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Analysis of extreme weather events over Kolhapur district of Western Maharashtra using RClimDex model

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Abstract
The study titled "Analysis of extreme weather events of Western Maharashtra region using RClimDex model" was conducted at the Department of Agricultural Meteorology, College of Agriculture, Pune, from 2021 to 2023. It analyzed 27 core indices derived from daily temperature and precipitation data collected from Kolhapur district over a 40-year period (1982-2022). The investigation revealed notable trends in extreme weather events within the region. Of the 19 temperature-based indices, five exhibited a decreasing trend, while twelve showed an increasing trend. Two indices, namely the number of frost days (FD0) and the number of ice days (ID0), were found to be non-significant.

Specifically, indices such as the number of cold days (FD15), number of cool nights (TN10p), cold spell duration indicator (CSDI), and diurnal temperature range (DTR) demonstrated a significant decreasing trend. On the other hand, the number of tropical nights (TR20) and the number of warm nights (TN90p) indicated an increasing trend over the studied period. This comprehensive analysis of extreme weather events in Kolhapur district provides valuable information into the agro-climatic resources of the region. Such understanding is essential for optimizing agricultural output while ensuring the sustainable utilization of resources.

Keywords: Extreme weather events, RClimDex model, climate analysis

Introduction
The primary objective of developing climate extreme indices by the Expert Team on Climate Change Detection and Indices (ETCCDI) was to monitor changes in the general climate and support detection investigations. According to the IPCC Sixth Assessment Report, an "extreme weather event" is defined as an event that is rare for a particular place and time of year. While definitions of "rare" vary, such events are typically as rare as or rarer than the 10th or 90th percentile of a probability density function derived from observations. Therefore, analyzing extreme events is critical for understanding climate change.

Extreme weather refers to unusual events that deviate significantly from the historical distribution for a given area. These events can be unexpected, unusual, severe, or unseasonal. Climate change, which involves significant variations in average weather conditions, presents one of the most pressing challenges for human society. As the climate changes, the frequency and intensity of extreme weather events are expected to increase. Given the importance of weather variables and climate in agriculture, particularly in light of the changing climatic conditions, it becomes essential to analyze long-term weather data and identify trends. This allows for the recording, evaluation, and application of this data by various stakeholders for different purposes. The RClimDex model was used for decadal trend analysis of extreme weather events. The study conducted for the analysis of extreme weather events in the Kolhapur district, located in the Western Maharashtra region, serves this purpose.

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 the West and the states of Karnataka and Goa to South. The Kolhapur district is South-west Maharashtra district which is a part of Deccan table land with an average height of 550 meters. There is only one main mountain range and hills that is the Sahyadri range. In contrast the eastern part of the district is plain. The district experiences tropical monsoon climate. The climate of Kolhapur district is generally pleasant, with general dryness except during the southwest monsoon season. On average there are 75 rainy days (i.e. days with rainfall of 2.5 mm or more) in a year in the district. This number varies from 122 mm at Gaganbawada to 43 mm at Kurundwad near the eastern border. The heaviest rainfall in 24 hours recorded at any station in the district was 499.0 mm at Gaganbawada in 1989. The highest maximum temperature ever recorded at Kolhapur was 42.3 °C on 9th May 1988 while the lowest minimum ever recorded was 8.6 °C in 1968. (Climate of Maharashtra, GOI, IMD, Pune).

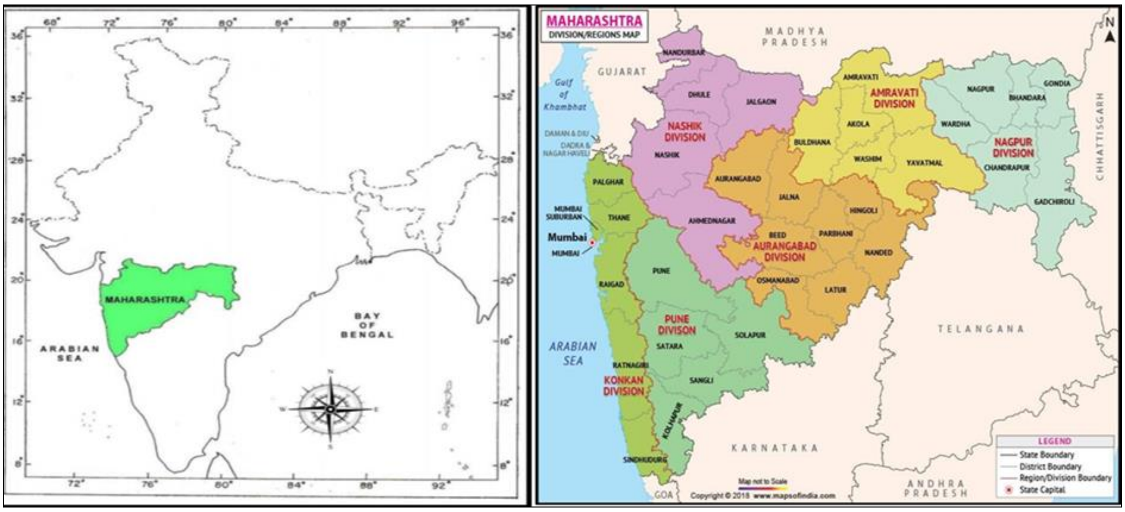

Fig 1: Location of maharashtra in india and western maharashtra in maharashtra state

Fig 2: Map of Kolhapur district

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

Location / District Name	Base period	Latitude	Longitude
Kolhapur	1983-2021	16.7050° N	74.2433° E

Information about RClimDex

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

How to run R
Under the Windows environment, double click the R icon on your desktop, or launch it through Windows "start" menu. This usually gets you into the R user interface. For some computers, you may need to first setup an environment variable called "HOME".
Under a Unix environment, just run R to give you the R console.
Exit from R by entering (q) in the R console under both Windows and Unix. Under Windows, you may also click "**File**" menu and then "**Exit**".

Loading of RClimDex
Within the R console prompt ">" enter source ("rclimdex.r"). This will load RClimDex into R environment. You may need to include the full path before the filename rclimdex.r or you may download the most recent version.
Under windows, RClimDex can also be loaded from drop down menu. Choose the "File" from the RGui menu, and then select "Source R code". This will bring a new pop-up window within which you can select our R source code "rclimdex.r" from the directory where the program was saved or type http://cccma.seos.uvic.ca/ETCCDMI/RClimDex/rclimdex.r to download the latest version from the website.

Indices calculation
RClimDex is capable of computing all 27 core indices listed in the following table. Users may, however, compute only those indices they require.
After selecting "Indices Calculation" from the main menu, a user is asked to set up some parameters for the indices calculation. The "Set Parameter Values" window allows the user to enter the first and last years of the base period for the threshold calculation, the station latitude (Southern Hemisphere is negative) to determine in which hemisphere the station is located, a user defined daily precipitation threshold, P (in mm), to compute the number of days when daily precipitation amounts exceed this threshold (the Rnn indicator), and 4 user defined temperature thresholds.
Once this step is completed, a window will appear to allow the user to select their desired indices for calculation. All indices are selected by default.

District- Kolhapur

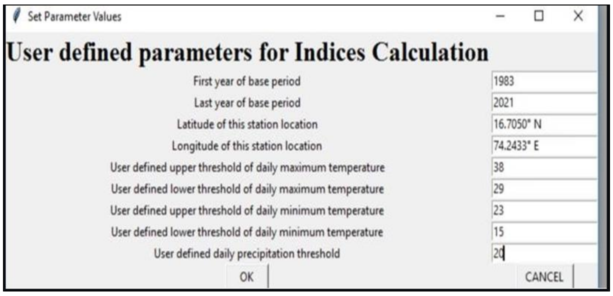

Table 2: List of all core Climate Indices used in the study

Indices	Indicator name	Definitions	UNITS
FD0	Frost days	Annual count when TN(daily minimum)<0 °C	Days
SU25	Summer days	Annual count when TX(daily maximum)>25 °C	Days
ID0	Ice days	Annual count when TX(daily maximum)<0 °C	Days
TR20	Tropical nights	Annual count when TN(daily minimum)>20 °C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
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	°C
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>=10 mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20 mm	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 Kolhapur district from Western Maharashtra using RClimDex model. 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) [20, 5, 14]. This study highlights shifting pattern of temperature and precipitation over Kolhapur 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.

Kolhapur District

Table 3: Result and trend analysis of temperature-based indices for Kolhapur 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	12.9	0.021	-0.408	0.17
Ice days(days)	ID0	NaN	NaN	0	0
Ice days (days) < 20° C	ID20	1.2	0.499	0.289	0.424
Summer days (days)	SU25	0.3	0.749	0.022	0.07
Very hot days (days)	SU38	0.4	0.687	0.066	0.162
Hot nights (days)	TR23	31.4	0	0.659	0.156
Tropical nights (days)	TR20	47.1	0	1.049	0.178
Cool nights (days)	TN10p	49.9	0	-0.285	0.046
Cool days (days)	TX10p	4.2	0.199	0.104	0.08
Warm nights (days)	TN90p	31.1	0	0.292	0.07
Warm days (days)	TX90p	3.2	0.266	0.106	0.094
Cold spell duration indicator (days)	CSDI	24.3	0.001	-0.355	0.1
Warm spell duration indicator (days)	WSDI	1.4	0.46	0.152	0.204
Diurnal Temperature Range	DTR	23.2	0.001	-0.025	0.007
Maximum Tmax (°C)	TXx	6	0.121	-0.015	0.01
Maximum Tmin (°C)	TNx	12.1	0.026	0.018	0.008
Minimum Tmax (°C)	TXn	1	0.533	0.008	0.012
Minimum Tmin (°C)	TNn	0.7	0.616	0.007	0.013

According to the data, there are no frost days or ice days in the Kolhapur district (Table 3). The number of cold days (FD15) showed significant decreasing trend (p=0.021). The decadal trend for the annual number of summer days (SU25) and the number of very hot days (SU38) indicated non-significant increasing trend which illustrated decrease in frequency of occurrence of heat wave in Kolhapur region more predominantly. There existed significant increasing trend in annual count of number of days when TN (daily minimum) temperature was recorded greater than 20° C i.e. number of tropical nights (TR20) and annual count of number of hot nights (TR23) over Kolhapur district from 1982-2022. TR23 index showed considerable increase from thirteen days in 1990 to about 45 days in 1998 and from about 15 days in 2000 to about 60 days in 2010. From 1982-2022 TR23 increased exponentially.

The decadal trend for number of cool nights over Kolhapur district during the period of 1982-2022 has found to be (p=0) decreasing significantly with slope estimate = - 0.285 whereas the decadal trend for annual number of warm nights (TN90p) was found to be significantly increasing in Kolhapur district (p=0). The number of cool days (TX10p) and number of warm days (TX90p) have indicated non-significant increasing trend with p=0.199 and p=0.266 respectively. Decadal trend for diurnal temperature range (DTR) that represented the mean difference between TX and TN over time period of 1982-2022 indicated significantly decreasing trend over Kolhapur district (p=0.001). The DTR for 1992 was about 13° which decreased to about 5 ° C in the year 2021 and 2022. The similar results were found by Frich *et al* (2002) [8]. The extreme temperature index cold spell duration indicator (CSDI) where annual count of days with at least 6 consecutive days when TN (minimum temperature) < 10th percentile was found to be decreasing significantly (p=0.001) over Kolhapur district during the period of 1982-2022 whereas the other temperature extreme named warm spell duration indicator (WSDI) where the annual count of days with at least 6 consecutive days when TX (maximum temperature) > 90th percentile was found to follow non-significant increasing trend over period from 1982- 2022 over Kolhapur district (p= 0.46).The decadal trend for the warmest daily maximum temperature (TXx) have indicated decreasing trend over the period of 1982-2022 for Kolhapur district with p value = 0.121 while the decadal trend for the warmest daily minimum temperature (TNx) has showed significantly increasing trend over the Kolhapur district (p=0.026). The coldest daily maximum air temperature (TXn) for Kolhapur district showed non-significantly increasing trend over the period of 1982-2022 (p=0.533). The monthly minimum values of daily minimum temperature (TNn) have showed non-significant increasing trend.

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

Indicators (units)	Indices	R2 (Linear trend)	p-value	Slope estimate	Slope error
Maximum 1-day precipitation amount (mm)	RX1day	16.2	0.009	0.975	0.355
Number of heavy precipitation days (days)	R10	6.1	0.12	0.273	0.172
Number of very heavy precipitation days (days)	R20	9.3	0.052	0.222	0.111
Consecutive dry days (days)	CDD	0.1	0.872	0.068	0.419
Consecutive wet days (days)	CWD	7.6	0.081	0.512	0.286
Very wet days (days)	R95p	15.4	0.011	8.634	3.234
Extremely wet days (days)	R99p	24.3	0.001	6.655	1.878
Simple daily intensity index (mm/day)	SDII	4.3	0.194	0.035	0.026
Annual total wet days precipitation (mm)	PRCPTOT	13.3	0.019	11.881	4.859

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. This study revealed that for the Kolhapur district annual maximum consecutive 1-day precipitation (RX1day) indicated significantly increasing trend from 1982 to 2022 (p=0.009) with slope estimate= 0.975. Number of days with total rainfall of 10mm, i.e. number of heavy precipitation days (R10), with p=0.12 and slope estimate value = 0.273, showed a non- significant increasing trend, whereas number of days with very heavy precipitation (R20) showed a significantly increasing trend over Kolhapur district (p=0.052). The decadal increase in R20 witnessed increase in number of very heavy precipitation from about 11 days in 1990 to 13 days in 2000 and from 15 days in 2010 to about 35 days in 2020. Hence, it was observed that R20 index indicated huge rise in decadal period from 2010 to 2020.

The consecutive dry days (CDD) where maximum number of consecutive days with RR<1mm was found to be increasing over period of 1982-2022 but non-significantly (p=0.872) also the consecutive wet days (CWD) where maximum number of consecutive days with RR ≥ 1mm was found to be increasing over the period of 1982-2022 for Kolhapur district (p=0.081) but non-significantly. About 14 consecutive wet days were observed in year 1983 whereas about 140 days where observed in year 2022. This indicated that there was rise in number of CWD over decades. On the other hand, CDD decreased from about 105 days to about 65 days over the same period. Toure *et al* (2017) [24] discovered the same results.

The annual number of very wet days (R95p) where annual total precipitation when RR > 95th percentile, extremely wet days (R99p) and annual total wet-day precipitation (PRCPTOT) indicated significantly increasing trend over the period of 1982-2022 for Kolhapur district with p=0.011; p=0.001 and p=0.019 respectively whereas the simple daily intensity index obtained when the annual total precipitation is divided by the number of wet days in the year (SDII) showed increasing trend over Kolhapur district for the period of 1982-2022 but non-significantly (p=0.194) with slope estimate=0.035.

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.

Conclusion

When looking at the extreme weather events in the Kolhapur district, 5 of the 19 temperature-based extreme indices showed a decreasing trend while 12 indices showed increasing trend whereas two indices *viz*. number of frost days (FD0) and number of ice days (ID0) were found non-significant. Number of cold days (FD15), number of cool nights (TN10p), cold spell duration indicator (CSDI) and Diurnal Temperature Range (DTR) showed significantly decreasing trend over 1982-2022 in Kolhapur district whereas number of tropical nights (TR20) and number of warm nights (TN90p) illustrated increasing trend over the period. All studied 9 precipitation based extreme indices showed increasing trend over Kolhapur district from 1982 to 2022.

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