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

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Abstract
The study on Extreme temperature and precipitation based climatic indices was carried out at Department of Agricultural Meteorology, College of Agriculture, Pune entitled "Analysis of extreme weather events of Western Maharashtra using RclimDex model" during 2021-2023. Daily resolution data required for the monitoring, identification, and attributing to changes in the climatic extreme conditions for Satara district was obtained from website of India Meteorological Department, Pune. The extreme temperature and precipitation-based indices were calculated by using RClimDex model. The RClimDex model was developed and maintained by Xuebin Zhang and Yang Feng at the Climate Research Branch of the Meteorological Service of Canada. The Mann-Kendall trend test was used in this study to determine whether there was a statistically significant increasing or decreasing trend of indices. If significant trend was observed the Sen's slope estimator test was employed to detect whether the trend is positive or negative. The data analyzed (40 years data) showed variations in frequency and intensity of extreme weather events. Out of the total 19 temperature-based extreme indices for Satara district, 6 indices showed a decreasing trend, 11 indices showed an increasing trend, and two indices did not occur in Satara region. In terms of the precipitation based indices over Satara district out of nine precipitation indices 7 indices showed significantly positive (increasing) trend whereas only two indices namely annual maximum consecutive 1-day precipitation (RX1day) and 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.

Keywords: Index, extreme, region, trend, weather, temperature

Introduction
There is a general consensus within the climate community that, any change in the frequency or severity of extreme climate events would have profound impacts on nature, human society and natural ecosystems. It is thus, very important to analyse extreme events. Extreme weather describes unusual weather events that are at the extremes of the historical distribution for a given area. Extreme weather includes unexpected, unusual, severe or unseasonal weather. The major forms of extreme weather include heat waves, cold waves, heavy precipitation and storm events. Increase in the frequency and intensity of extreme weather events for a particular region indicates change in climatic conditions of that region.
Western Maharashtra majorly has a tropical monsoon climate, which is characterized by hot summers and cool winters and by high rainfall during monsoon season (Koppen climate classification: Aw). Western Maharashtra region extending in Satara district experiences moderate type of climate. Some part of the region experiences heavy rainfall while other part of same district witness very less intense rain due to topography of region. Most of the rain is brought by the southwest monsoon winds during the summer and about 87% of rainfalls during the monsoon months. The topography of the region makes the study of extreme weather events necessary to analyse historical data on climatic factors using proper statistical tools to enable the creation of location-specific technologies and adaptation strategies. Also, the micro level analysis plays crucial role in understanding region's climatic characteristics which in turn helps in formulating location-specific developmental approaches.

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.

Location and Extent

Western Maharashtra 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. Satara is district of Western Maharashtra which is situated such that it has Western Ghats to west and Deccan Plateau to the east. The study area experiences tropical monsoon climate. The low rainfall is observed over rain shadow region which is to the east of Western Ghats. With the exception of the western hilly region, Satara district experiences 49 rainy days annually on average. Similar to the quantity of rainfall, the Ghats region experiences the greatest number of rainy days, while the eastern border region experiences the least. While Mahabaleshwar on the hills has on an average 119 rainy days in a year, Mhaswad near the eastern border has only 30 rainy days in a year. At Mahabaleshwar the highest rainfall in 24 hours ever recorded was 458.5 mm in 1896. In the plains of the district, the highest rainfall in 24 hours at any station was 330.3 mm at Mhaswad in 1961. At Satara the highest maximum temperature ever recorded was 41.4°C. (Climate of Maharashtra, GOI, IMD, Pune).

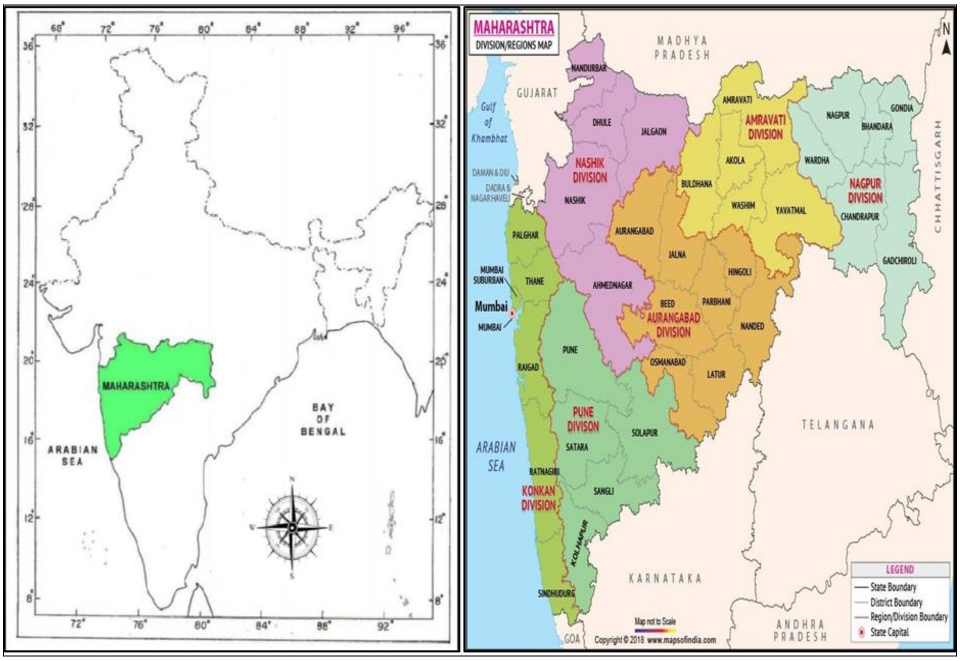

Fig 1: Location of Maharashtra in India and Pune division in Maharashtra state

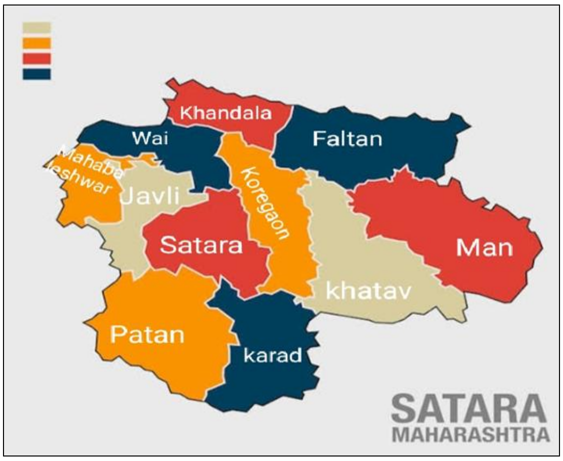

Fig 2: Map of Satara district

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

Location / District Name	Base period	Latitude	Longitude
Satara	1983-2021	17.6805° N	74.0183° E

Information about RClimDex model

The model used in the investigation of extreme weather events in Satara district has software packages that performed 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. 'R' is a language and environment for statistical computing and graphics. It is a GNU implementation of the S- language developed by John Chambers and colleagues at Bell Laboratories (formerly AT & T, now Lucent Technologies). S-plus provides a commercial implementation of the S language. RClimDex requires the base package of R and graphic user interface. The installation of R involves a very simple procedure:

1. Connect to the R project website at *http://www.r-project.org*
2. Follow the links to download the most recent version of R for your computer operating system from any mirror site of CRAN.

R is an integrated set of tools for calculating, manipulating data, and displaying graphics. 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

The RClimDex QC performs the following procedure:

i) Replace all missing values (currently coded as -99.9) into an internal format that R recognizes (i.e. NA, not available)

ii) Replace all unreasonable values into NA. Those values include a) daily precipitation amount-less than zero and b) daily maximum temperature less than daily minimum temperature. In addition, QC also identifies outliers in daily maximum and minimum temperature. The outliers are daily values outside a region defined by the user. Currently, this region is defined as the mean plus or minus n times standard deviation of the value for the day, that is, [mean n*std, mean+n*std]. Here std represents the standard deviation for the day and n is an input from the user and mean is computed from the climatology of the day.

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>=10 mm	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

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. Satara District

Table 3: Result and trend analysis of temperature-based indices for Satara 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	15.7	0.01	-0.442	0.164
Ice days(days)	ID0	NaN	NaN	0	0
Ice days (days)< 20° C	ID20	2.5	0.329	0.354	0.358
Summer days (days)	SU25	3.6	0.236	0.094	0.078
Very hot days (days)	SU38	9.9	0.045	0.318	0.154
Hot nights (days)	TR23	32.5	0	0.834	0.193
Tropical nights (days)	TR20	47.3	0	0.905	0.153
Cool nights (days)	TN10p	52	0	-0.293	0.045
Cool days (days)	TX10p	0.2	0.772	-0.018	0.063
Warm nights (days)	TN90p	33.3	0	0.311	0.07
Warm days (days)	TX90p	0.7	0.617	0.043	0.086
Cold spell duration indicator (days)	CSDI	26.5	0.001	-0.36	0.096
Warm spell duration indicator (days)	WSDI	0.1	0.841	0.036	0.18
Diurnal Temperature Range (°C)	DTR	23	0.002	-0.023	0.007
Maximum Tmax (°C)	TXx	4.5	0.182	-0.016	0.011
Maximum Tmin (°C)	TNx	6.8	0.099	0.017	0.01
Minimum Tmax (°C)	TXn	0.3	0.719	0.004	0.012
Minimum Tmin (°C)	TNn	0.1	0.848	-0.003	0.016

The data revealed that there do not exist any frost days or ice days in Satara district (Table 3). Over the period 1982-2022, the number of cold days (FD15) decreased significantly while the (TXn) coldest daily maximum air temperature for Satara district increased significantly. Over the study period, along with the rise in the number of extremely hot days (SU38), there has also been a significant annual increase in the number of summer days (SU25). Annual number of summer days for 1993 was highest 73 days whereas for the year 1982 it was less than 25 days. The decadal trend for SU38 increased from 42 days in 2000 to 60 days in 2010. This showed significant increase in SU38 over decades. New Mark *et al* (2006) [16] observed similar results when studying daily temperature (maximum and minimum) and precipitation data from 14 southern and western African countries from 1961 to 2000. The number of cool nights (TN10p) over Satara district during the period of 1982-2022 has found to be (p=0) decreasing significantly whereas the temperature index namely warm nights (TN90p) was found to be significantly increasing in Satara district (p=0). The decadal trend of number of cool days (TX10p) followed non-significant decreasing trend with p=0.772, while the number of warm days (TX90p) followed non-significant increasing trend with p=0.617. Ladislaus *et al*. (2017) [14] obtained similar results. The number of cool nights decreased from 24 days in 1983 to four in 2002, 2009 and five in 2014. This indicated significant decrease in number of cool nights over decades in Pune district. However, it was observed that number of warm nights increased from four in 2000 to twenty-six in 2010 year which indicated significant increasing trend of TN90p.

The warmest daily maximum temperature (TXx) showed significant decreasing trend over Satara district whereas the monthly minimum value of daily minimum temperature (TNn) have showed non- significant decreasing trend. The study conducted by Kalita *et al* (2020) [11] on maximum and minimum temperatures in the Eastern state of Meghalaya revealed a positive trend for all months except July and September, as well as a similar increasing trend for maximum temperature. The decadal trend for the warmest daily minimum temperature (TNx) has been observed to have a non-significant increasing trend over time in the Satara district. The Satara district's diurnal temperature range (DTR) demonstrated highly significant declining trends over the 1982–2022 period. There was most significant increase in number of tropical nights (TR20) and hot nights (TR23) from 1982-2022. Over the period 1982-2022, the temperature index, cold spell duration indicator (CSDI), showed a very significant decreasing trend, whereas the warm spell duration indicator (WSDI) showed a non-significant increasing trend. Brown *et al* (2010) [3] found similar result.

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

Indicators (units)	Indices	R2	p-value	Slope estimate	Slope error
Maximum 1-day precipitation amount (mm)	RX1day	7.9	0.075	0.829	0.453
Number of heavy precipitation days (days)	R10	23	0.002	0.534	0.157
Number of very heavy precipitation days (days)	R20	15.4	0.011	0.326	0.122
Consecutive dry days (days)	CDD	0.1	0.826	0.124	0.56
Consecutive wet day (days)	CWD	16.8	0.008	0.81	0.288
Very wet days (days)	R95p	25.4	0.001	13.68	3.757
Extremely wet days (days)	R99p	22	0.002	6.97	2.104
Simple daily intensity index (mm/day)	SDII	12.1	0.026	0.081	0.035
Annual total wet days precipitation (mm)	PRCPTOT	25.9	0.001	21.776	5.905

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. Annual maximum consecutive 1-day precipitation (RX1day) in Satara district increased (p=0.075) but not significantly from 1982 to 2022. Number of heavy precipitation days (R10) with p=0.002 and slope estimate value = 0.534 as well as number of very heavy precipitation days (R20) showed significantly increasing trend over Satara district (p=0.011).

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=0.826) whereas the consecutive wet days (CWD) where maximum number of consecutive days with RR≥1mm was found to be significantly increasing over the period of 1982- 2022 for Satara district (p=0.008). Significant increase in CWD and non-significant increase in CDD implies that the considerable variation exists in the frequency and intensity of rainfall over the different parts of the study area. The annual number of very wet days (R95p) where annual total precipitation when RR>95th percentile, extremely wet days (R99p), simple daily intensity index (SDII) and annual total wet-day precipitation (PRCPTOT) all indicated significantly increasing trend over the period of 1982-2022 for Satara district with p=0.001; p=0.002 and p=0.026 and p=0.001 respectively. Rao K.K *et al* (2014) [18] observed similar trends. Due to circulation changes and presence of Western Ghats over the region majorly even though the studied precipitation indices showed increasing trends the distribution of rainfall over the study region plays major role due to which there exists heaviest rainfall area as well as rain shadow region in study area. Out of nine precipitation indices 7 indices showed significantly positive (increasing) trend whereas only two indices showed positive trend but non-significantly (Table 04). The investigation revealed that decadal trend in precipitation indices is consistently positive since 1982.

Conclusion

In case of Satara district the indices such as number of cold days (FD15), number of cool nights (TN10p), cold spell duration indicator (CSDI) and Diurnal Temperature Range (DTR) have indicated significantly decreasing trends over the period of 1982-2022 whereas temperature indices like number of very hot days (SU38), annual count of number of tropical nights (TR20), number of hot nights (TR23) and number of warm nights (TN90p) have showed significant increasing trend over Satara district for the period of 1982-2022. Out of nine precipitation indices 7 indices showed significantly positive (increasing) trend whereas only two indices showed positive trend but non-significantly (Table 04). The investigation revealed that decadal trend in precipitation indices is consistently positive since 1982.

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