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

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Abstract
The study, conducted from 2021 to 2023 at the Department of Agricultural Meteorology, College of Agriculture, Pune, analyzed extreme weather events in the Solapur district using the RClimDex model. Daily temperature and precipitation data collected over a 40-year period (1982-2022) were used to derive 27 core indices. Of the 19 temperature-based indices, twelve showed an increasing trend, five exhibited a decreasing trend, and two—namely the number of frost days (FD0) and ice days (ID0)—were non-significant. Notably, indices such as the number of cold days (FD15), cool nights (TN10p), cold spell duration indicator (CSDI), and diurnal temperature range (DTR) exhibited a significant decreasing trend, while the number of tropical nights (TR20) and warm nights (TN90p) displayed an increasing trend. This comprehensive analysis provides valuable insights into the region's agro-climatic resources, offering essential knowledge for optimizing agricultural output and promoting sustainable resource use.

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) is to monitor shifts in the overall climate and aid in climate change detection investigations. According to the IPCC Sixth Assessment Report, an "extreme weather event" is defined as a rare event for a specific place and time of year. While the definition of "rare" varies, such events typically fall at or beyond the 10^{th} or 90^{th} percentile of a probability distribution based on historical observations. Therefore, studying extreme weather events is crucial for comprehending climate change.
Extreme weather refers to events that significantly deviate from the historical norms of a given area. These events are often unexpected, unusual, severe, or unseasonal. As climate change—characterized by substantial alterations in average weather patterns—emerges as one of the most critical challenges facing human society, the frequency and intensity of extreme weather events are projected to increase. Analyzing long-term weather data and identifying trends are vital in this context, especially given the significance of weather variables in agriculture and the evolving climate conditions.
To achieve this, the RClimDex model was employed for decadal trend analysis of extreme weather events. The study focuses on the Kolhapur district in the Western Maharashtra region providing valuable information into extreme weather patterns in the area.

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 Solapur district is situated on the south east fringe of Maharashtra state and lies entirely in the Bhima and Seena basins. Solapur has flat or undulating terrain in general, it has no important hill system. Only some spurs of Balghat range pass to the north of Barshi. Solapur district experiences tropical monsoon climate. In Solapur district on an average there are 38 rainy days (i.e. days with rainfall of 2.5 mm or more) in a year in the district. This number increases from 32 at Malsiras near the western border of the district to 45 at Solapur near the south eastern border. The highest maximum temperature ever recorded at Solapur was 46.0 °C in 1988 and the lowest minimum temperature ever recorded was 4.4 °C in 1945. The highest maximum temperature ever recorded at Jeur was 46.6 °C in 1989 and the lowest minimum temperature ever recorded was 3.2 °C on 2nd January 1991. (India Meteorological Department, Pune).

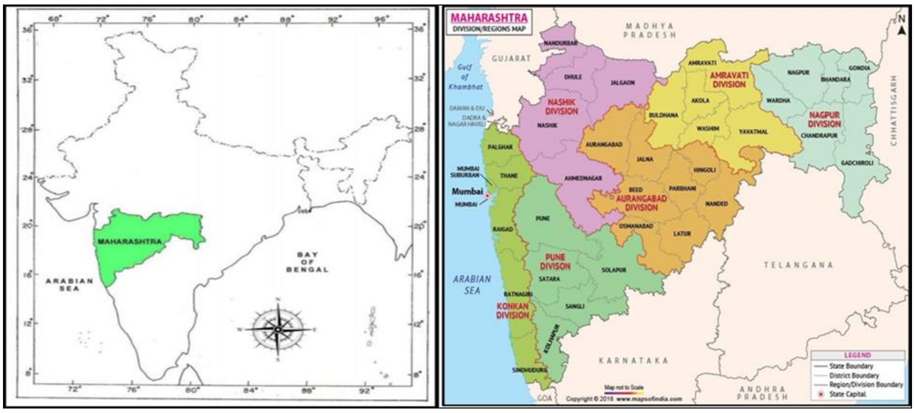

Fig 1: Location of maharashtra in india and western maharashtra in maharashtra state

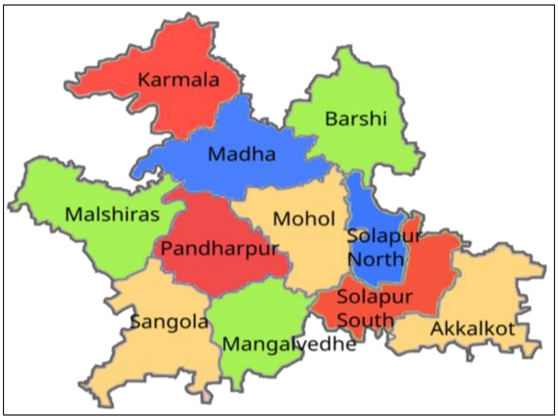

Fig 2: Map of Solapur district

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

Location / District Name	Base period	Latitude	Longitude
Solapur	1983-2021	17.6599° N	75.9064° 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 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.

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 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.

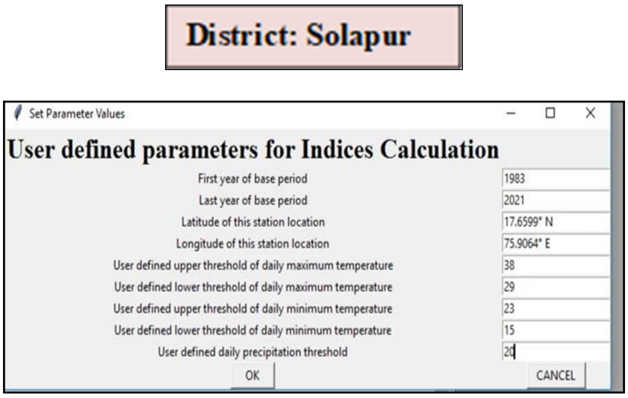

Table 2: List of all core Climate Indices used in the study

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 Kolhapur district from Western Maharashtra using RClimDex model. The indices have been utilized to monitor climate change and undertake investigations regarding extreme weather events. Khoir Aulia N *et al.* (2018) [10], Kaur Baljeet *et al.* (2022) [8], and Singh Waikhom *et al.* (2021) [18] used similar indices for analysis. 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.

Solapur District

Table 3: Result and trend analysis of temperature-based indices for Solapur 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	9.3	0.052	-0.347	0.173
Ice days(days)	ID0	NaN	NaN	0	0
Summer days (days)	SU25	0	0.94	0.001	0.014
Very hot days (days)	SU38	0.5	0.662	-0.076	0.173
Hot nights (days) (user defined threshold)	TR23	33.5	0	0.971	0.219
Tropical nights (days)	TR20	12.9	0.021	0.383	0.16
Cool nights (days)	TN10p	46.1	0	-0.28	0.049
Cool days (days)	TX10p	1.7	0.416	0.068	0.083
Warm nights (days)	TN90p	19.5	0.004	0.197	0.064
Warm days (days)	TX90p	0.2	0.769	-0.023	0.079
Cold spell duration indicator (days)	CSDI	7.6	0.082	-0.206	0.115
Warm spell duration indicator (days)	WSDI	3.1	0.267	0.172	0.152
Diurnal Temperature Range	DTR	23.2	0.001	-0.026	0.008
Maximum Tmax (° C)	TXx	10.3	0.041	-0.021	0.01
Maximum Tmin (° C)	TNx	0.8	0.584	0.006	0.012
Minimum Tmax (° C)	TXn	11.5	0.03	0.033	0.015
Minimum Tmin (° C)	TNn	0.2	0.763	-0.004	0.015

The study indicated that there does not exists any frost days and ice days in Solapur district (Table 3) from which it is understood that the daily temperature range for Solapur district do not fall at considerable cold extremes that would lead to formation of frost and ice in the study area. The number of cold days (FD15) showed significant decreasing trend (p=0.052) over study area during the period of 1982-2022. The similar results were obtained by Deshmukh *et al* (2020) [5]. The annual number of summer days (SU25) showed a non- significant increase (p= 0.94), whereas the number of very hot days (SU38) showed a non-significant decrease (p=0.662) (Table 3). There was a 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) as well as annual count of number of hot nights (TR23) over Solapur district from 1982-2022 with p= 0.021 and p=0 respectively. The number of cool nights (TN10p) showed significant decrease over Solapur district (p=0) whereas number of warm nights (TN90p) showed significant increase over the period of 1982-2022 in Solapur district (p=0.004). Vincent *et al* (2005) [20] showed the similar results which indicated warming was majorly due to significant increase in frequency of warm nights. While the number of cool days (TX10p) increased but not significantly, the number of warm days (TX90p) decreased significantly (p=0.769) over the Solapur district from 1982 to 2022.

The extreme temperature index cold spell duration indicator (CSDI) has been found to be decreasing non-significantly over the Solapur district between 1982 and 2022 (p=0.082) whereas the other temperature extreme named warm spell duration indicator (WSDI) was found to be increasing but non-significantly (p=0.267). The diurnal temperature range (DTR), which referred to the mean difference between TX and TN from 1982 to 2022, indicated a significantly decreasing trend over the Solapur district (p=0.001).

The warmest daily maximum temperature (TXx) showed a significantly decreasing trend for the Solapur district from 1982 to 2022, with a p value of 0.041, whereas the warmest daily minimum temperature (TNx) showed a non-significantly increasing trend (p=0.584) for the same period. The coldest daily maximum air temperature (TXn) for Solapur showed particularly significant increasing trend (Table 3) over the period of 1982-2022 (p=0.03) whereas the annually minimum values of daily minimum temperature (TNn) have showed non-significant decreasing trend with p=0.763 and slope estimate is negative 0.004. Panda *et al* (2014) obtained similar outcomes. This study observed a significant increase in the frequency and intensity of heat waves over the investigated area (Solapur).

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

Indicators (units)	Indices	R2 (Linear trend)	p-value	Slope estimate	Slope error
Maximum 1-day precipitation amount (mm)	RX1day	0	0.953	0.019	0.315
Number of heavy precipitation days (days)	R10	4.2	0.197	0.134	0.103
Number of very heavy precipitation days (days)	R20	0.8	0.582	0.036	0.065
Consecutive dry days (days)	CDD	1.2	0.493	0.332	0.480
Consecutive wet days (days)	CWD	9.4	0.051	0.206	0.102
Very wet days (days)	R95p	0.9	0.544	1.521	2.485
Extremely wet days (days)	R99p	0.8	0.571	0.925	1.62
Simple daily intensity index (mm/day)	SDII	0.1	0.855	-0.004	0.019
Annual total wet days precipitation (mm)	PRCPTOT	4.1	0.204	4.359	3.375

This study revealed that for the Solapur district annual maximum consecutive 1-day precipitation (RX1day) indicated increasing trend over the period of 1982-2022 (p=0.953) with slope estimate= 0.019 but non- significantly. Number of days having total rainfall of 10mm i.e number of heavy precipitation days (R10) with p=0.197 showed increasing trend but non-significantly and also the number of very heavy precipitation days (R20) showed increasing trend over Solapur district (p=0.582) but non- significantly. Hence it was found that most of the indices showed non-significant positive trend (Table 4).

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=0.493) whereas 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 Solapur district (p=0.051) significantly. 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 Solapur district with p=0.054; p=0.571 and p=0.204 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) indicated negative trend but non-significantly over Solapur district for the period of 1982-2022 (p=0.855) with slope estimate= -0.004.

Conclusion

The study on extreme weather events in Solapur district revealed that the temperature-based indices *viz*. Number of cold days (FD15), number of cool nights (TN10p), Diurnal Temperature Range (DTR) and warmest daily maximum temperature (TXx) showed significant decreasing trend whereas number of hot nights (TR23), annual count of number of tropical nights (TR20), number of warm nights (TN90p) and coldest daily maximum air temperature (TXn) has indicated significant increasing trend over Solapur district during the period of 1982-2022. Nine precipitation indices were analyzed; only one index showed a significantly increasing (positive) trend; the other seven indicated a positive but non-significant trend, and the other remaining index showed a significantly decreasing (negative) trend.

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