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

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## Abstract
Western Maharashtra majorly has a tropical monsoon climate, which is characterized by hot summers and cool winters and by high rainfall during monsoon season. Western Maharashtra experiences moderate type of climate. Some part of the region adjacent to coast is hilly area having forest cover, due to which the rainfall intensity is more in such areas as compared to the eastern parts. The increased events of extreme weather conditions and growing consensus demands micro-level analysis in order to formulate location specific improvement programmes. The primary objective of the research was to compute temperature and precipitation-based extreme indices during the period from 1982 to 2022 Sangli district of Western Maharashtra using RClimDex model. The study was carried out at Department of Agricultural Meteorology, College of Agriculture, Pune during 2021-2023. Daily meteorological data of maximum temperature, minimum temperature and rainfall was obtained from website of India Meteorological Department, Pune. A Microsoft Excel-based application called RClimDex which offers a user- friendly package for calculating climate extreme indices, allowing users to monitor evolving trends in the environment and identify evidence of climate change was used for analysis. Analysis of extreme temperature and precipitation indices of Sangli district gave following results: out of total 18 temperature based extreme indices only 4 indices indicated 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. Maximum consecutive 1-day precipitation (RX1day), consecutive wet days (CWD), annual number of very wet days (R95p), extremely wet days (R99p) and annual total wet-day precipitation (PRCPTOT) indicated significantly increasing trend over Sangli district region.

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

## Introduction
The primary objective of developing climate extreme indices by ETCCDI: Expert Team on Climate Change Detection and Indices was to use them for monitoring the changes in general climate and detection investigations. The IPCC Sixth Assessment Report defines an ‘extreme weather event’- as: “An event that is rare at a particular place and time of year. Definitions of “rare” vary, but an extreme weather event would normally be as rare as or rarer than the $10^{th}$ or $90^{th}$ percentile of a probability density function estimated from observations.” It is thus, very important to analyse extreme events to study climate change. 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. Climate change is the significant variation of average weather conditions which presents most crucial challenges before human society. As the climate changes, the frequency and intensity of extreme weather events increases. For decadal trend analysis of extreme weather events RClimDex model was used. Given the importance of the weather variables and the climate in agriculture in light of the changing climatic circumstances, it is important to analyse long-term weather data and identify trends so that variability can be recorded, evaluated, and applied by many stakeholders for their own goals. The study carried out for the analysis of extreme weather events of Sangli district from Western Maharashtra region would help in this aspect. This study analyzes nine rainfall indices and eighteen temperature indices that were used by Khoir *et al*. (2018) [13], Kaur *et al*. (2022) [12], and Singh *et al*. (2021) [19].

## 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. Sangli district is located in southwestern part of Maharashtra bounded by the Western Ghats to the west, situated in the Krishna river valley. Sangli district is the part of Deccan plateau, with elevation ranging from 500-700 meters above mean sea level. Sangli experiences tropical monsoon climate with average annual rainfall 400-600 mm. On an average there are 47 rainy days in the Sangli district. The heaviest rainfall in 24 hours recorded at any station in the district was 261.6 mm on 26$^{th}$ July 1898 at Shirala. The highest maximum temperature ever recorded at Sangli was 43.0 °C in 1973 and the lowest minimum temperature ever recorded was 6.5 °C in 1970. (Climate of Maharashtra, GOI, IMD, Pune)

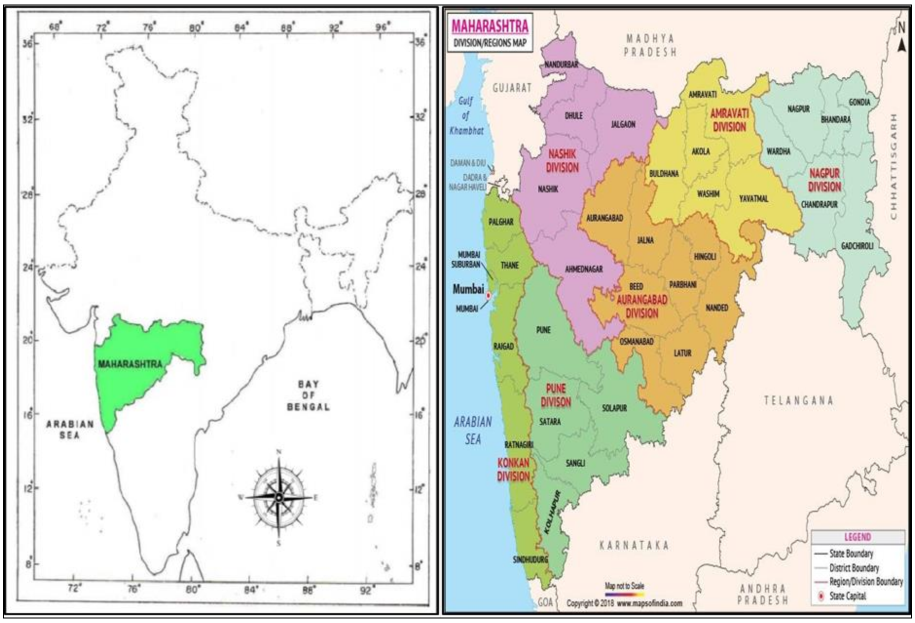


**Fig 1:** Location of maharashtra in india and pune division in maharashtra state

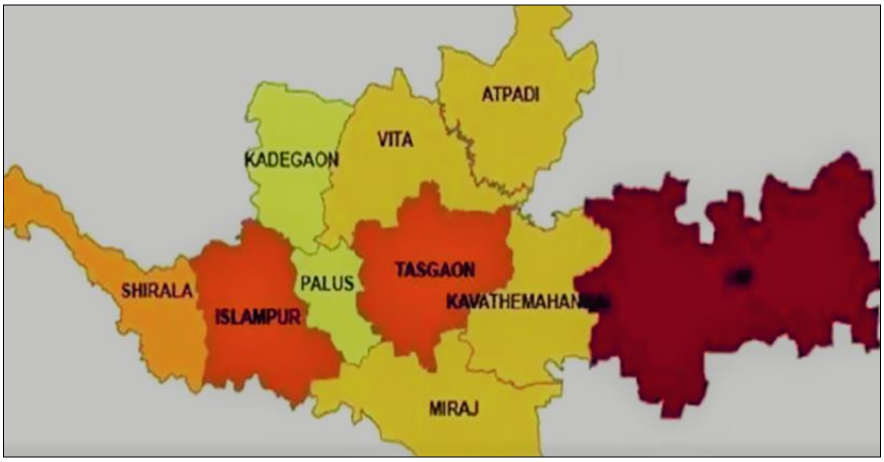


**Fig 2: Map of Sangli district**

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

| Location / District Name | Base period | Latitude | Longitude |
|---|---|---|---|
| Sangli | 1983-2021 | 16.8524° N | 74.5815° E |

## Information about RClimDex model

The model used in the investigation of extreme weather events in Sangli 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

**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".

**Load data and run Quality Control**

Data Quality Control is a prerequisite for indices calculations. The RClimDex QC performs the following procedure:

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

2)Replace all unreasonable values into NA. Those values include a) daily precipitation amounts 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.

Select - "Load Data and Run QC" from the RClimDex Menu to open a window as shown below. This allows users to select (load) the data file from which indices are to be computed.

The filename should be of the form "stationname.txt".

**Indices calculation**

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.

**District- Sangli**

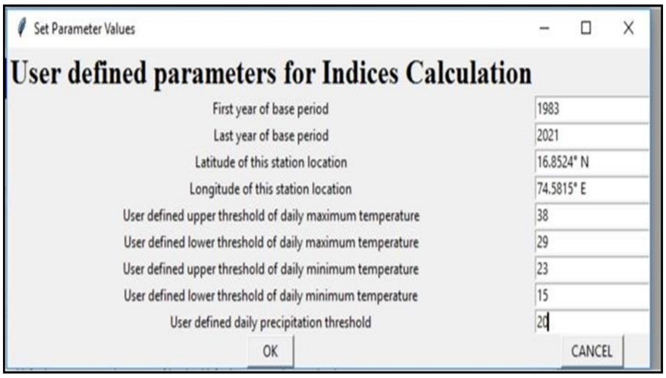


**Table 2:** List of all core Climate Indices used in the study

| 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

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.

### Sangli District

**Table 3:** Result and trend analysis of temperature-based indices for Sangli 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 | 18 | 0.006 | -0.511 | 0.175 |
| Ice days (days) | ID0 | NaN | NaN | 0 | 0 |
| Summer days (days) | SU25 | 0 | 0.906 | 0.007 | 0.06 |
| Very hot summer days (days) (user defined threshold) | SU38 | 0.5 | 0.652 | 0.075 | 0.165 |
| Hot nights (days) | TR23 | 32 | 0 | 0.653 | 0.152 |
| Tropical nights (days) | TR20 | 51.2 | 0 | 1.054 | 0.165 |
| Cool nights (days) | TN10p | 48.5 | 0 | -0.272 | 0.045 |
| Cool days (days) | TX10p | 2.3 | 0.347 | 0.076 | 0.08 |
| Warm nights (days) | TN90p | 25.7 | 0.001 | 0.267 | 0.073 |
| Warm days (days) | TX90p | 1.2 | 0.486 | 0.07 | 0.099 |
| Cold spell duration indicator (days) | CSDI | 22 | 0.002 | -0.267 | 0.08 |
| Warm spell duration indicator (days) | WSDI | 0.4 | 0.714 | 0.082 | 0.222 |

The present research investigation identified variations in temperature extremes. The data suggested that there were no frost days or ice days in Sangli district (Table 3). The decadal trend for number of cold days (FD15) showed significant decreasing trend. Kothawale *et al* (2010) [14] generated similar findings. The annual number of summer days (SU25) and the number of very hot days (SU38) have both indicated non-significant increasing trend, (Table 3). The decadal trend for SU38 indicated gradual increasing trend from 45 days in year 2000 to about 60 days in year 2010 and about 55 days in 2020. There existed considerable variation in pattern of SU38 index. The significant increasing decadal trend for 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 Sangli district from 1982-2022. The number of cool nights (TN10p) 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 Sangli district (p=0.001). In addition, there has been a non-significant increasing trend in the number of cool days (TX10p) and warm days (TX90p), as shown in Table 3 with p=0.347 and p=0.486, respectively.

Over the period of 1982–2022, the diurnal temperature range (DTR), which represented the mean difference between TX and TN, indicated a significantly decreasing trend over the Sangli district (p=0.002). The decadal trend for extreme temperature index namely cold spell duration indicator (CSDI) was found to be decreasing significantly over Sangli district on the other hand the warm spell duration indicator (WSDI) where the annual count of days with at least 6 consecutive days when TX (maximum temperature) > $90^{th}$ percentile showed non-significant increase over the same period over Sangli district (p= 0.714).

Over the 1982–2022 period, the warmest daily maximum temperature (TXx) for the Sangli district showed a decreasing trend (p = 0.099), while the warmest daily minimum temperature (TNx) showed a significantly increasing trend (p = 0.014) for the concerned district. The coldest daily maximum air temperature (TXn) showed non- significantly increasing trend over the period of 1982-2022 (p=0.412). The monthly minimum values of the daily minimum temperature (TNn) shown a non-significant increasing trend, indicating that the frequency and intensity of heat waves and cold waves in the study area had not increased significantly. The results of this study correspond with the conclusions drawn by Marofi *et al* (2011) [15].

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

| Indicators (units) | Indices | R2 | p-value | Slope estimate | Slope error |
|---|---|---|---|---|---|
| Maximum 1-day precipitation amount (mm) | RX1day | 22.4 | 0.002 | 1.108 | 0.33 |
| Number of heavy precipitation days (days) | R10 | 5.8 | 0.129 | 0.252 | 0.162 |
| Number of very heavy precipitation days (days) | R20 | 8 | 0.073 | 0.164 | 0.089 |
| Consecutive dry days (days) | CDD | 0 | 0.962 | 0.022 | 0.458 |
| Consecutive wet days (days) | CWD | 15.5 | 0.011 | 0.609 | 0.228 |
| Very wet days (days) | R95p | 20.4 | 0.003 | 8.953 | 2.831 |
| Extremely wet days (days) | R99p | 30.9 | 0 | 7.718 | 1.849 |
| Simple daily intensity index (mm/day) | SDII | 6.6 | 0.105 | 0.041 | 0.024 |
| Annual total wet days precipitation (mm) | PRCPTOT | 12.2 | 0.025 | 10.211 | 4.393 |

Annual maximum consecutive 1-day precipitation (RX1day) in Sangli district showed a significantly increasing trend from 1982 to 2022 (p=0.002). Number of days having total rainfall of 10mm i.e number of heavy precipitation days (R10) with p=0.129 and slope estimate value=0.252 and number of very heavy precipitation days (R20) with p=0.073 and slope estimate=0.164 showed increasing trend over Sangli district but non- significantly.

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=0.962) while on the other hand the consecutive wet days (CWD) where maximum number of consecutive days with RR ≥ 1mm was found to be significantly increasing over the same period (p=0.011). The annual number of very wet days (R95p) where annual total precipitation when RR > 95$^{th}$ percentile, extremely wet days (R99p), and annual total wet-day precipitation (PRCPTOT) indicated significantly increasing trend over the period of 1982-2022 for Sangli district with p=0.003; p=0 and p=0.025 respectively. Simple daily intensity index (SDII) showed non-significant increasing trend over the Sangli district. Five of the nine precipitation indices showed a significantly positive (increasing) trend, while the other four showed a positive but non-significant trend (Table 04).

## Conclusion

The investigation in case of Sangli district revealed that the number of cold days (FD15), Diurnal Temperature Range (DTR), cold spell duration indicator (CSDI) and number of cool nights (TN10p) has indicated significantly decreasing trend over 1982-2022 in Sangli district whereas number of tropical nights (TR20), number of warm nights (TN90p) and warmest daily minimum temperature (TNx) has showed significant increasing trend over Sangli district. Five of the nine precipitation indices showed a significantly positive trend, while the other four showed a positive but non-significant trend.

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