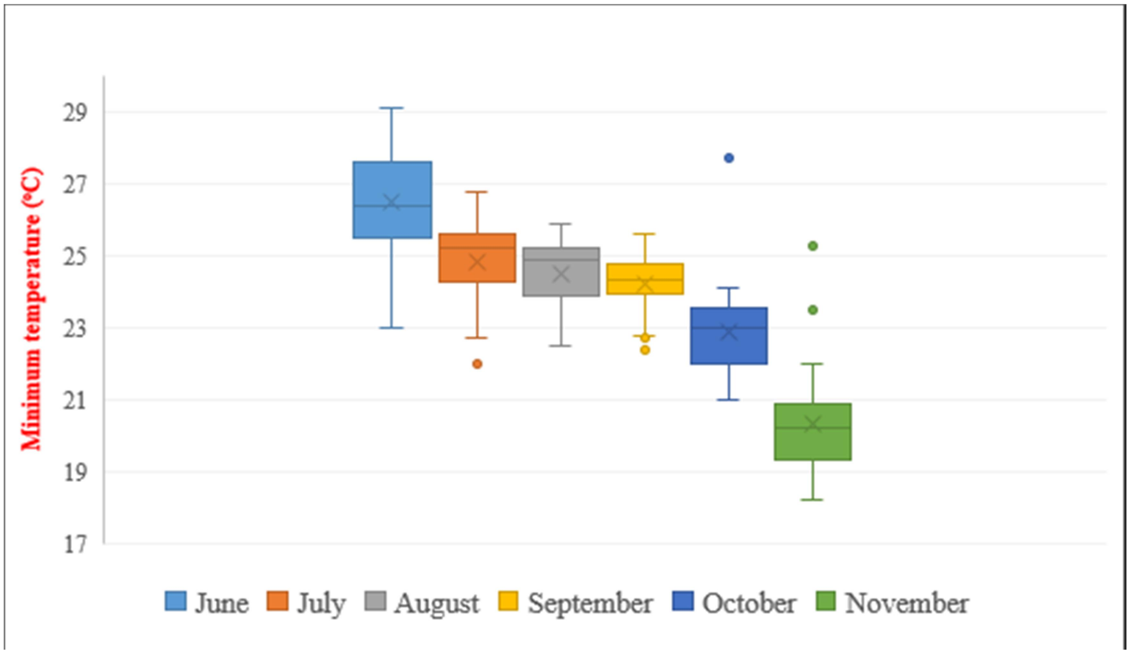

Figure 10: Box whisker plot of minimum temperature (^{o}C) grouped by months

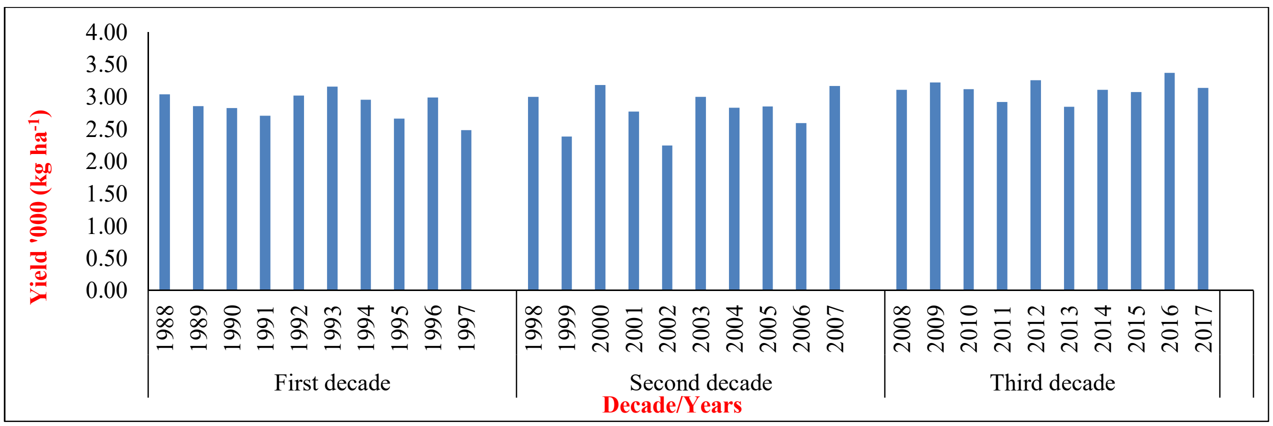

Figure 11: Historical yields of rice (kg/ha) during *kharif* season

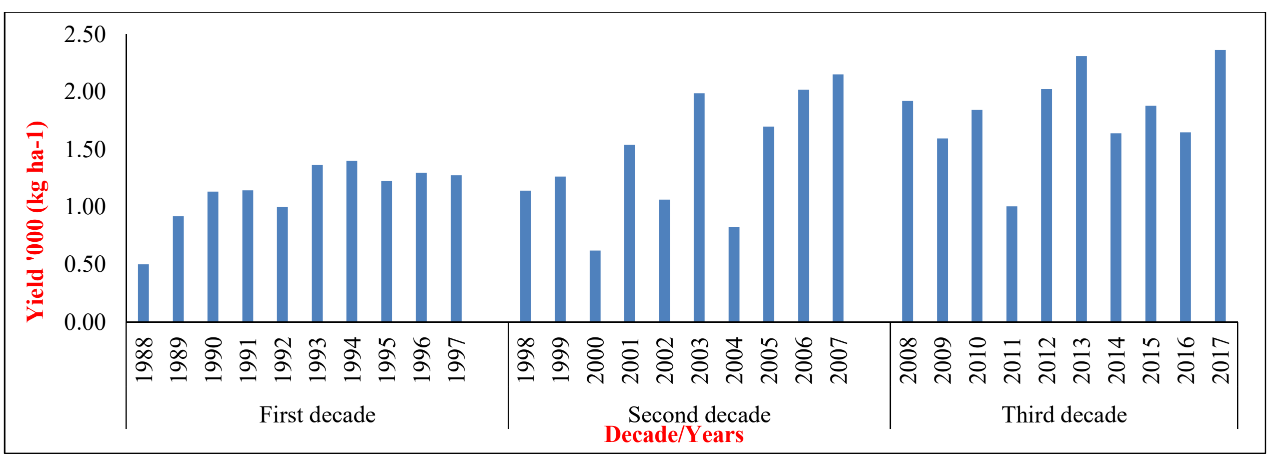

Figure 12: Historical yields of lint cotton (kg/ha) during *kharif* season

Correlational analysis of Rice crop yields with temperature (maximum and minimum)

The grain yield of rice was negatively correlated with a minimum temperature of October month at a 10 % level of significance during the third decade (2008-2017). The rise in mean minimum temperature by about 0.2 ^{o}C and 1.1 ^{o}C in the third decade as compared to the first and second decades, respectively (Figure 9), might have coincided with the flowering stage of the rice crop, causing increased spikelet sterility and thus reduction in yield. Further, the elevated temperature at the reproductive stage reduces the grain filling period in rice crops (Palanisami *et al.*, 2019). The current climate change scenario indicated that a rise in temperature above 25 ^{o}C might lead to the loss of grain mass up to 4.4 % per 1^{o}C rise in temperature and decline in yield as much as 9.6-10.0 % for each 1^{o}C increase in temperature, respectively (Alam, *et al.,* 2012., Baker and Allen, 1993). Further, Saxena and Kumar (2014) and Padakandla (2016) reported that rice yield is negatively affected by maximum temperatures, which causes a decrease in the yields.

Correlational analysis of Cotton crop yields with rainfall

Table 8 reveals that the rainfall (mm) during September month in the second decade and October month during the third decade was positively correlated with the lint yield of cotton. The positive association with lint yield of the cotton crop (kg/ha) might be due to the favourable conditions for boll formation and increase in boll weight. Cotton is mainly a rainfed crop that is dependent on rainfall in all stages, *viz.,* vegetative stage, reproductive stage, boll formation *etc*. (Guntukula, 2020., Padakandla, 2016).

Correlational analysis of Cotton crop yields with temperature (maximum and minimum)

The minimum temperatures have shown a significant positive association with the cotton crop yields during the October month in the first decade, which might have triggered the seed set, increased size of bolls, number of seeds per boll, and the number of fibres per seed (Soliz *et al.,* 2008). During the third decade, the association of maximum temperatures of October and November months with the lint yields of cotton was significantly negative. The rise in maximum temperature by about 0.3^{o}C over the first decade in the months of October and November (Figure 6) might have affected the retention of bolls due to increased abortion of squares and young bolls. These results are in compliance with the findings of Reddy *et al.* (1991). Oosterhuis (1999) also reported that despite the cotton crop's origin from hotter climates, it does not essentially produce better yields at high temperatures. Besides that, a negative correlation was reported between the cotton lint yield and high temperature during flowering and early stages of boll development.

A brief summary of the key findings from the analysis are,

1. The rainfall variability of the recent decade was very high (29.03%) as compared to the first (19.7%), second (13.1%) decades, and 30 years' mean annual rainfall (21.9%), indicating the least consistency in rainfall received.
2. A decrease in the average rainfall of July month was observed in the third decade as compared to the first decade.
3. The lengthier lower side whisker of September month indicated the higher risk of recording low rainfall conditions as compared to the July and August months.
4. The mean maximum temperature of the third decade (2008-2017) had the higher coefficient of variation (2.38%) as compared to the first (2.24%), second (0.99%) decades, and 30 years mean maximum temperature (1.96%) which indicates that the recent decade (2008-2017) had higher fluctuations in maximum temperatures than the earlier two decades.
5. The mean minimum temperature of the first decade had the highest coefficient of variation (3.41%) than the second (1.68%), third decades (1.69%), and 30 years mean minimum temperature (2.54%), which indicates that the first decade had the higher fluctuations in the minimum temperatures as compared to the latter two decades.
6. The rice crop yields during the recent decade (2008-2017) were found to have a significant positive association with the rainfall in September month and a significant negative association with October month.
7. A significant negative association was observed between the maximum temperatures of October and November months and lint yields of cotton, probably due to the affected boll retention and greater abortion of squares and young bolls.

All the above results have clearly indicated that climatic variability exists in the Nalgonda district, which was a major concern to farmers and the major crops grown in the district. In order to minimize the adverse effects of climate change and variability on agricultural production, farmers tend to use Indigenous Technical Knowledge (ITK) and innovative practices as climate-resilient initiatives. Further, these climatic variability concerns necessitate the administrators, policymakers, and researchers to come out with suitable interventions to combat the detrimental effects of climate change.

Conclusion

The obtained results clearly pointed out that there is an apparent decadal change in the trends of rainfall minimum and maximum temperatures in the district. The key finding realised was that there exists climate variability and change in the Nalgonda district, and the climate variables had significant effects on the major crop yields of the district. Therefore, it is important in the present scenario to provide necessary assistance to the farming community towards enhancing their preparedness for climatic aberrations. This could be possible by upscaling CRA technologies on a large scale in the social system. The in-depth climate variability analysis of the district could assist the institutions promoting CRA technologies in preparing contingency plans precisely for each month and several crops grown in the district, thus providing advisory support to the farmers accordingly. The findings of the study may have large implications in designing climate change adaptation programmes keeping in view the existing climatic variability pattern of the district.

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Conflict of interest

The authors declare that they have no conflict of interest.

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