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Pooja Y Durgawale
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

Vikas M Londhe
Junior Agronomisr, AICRPAM, ZARS, Solapur, Maharashtra, India

Sujeet S Deshmukh
Technical officer, GKMS, DBSKKV, Dapoli, Maharashtra, India

Aman A Deshmukh
Department of Horticulture, College of Agriculture, Pune, Maharashtra, India

Corresponding Author:
Pooja Y Durgawale
Department of Agricultural Meteorology, College of Agriculture, Pune, Maharashtra, India

Analysis of extreme weather events over Pune district of western Maharashtra using RClimDex model

Pooja Y Durgawale, Vikas M Londhe, Sujeet S Deshmukh and Aman A Deshmukh

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Abstract
An investigation was carried out during 2021-2023 at Department of Agricultural Meteorology, College of Agriculture, Pune entitled "Analysis of extreme weather events of Western Maharashtra using RclimDex model" to estimate the temperature and precipitation based extreme indices of Pune district from Western Maharashtra region. The data required was collected from the website of India Meteorological Department (IMD, Pune). The Expert Team on Climate Change Detection and Indices has identified 27 core indices based on daily temperature and daily precipitation data which were actively used in this study. The extreme temperature and precipitation-based indices were calculated by using RClimDex model. The changes that occur in the frequency of extreme weather events are considered an indicator of climatic variability. When considering the extreme weather events of Pune district out of total 19 temperature based extreme indices 8 indices showed decreasing trend while 9 indices showed an increasing trend whereas two indices viz. number of frost days (FD0) and number of ice days (ID0) were not observed in the study region. The analysis of weather data during the years 1982-2022 (40 years data) showed variability in climatic conditions among various districts of Western Maharashtra region. The outcomes of the present investigation can be considered as an evidence for climate change over the study area. Thus, this study was carried out with the view to analyse historical data on climatic variables, study regional variations in frequency and intensity of extreme events and comprehend climatic characteristics for the region.

Keywords: Weather, trend, temperature, precipitation, climate, index

Introduction

Tragedies resulting from extreme weather occurrences account for over 85% of all natural disasters worldwide (Obasi, 1994) [19]. According to Chhabra *et al*. (2015) [6], extreme weather events like flood, occurrence of drought, stormy rainfall and cyclone put a major impact on human society. According to Plummer *et al* (1999) [21], extreme meteorological events cause the majority of natural disasters worldwide. Therefore, there is a great deal of interest in researching climate extremes. According to the Inter-governmental Panel on Climate Change (IPCC, 2014) [10] study, the average global Tmax and Tmin temperatures across the terrestrial surface have risen by more than 0.1 °C per ten years since 1950. The evolving patterns of climate extremes demanded increased attention.

The changes that occur in the frequency of extreme weather events are considered an indicator of climatic variability. India's agricultural production systems are quite susceptible to climatic fluctuations. The ideal climatic parameters for each crop must be met in order to maximize output. It is crucial to have adequate understanding of the agro-climatic resources of the location/region in order to produce maximum output possible while utilizing farm resources sustainably. With more frequent occurrences of extreme weather events including droughts, floods, heat or cold waves, cyclones, and hailstorms due to climate change, the sensitivity of agricultural production systems to various climatic aberrations is growing. It is necessary to analyze historical data on climatic factors using proper statistical tools to enable the creation of location-specific technologies and adaptation strategies. Also, it is crucial to comprehend a region's climatic characteristics in order to enhance agricultural operations and boost farmer output and profits. The choice of agricultural systems and resource management alternatives for greater profitability depends on the micro-scale characterization of the agro-climate. This climate microanalysis may be incorporated into a bottom-up strategy to create a national climate database. This study highlighted regional variations in the frequency and intensity of extreme weather events across five districts in Western Maharashtra. This study aided climatic analysis of the study area and made it possible to comprehend the climatic characteristics of the region concerned.

Materials and Methods

This chapter deals with description of study area, data collected for the study and their sources and methodologies adopted for research work of "Analysis of extreme weather events of Western Maharashtra region using RClimDex model" using temperature and precipitation data from 1982-2022 are briefly presented. The data was first homogenized, and then quality control was performed in RClimDex model.

Location and Extent

Western Maharashtra is division of Maharashtra state also called as "Desh" is the region adjacent to Western Ghats between the Godavari River and Krishna River, a part of Deccan Plateau. It is bordered by the Konkan region to West and the states of Karnataka and Goa to South. The Pune district is situated near the Western Ghats, with Deccan Plateau to the east. The diverse landscape of study region includes hills, valleys and Plateaus. The entire Pune climate is whole dry. The hot season, which lasts until early June, comes after the cold season, which runs from November to February. On an average, there are 53 rainy days (i.e. days with rainfall of 2.5 mm or more) in a year in the Pune district. This number varies from 30 at Daund and Jejuri to 104 days at Khandala. The heaviest rainfall in 24 hours recorded at any station in this district was 578.0 mm at Lonavala. The highest maximum temperature ever recorded at Pune was 43.3 °C in 1897 and in 1889. The lowest minimum temperature ever recorded was 1.7 °C on 17th January 1935. Corresponding data for Baramati is, 43.8 °C in 1988 and lowest 5.0 °C in 1971. (Climate of Maharashtra, GOI, IMD, Pune)

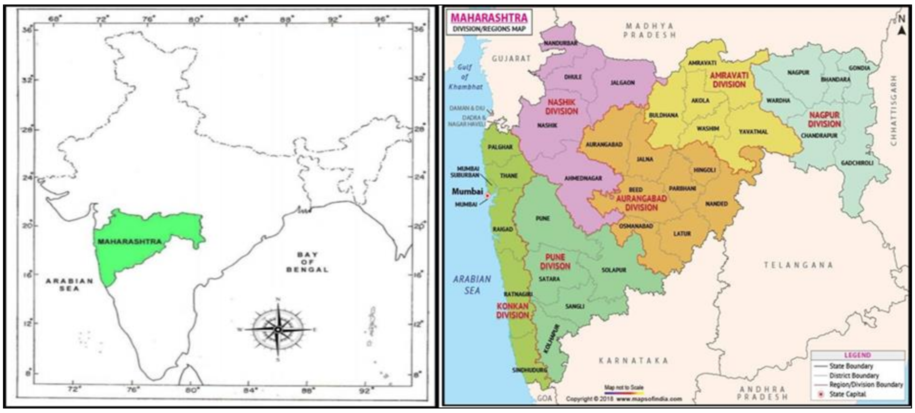

Fig 1: Location of maharashtra in india and western maharashtra in maharashtra state

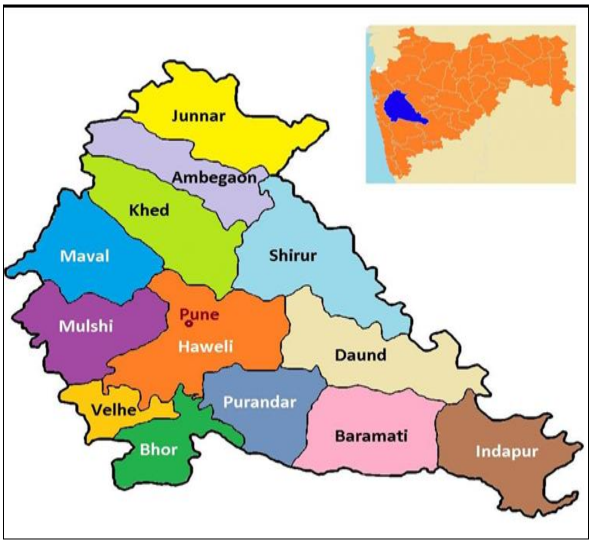

Fig 2: Map of Pune district

Table 1: Name and geographical co-ordinates of the Pune district from Western Maharashtra used in this study

Location / District Name	Base period	Latitude	Longitude
Pune	1983-2021	18.5204° N	73.8567° E

Information about RClimDex

Daily resolution data is typically required for the monitoring, identification, and attributing to changes in the climatic extreme conditions. Detection of climate change in the observed record refers to the identification of the statistically significant changes in weather variables for the concerned regions. In 2003, it was discovered that the methods used for computing percentile-based temperature indices in ClimDex model and other programs would produce inhomogeneity in indices series. A permanent solution for this was development of the software packages that would perform data homogenization (RHtestsV4) and calculation of the indices (RClimDex) based on a very robust and freely available (open-source) statistical package 'R' which is able to perform under both Microsoft Windows as well as Linux/Unix. A "user-friendly Graphical User Interface" (GUI) in "R" is offered by the RClimDex library, which facilitates the computation of the 27 (fundamental) core indices of extreme climatic events as recommended by the ETCCDI: Expert Team on Climate Change Detection and Indices.

RClimDex includes a simple- procedure for available meteorological data quality control that was provided in ClimDex, as in it, the quality-controlled data is required before the indices can be computed and analysed. The software modifies the following aspects:

1. The deviation (eccentricity) in the daily precipitation, daily average temperature, daily minimum temperature and daily maximum temperature data were identified.
2. The unreasonable data (outliers) mainly included data that the daily minimum temperature is greater than the daily maximum temperature and the daily precipitation is negative.

3. RClimDex QC performs the procedures like: replace all missing values into an internal format that R recognizes and also replace all unreasonable values into NA.

The latest version of RClimDex has been developed under "R 2.15.2". It is also dependent on the R library of climdex.pcic (Version 1.1-6) and PCICt (Version 0.5-4) for computing the 27 core indices and the R library of Tcl/Tk (Version 2.15.2) for the graphical user interface. This particular package of RClimDex runs with R 2.15.2 or a later version. The depended R libraries are available from the official CRAN website and needs to be downloaded and installed before the installation of the RClimDex package. The user manual on RClimDex provides the step-by-step instructions on following:

1. R installation and user environment configuration (setting up the user environment),
2. Perform quality control of daily meteorological data,
3. Calculate the 27 (fundamental) core indices.

Table 2: List of all core Climate Indices used in the study

Indices	Indicator name	Definitions	UNITS
FD0	Frost days	Annual count when TN(daily minimum)<0 ºC	Days
SU25	Summer days	Annual count when TX(daily maximum)>25 ºC	Days
ID0	Ice days	Annual count when TX(daily maximum)<0 ºC	Days
TR20	Tropical nights	Annual count when TN(daily minimum)>20 ºC	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	ºC
TNx	Max Tmin	Monthly maximum value of daily minimum temp	ºC
TXn	Min Tmax	Monthly minimum value of daily maximum temp	ºC
TNn	Min Tmin	Monthly minimum value of daily minimum temp	ºC
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
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN<10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the yr	mm/day
R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
Rnn	Number of days above nn mm	Annual count of days when PRCP>=nn mm, nn is user defined threshold	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Annual total PRCP when RR>95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

Results and Discussion

The primary objective of the research was to compute temperature and precipitation based extreme indices during the period from 1982 to 2022 for Pune district from Western Maharashtra using RClimDex model (Zhang and Yang 2004) [25]. The indices have been utilized to monitor climate change and undertake investigations regarding extreme weather events. (Revadekar *et al.*, 2012; Chaudhary Anil *et al.*, (2023); Nayak *et al.*, 2022) [22, 5, 17]. This study highlights shifting pattern of temperature and precipitation over Pune district as well as the regional variations in frequency and intensity of extreme weather events.

Using the RClimDex model, extreme weather events were assessed. The significance of the variations that arise from the RClimDex model's computation was investigated more thoroughly. The p-value and a comparison of the estimate and error slopes were used to test the significance. This test was used to calculate the magnitude of trends. If the p-value is less than 0.05, significant changes will be identified. Significant changes were recognized when p-value was less than 0.05 and slope estimate was larger than the slope error value.

1. Pune District

The data revealed that, there were no frost days or ice days in Pune district (Table 3), indicating that the range of daily temperatures for Pune district does not fall at significant cold extremes, which would lead to the formation of frost and ice in the study area. The number of cold days (FD15) showed significant decreasing trend (p=0.007). The annual number of summer days (SU25) in Pune district indicated a non-significant decreasing (negative) trend, whereas for the number of summer days (very hot days) (SU38) trend was found significantly increasing. Table 3 shows a significant increase in the annual count of days when the TN (daily minimum) temperature was greater than 20° C, i.e. the number of tropical nights (TR20) in the Pune district from 1982 to 2022 (p=0). Arthur DeGaetano *et al.* (2002) [2] observed similar trends regarding minimum temperature indices. The increasing trends for annual count of number of tropical nights (TR20) and number of tropical nights (user defined) (TR23) with p=0 indicated warming of region. Diurnal temperature range (DTR) that represented the mean difference between TX and TN over time period of 1982-2022 showed significantly decreasing trend over Pune district (p=0.001). It suggests that increased warming is predominantly due to more warm nights and fewer cold nights during summer. Decadal trends for DTR for 1990-2000 and 2000-2010 showed huge variation from decrease in difference of Tmax mean and Tmin mean from 11.5° C to 12.3 ° C and from 12.3° C to 10.5 ° C respectively.

Table 3: Result and trend analysis of temperature-based indices for Pune district

Indicators (units)	Indices	R2 (Linear trend)	p-value	Slope estimate	Slope error
Frost days(days)	FD0	NaN	NaN	0	0
Cold days(days)	FD15	17.4	0.007	-0.492	0.172
Ice days(days)	ID0	NaN	NaN	0	0
Summer days (days)	SU25	2.5	0.32	-0.106	0.105
Summer days (days) (user defined)	SU38	6.6	0.106	0.253	0.152
Hot tropical nights (days) (user defined)	TR23	30.1	0	0.511	0.125
Tropical nights (days)	TR20	43.8	0	0.854	0.155
Cool nights (days)	TN10p	55.8	0	-0.309	0.044
Cool days (days)	TX10p	1.9	0.388	0.063	0.072
Warm nights (days)	TN90p	21.5	0.002	0.223	0.068
Warm days (days)	TX90p	0.8	0.57	-0.059	0.102
Cold spell duration indicator (days)	CSDI	24.3	0.001	-0.297	0.084
Warm spell duration indicator (days)	WSDI	0.5	0.653	-0.092	0.203
Diurnal temperature range (°C)	DTR	26.6	0.001	-0.027	0.007
Maximum Tmax (°C)	TXx	3.7	0.226	-0.015	0.012
Maximum Tmin (°C)	TNx	1.7	0.42	0.011	0.014
Minimum Tmax (°C)	TXn	11.1	0.034	-0.027	0.012
Minimum Tmin (°C)	TNn	0.1	0.838	-0.004	0.018

The extreme temperature index cold spell duration indicator (CSDI) was found to be significantly decreasing (p=0.001) with slope estimate = - 0.297 over Pune district during the period of 1982-2022 also the other temperature extreme viz. warm spell duration indicator (WSDI) has followed non-significant decreasing trend over same period with slope estimate is negative 0.092. Cold spell duration indicator (CSDI) was found decreasing from 40-60 days to 10-15 days from 2022-2010. The decadal trend for CSDI was found decreasing for the period of 1990-2000. In the case of WSDI the decadal trend showed decrease from 0 days in year 1989, 1991, 1993, to 38 days in year 2000. The decadal trend for WSDI was found to be decreasing gradually from 2010 to 2020. The warmest daily maximum temperature (TXx) with p= 0.226 and the value of slope estimate is -0.015 and annually minimum value of daily minimum temperature (TNn) have showed non-significant decreasing trend with p=0.838 over period, whereas the warmest daily minimum temperature (TNx) has showed increasing trend over the period of time (p=0.42). The coldest daily maximum air temperature (TXn) for the Pune district decreased significantly from 1982 to 2022 (p=0.034). Similar conclusions were obtained by Singh *et al* (2015) [3] in the research performed on the detailed analysis of extreme temperature indices for the Sutlej river basin from 1970 to 2005.

The number of cool nights (TN10p) showed significant decrease over Pune district (p=0) whereas number of warm nights (TN90p) showed significant increase in Pune district (p=0.002). The decadal trend for this index TN10p decreased from 14 nights in 1990 to seven nights in 2000 year. In 2010 five cool nights were observed while in year 2016 14 nights were recorded. This showed significant decreasing trend over Pune district from 1982-2022. These outcomes are consistent with the findings of Manton *et al.* (2001) [15] in the assessment of trends in extreme daily temperature and rainfall for Southeast Asia and the South Pacific from 1961 to 1998. While the decadal trend of number of cool days (TX10p) showed non-significant increasing trend, the decadal trend for number of warm days (TX90p) showed non-significant decreasing trend during the period of 1982-2022 over Pune district (p=0.57).

Table 4: Result and trend analysis of precipitation-based indices for Pune district

Indicators (units)	Indices	R2 (Linear trend)	p-value	Slope estimate	Slope error
Maximum 1-day precipitation amount (mm)	RX1day	0.4	0.692	0.167	0.418
Number of heavy precipitation days (days)	R10	37.4	0	0.745	0.154
Number of very heavy precipitation days (days)	R20	36.8	0	0.506	0.106
Consecutive dry days (days)	CDD	2.9	0.286	0.559	0.516
Consecutive wet days (days)	CWD	22.6	0.002	0.846	0.251
Very wet days (days)	R95p	21.9	0.002	12.36	3.741
Extremely wet days (days)	R99p	6.7	0.102	3.241	1.933
Simple daily intensity index (mm/day)	SDII	27.5	0	0.12	0.031
Annual total wet days precipitation (mm)	PRCPTOT	36.7	0	26.395	5.556

Out of 27 core indices 9 precipitation based extreme indices were analyzed using RClimdex model in this study. The Man-Kendall trend test and Sen's slope estimation test was used to determine the magnitude of trends and to determine whether trends are increasing or decreasing in their approach. For Pune district annual maximum consecutive 1-day precipitation (RX1day) indicated increasing trend (Table 4) over the period of 1982-2022 (p=0.692) but non-significantly. Number of days having total rainfall of 10mm i.e number of heavy precipitation days (R10) with p=0 and slope estimate value = 0.754 as well as the number of very heavy precipitation days (R20) indicated significantly increasing trend over Pune district (p=0). The study carried by Kaur Baljeet *et al* (2022) [13] showed similar outcomes.

The consecutive dry days (CDD) where maximum number of consecutive days with RR<1 mm was found to be increasing over period of 1982-2022 but non-significantly (p=0.286) whereas the consecutive wet days (CWD) where maximum number of consecutive days with RR≥1 mm was found to be significantly increasing over the period of 1982- 2022 for Pune district (p=0.002). Singh W. R *et al* (2021) [24] showed similar trends in the study carried over Arunachal Pradesh. The simple daily intensity index (SDII), the annual total wet-day precipitation (PRCPTOT) and the annual number of very wet days (R95p), where annual total precipitation when RR > 95th percentile all showed a significantly increasing trend over the

1982–2022 period for Pune district (p=0.002; p=0, and p=0, respectively). In contrast, the extremely wet days (R99p) showed an increasing trend, but non-significantly over the same period (p=0.102). From the study it is clear that the intensity as well as duration of rainfall has increased over the studied period over Pune district. Out of nine precipitation indices 6 indices showed significantly positive (increasing) trend while the other 3 indices showed positive trend but non-significantly (Table 4).

Conclusion

The study on 27 core indices based on daily temperature and daily precipitation in case of Pune district indicated that the number of cold days (FD15), number of cool nights (TN10p), Diurnal Temperature Range (DTR), cold spell duration indicator (CSDI) and the coldest daily maximum temperature (TXn) showed significantly decreasing (negative) trend whereas number of very hot days (SU38), annual count of number of tropical nights (TR20) and number of hot nights (TR23), warm nights (TN90p), cool days (TX10p), warmest daily minimum temperature (TNx) and the coldest daily maximum air temperature (TXn) have showed increasing trend in Pune district. In terms of the precipitation based extreme indices out of nine indices 6 showed significantly positive (increasing) trend whereas only 3 indices indicated positive trend but non-significantly.

This study aided climatic analysis of the study area and made it possible to comprehend the climatic characteristics of the region concerned. The findings in the study can be used by scientists for future investigations and also can be used by policy makers.

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