Original Research Article

Evaluation of changes in temperature and precipitation extremes in Vamsdhara River Basin, Odisha, India

Comment [U1]: Adjust Title

Abstract

With an emphasis on extreme events, several climate change indices that were derived from daily temperature data were computed and studied. Odisha is a coastal state of India which is very prone to extreme events. With climate change, extreme events are also increasing in the world especially in coastal regions. Vamsdhara river basin which is situated at Odisha is selected for the study.The objective of this study was to compute and analyze the Expert Team on Climate Change Detection and Indices (ETCCDI) extreme indices using CLIMPACT software. 14 temperature indices were used to analyze the signals of climate change in the study area. The IMD data for the period 1961-2022 has been used for the study. The trend detection of indices was done through Mann-Kendall test and magnitude of trend was calculated using Sen's Slope estimator. The result showed that warm days (TX90), Diurnal temperature range (DTR) and Warm Spell Duration Index (WSDI) are increasing with 1%, 10% and 1% level of significance respectively. This indicates that indices associated with warming are increasing in river basin. The cold night (TX10) indices found to be decreasing with 10% level of significance and TNx showed a negative trend at 10% level of significance.

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Keywords: Climate change, extreme events, ETCCDI, Trend, MK, Sen's slope

1. Introduction

Indices of climatic variability and extremes have been employed for a long time, frequently by evaluating days with temperature or precipitation readings above or below certain physically-based thresholds. While these indices gave information about local conditions, few physically based thresholds are applicable everywhere in the world. Indices derived from daily data are an effort to objectively extract information from daily weather records to address concernsabout extremes which have an impact on numerous natural and human systems (Zhang *et al.*, 2011). The ETCCDI developed a collection of 27 basic climate indices that show some of the properties of climate extremes (such as frequency, amplitude, and persistence), identify trends, and detect changes in behavior of rainfall and temperature of a region. These indices are calculated statistically and can be compared to absolute and relative thresholds (like percentiles) or combined indices (Aguirre, 2010). For the development of indices, freely available, user-friendly software packages that involve not only ETCCDMI members but also large number of other scientists, including many of the authors. For calculation of 27 climate indices, two software packages were developed in which one written in R (RClimdex) and another is written in FORTRAN (FClimDex).Detailed explanation of all indices, quality control procedures and references to relevant literature are available at http://ccma/seos.uvic.ca/ETCCDMI. Analyses conducted across different countries or regions can be effortlessly integrated by using the same software package and an exact formula for each index. In order to adapt and minimize the negative effects of climate change, it is essential to observe the trend in the time series of various meteorological variables (Mudelsee 2019). A significant pattern can be extracted by trend analysis utilizing a variety of statistical tools, which is an expressive way to understand the past and anticipate the future. In several studies, time series of various

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hydro-meteorological data, such as temperature, precipitation, humidity, air pressure, wind speed, solar radiation, and evaporation, are utilized to evaluate the impacts of climate change (Brown *et al*.2010). A study on global scale by Alexander et al. (2006) have shown that throughout 20^{th} century the extreme precipitation and temperature indices observed a statistically significant warming tendency and wetter conditions. In the Indian context, many studies on temperature and precipitation extremes have been carried out in search of a trend and variability among the parameters. Reddy *et al.* (2023) compared 17 CMIP6 (Coupled Model Intercomparison Project Phase 6) data sets along with IMD (Indian Meteorological Department) data sets in order to finding out ETCCDI extreme precipitation indices. In this study they found that out of selected indices, ensemble mean of RX1DAY, RX5DAY, R10MM, R20MM, and CWD detected to increase in northeastern and Western Ghatsregions of India. Pant *et al.* (2023) carried out a location-specific comprehensive analysis of precipitation over Indo Gangetic Plain, with the help of second generation CORDEX-CORE simulations in the present and future scenarios (under high emission RCP8.5 scenario). A substantial decline in mean Indian summer monsoon rainfall (ISMR) and wet days (rainfall ≥ 1 mm; 7%–14%) over Indo Gangetic Plains under RCP8.5 scenario is suggested under RegCM4 projections. The purpose of this study was to analyze the ETCCDI recommended extreme temperature indices and to assess the trends of indices.

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2. Study Area and Data Used

The study location falls in Odisha state and Andhra Pradesh in India. Vamsdhara River, locally known as Banshadhara River is an east flowing river between Rushikulya and Godavri. The origin of river is from Kalahandi district, and it joins Bay of Bengal in Andhra Pradesh. The basin region is situated in between $83^{0}15'$ and $84^{0}57'$ E longitude and $18^{0}15'$and $19^{0}57'$ N latitude. The location map of study area is shown in fig (1).Since 1965, Orissa has gone through 17 years of flooding, 19 years of drought, and 7 years of cyclone (Govt. of Odisha, 2004). Recent observations in Odisha reveal that local weather conditions are being impacted by global climate change, which is again having an impact on the state's agricultural activity (Dalei,2016).Daily minimum and maximum temperature (TN and TX, respectively) from IMD was used for the study for the period 1961-2022. Quality control of data was performed to identify the outliers and missing values.

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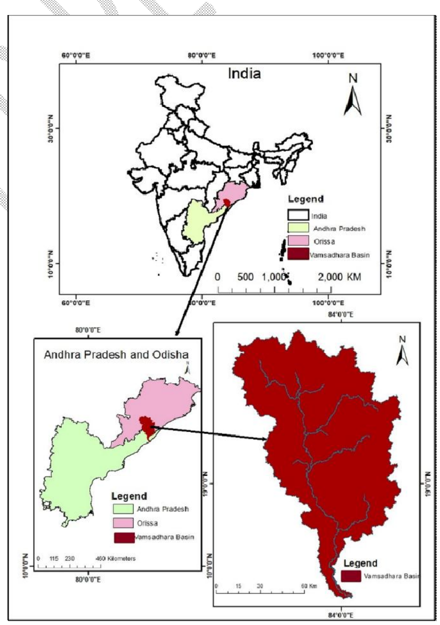

Fig1. Location map of study area

3. Methodology

Climpact software (written in R) was used to calculate climate indices. Climpact software is based on RClimDEX software which computes 27 climatic extreme indices recommended by ETCCDI along with some user defined indices and some important precipitation and temperature indices (Zhang *et al.*,2011). Following steps were involved to complete the study:

- Quality control of climate data
- Selection of suitable indices
- Calculation of indices

This study involves the estimation of only 14 temperature-based indices as recommended by ETCCDI. As these indices are applicable in every region of the world, thus selection of indices should be based on local conditions of each study (Santos et al. 2020). A total of 14 temperature (maximum and minimum)-related indices were computed. Table 1 provides a brief overview of the indices, while the ETCCDI website contains a more detailed definition of the indices (http://cccma.seos.uvic.ca/ETCCDMI/).

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Table 1.Definitions of selected indices used for analysis of extreme temperature in Vamsdhara River Basin.

Index	**Definition**	**Unit**
	Percentile-based	
TX90	Number of days with T_{max}>90th percentile reference period of daily T_{max}	d
TX10	Number of days with T_{max}<10th percentile reference period of daily T_{max}	d
TN90	Number of days with T_{min}>90th percentile reference period of daily T_{min}	d
TN10	Number of days with T_{min}<10th percentile reference period of daily T_{min}	d
	Absolute Indices	
TXx	Maximum value of daily T_{max}	°C
TXn	Minimum value of daily T_{max}	°C
TNx	Maximum value of daily T_{min}	°C
TNn	Minimum value of daily T_{min}	°C
	Threshold Indices	
SU	Summer days; number of days with daily T_{max} > 25°C	d
TR	Tropical nights; number of nights with daily T_{min}> 20°C	d
	Duration Indices	
CSDI	Cold spell duration index; annual count of days with at least 6 consecutive days when T_{min}< 10th percentile reference period	d
WSDI	Warm spell duration index; annual count of days with at least 6 consecutive days when T_{max} > 90th percentile reference period	d
GSL	Growing season length	d
	Other Indices	
DTR	Diurnal temperature range; yearly mean difference between T_{max} and T_{min}	°C

All indices were calculated annually. The reference period considered is the climatological normal period 1961-2022. After evaluating the significance of all the results, we decided to limit the analysis to the indices highlighted in Table 1.
After quality control of data, mentioned indices in Table 1 were calculated using Climpact and respective trends were plotted. Outliers of T_{min}, T_{max} and DTR are plotted on Box-plots (Fig 2).

3.1 Statistical Tests for Trend analysis

There are many parametric and non-parametric tests are available to assess long-term trend analysis. In this study, Mann-Kendall (MK) test is used for the significant trend detection of the extreme indices and Theil Sen's Slope (TSS)estimator is used to evaluate the magnitude of the trend.

3.1.1 Mann-Kendall (MK) test

MK test is a popular statistical test for analyzing trends in climatological and hydrological time series data. MK test is a rank-based, non-parametric test (Kendall, 1948; Mann, 1945). The test is used for the large samples (n>8). Test statistics (S) is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad (1)$$

Where, x_i and x_j are the data values in the time series in chronological order(j>i), respectively, $sgn(x_j - x_i)$ is the sgn function as:

$$sgn(x_j - x_i) = \begin{cases} +1 \; if \; (x_j - x_i) > 0 \\ 0 \; if \; (x_j - x_i) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases} \qquad (2)$$

When there are more than 10 observations, test statistics 'S' is nearly normally distributed having mean E(S)=0 (Kendall, 1948). In this case test statistics of variance is:

$$Var\;(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t_1(t_1-1)(2t_1-5)}{18} \qquad (3)$$

where t_i stands for the number of ties of extent i, n stands for the number of ties and m stands for the number of tied groups. A set ofsample data having the same value are known as tied group. In cases where the sample data size n>10, the standard normal test statistic Z_S is calculated as:

$$Z = \begin{cases} \frac{S-1}{\sigma} \text{if } S > 0 \\ 0 \quad \text{if } S = 0 \\ \frac{S+1}{\sigma} \text{if } S < 0 \end{cases} \qquad (4)$$

Positive values of Z indicate upward trends during the period, whereas negative Z values specify thedownward trends.

3.1.2 Theil Sen's Slope (TSS) Test

Theil Sen's Slope (TSS) method is used to calculate the magnitude of slope. TSS method is a non-parametric which is used to calculate slope and intercept of the trend which will eventually is used to evaluate the magnitude of the slope (Sen, 1968). Following equation is used to evaluate the slope of time series:

$$Q_i = \frac{z_i - z_j}{i - j} \text{ for all combinations of i} > j \qquad (5)$$

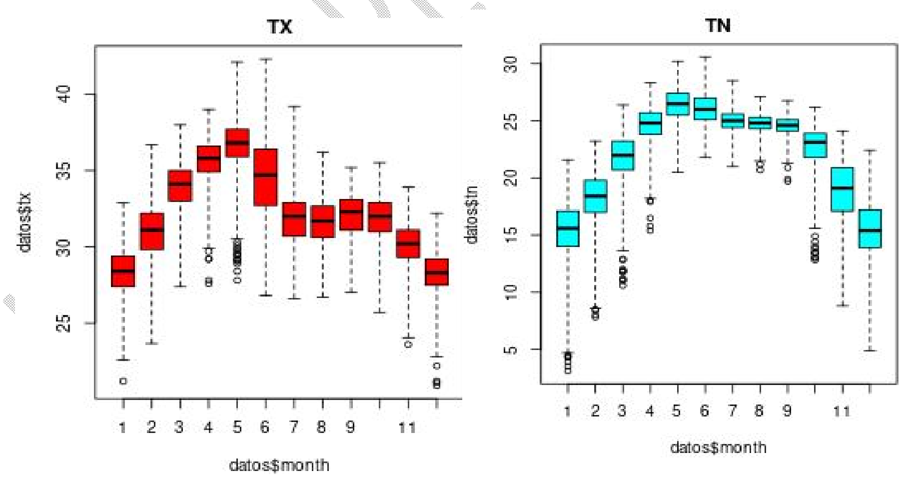
Where slope of data points is denoted by Q_i, z_i and z_j are the data values at times i and j (i>j) respectively. If each time period only contains one datum, then for 'n' years of data:
$N = n(n-1)/2$estimates of slope. If more than one observation is made during one or more time periods, then $N < n(n-1)/2$, where 'n 'is the number of years of data.The Q_i values were sorted in ascending order after being computed in a quantity of N. Following equation is used to determine the median of Q_i:

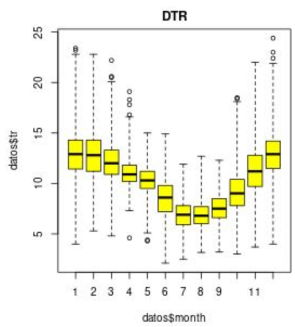
$$\beta = \begin{cases} Q\dfrac{(m+1)}{2} \text{ m is odd} \\ \dfrac{1}{2}\left(Q\dfrac{m}{2} + Q\dfrac{m+2}{2}\right) \text{ m is even} \end{cases} \qquad (6)$$

4. Results

4.1 Quality Control

The T_{max} varies from 42.3˚C to 20.9˚C and T_{min} 30.6˚C to 3.1˚C. No missing data and jumps were found in time series in both T_{max} and T_{min} for time period 1961-2022.





Fig(2) Outliers per calendar month (a)T_{max}, (b) $T_{min}$and (c) DTR

4.2 Trend analysis of Indices

Results of applying statistical tests for annual extreme indices over the period 1961-2022 are presented in Table 2. The graphical presentation of the trend is shown in Fig (3). As indicated in Table 2, according to datasets and methods used in study, out of 14 extreme indices only 5 indices showed significant trend according to MK test at different level of significance.

Table 2. Linear trend statistics of selected temperature ETCCDI Indices

Index	Frequency	StartYear	EndYear	Slope	MK
TX10	Annual	1961	2022	-0.06114	**-1.847***
TX90	Annual	1961	2022	0.127603	**3.626*****
TN10	Annual	1961	2022	-0.04063	-1.3
TN90	Annual	1961	2022	0.024539	0.462
TXx	Annual	1961	2022	-0.00934	-1.172
TNn	Annual	1961	2022	0	0.061
TNx	Annual	1961	2022	-0.01458	**-2.43*****
TXn	Annual	1961	2022	-0.00909	-0.808
WSDI	Annual	1961	2022	0.4285	**3.432*****
CSDI	Annual	1961	2022	-0.1333	-1.178
GSL	Annual	1961	2022	0	0.085
SU	Annual	1961	2022	0	0.05
TR	Annual	1961	2022	0.069767	0.82
DTR	Annual	1961	2022	0.006082	**1.65***

*Statistically significant at α = 10% (critical Z = ± 1.645), **Statistically significant at α = 5% (critical Z = ± 1.96), ***Statistically significant at α = 1% (critical Z = ± 2.33).

Forpercentile-based indices, only maximum temperature indicesTX10(cold night) and TX90(warm night) indices showed negative and positive indices respectively at 10% and 1% level of significance. No significant trends were shown in minimum temperature indices.For absolute indices, TNxshowed significant negative trend at 1%. Duration indices WSDI showed significant positive trend at 1%. No significant trends were found for threshold indices. As for other indices, DTR showed positive trend at 10% significance level.

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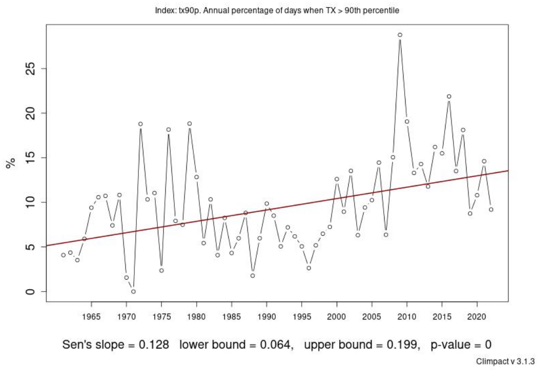
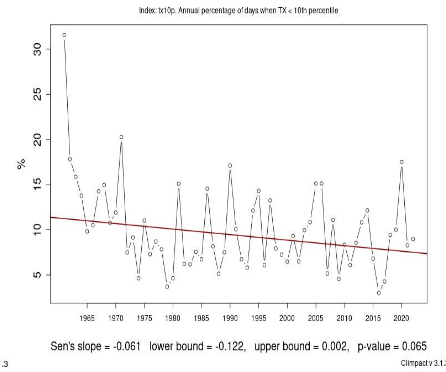
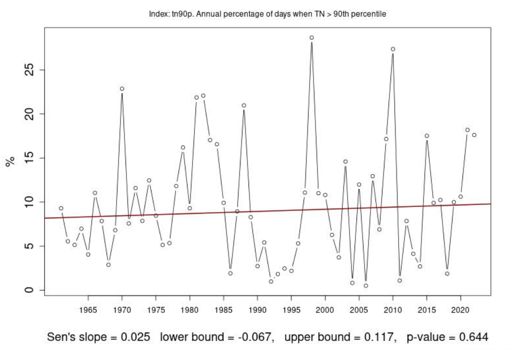
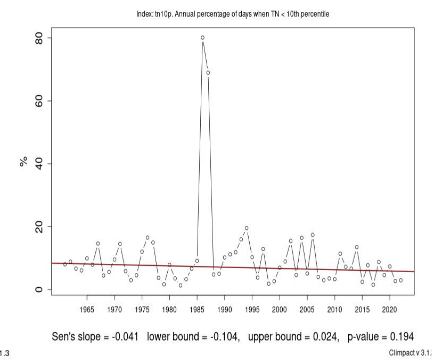
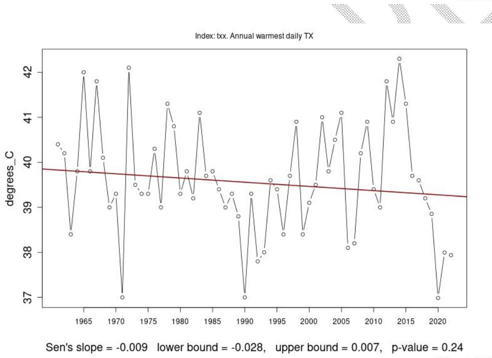
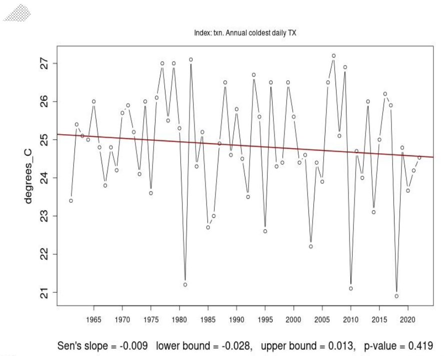

Index: tx90p. Annual percentage of days when TX > 90th percentile
%
Sen's slope = 0.128 lower bound = 0.064, upper bound = 0.199, p-value = 0
Climpact v 3.1.3

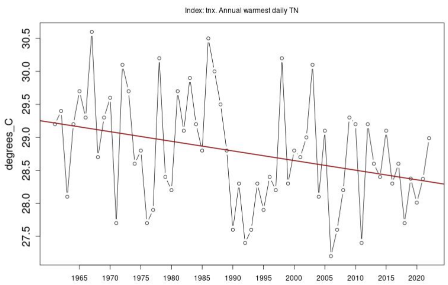

Index: tx10p. Annual percentage of days when TX < 10th percentile
%
Sen's slope = -0.061 lower bound = -0.122, upper bound = 0.002, p-value = 0.065
Climpact v 3.1.3


Index: tn90p. Annual percentage of days when TN > 90th percentile
%
Sen's slope = 0.025 lower bound = -0.067, upper bound = 0.117, p-value = 0.644
Climpact v 3.1.3


Index: tn10p. Annual percentage of days when TN < 10th percentile
%
Sen's slope = -0.041 lower bound = -0.104, upper bound = 0.024, p-value = 0.194
Climpact v 3.1.3

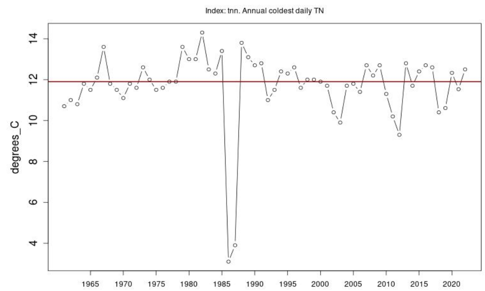

Index: txx. Annual warmest daily TX
degrees_C
Sen's slope = -0.009 lower bound = -0.028, upper bound = 0.007, p-value = 0.24
Climpact v 3.1.3


Index: txn. Annual coldest daily TX
degrees_C
Sen's slope = -0.009 lower bound = -0.028, upper bound = 0.013, p-value = 0.419
Climpact v 3.1.3



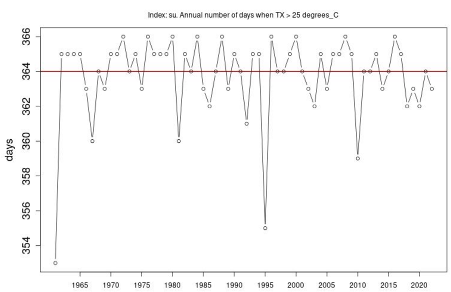
Sen's slope = -0.015 lower bound = -0.026, upper bound = -0.002, p-value = 0.015

Climpact v 3.1.3



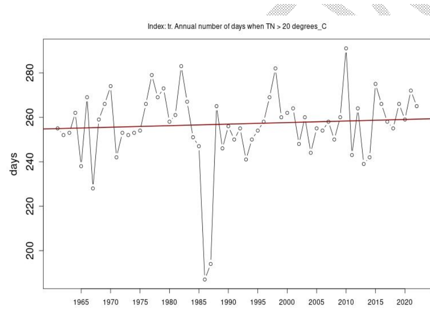
Sen's slope = 0 lower bound = -0.016, upper bound = 0.015, p-value = 0.952

Climpact v 3.1.3



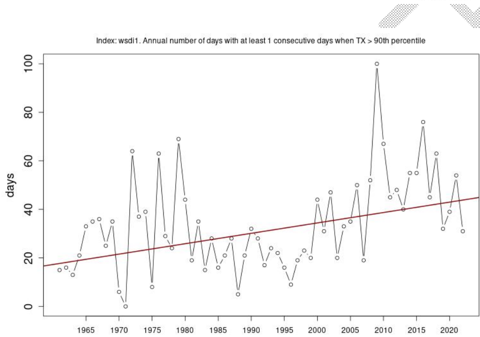
Sen's slope = 0 lower bound = -0.026, upper bound = 0, p-value = 0.375

Climpact v 3.1.3



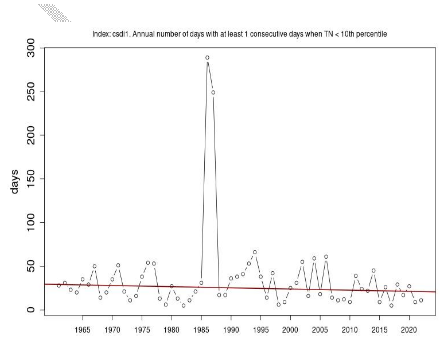
Sen's slope = 0.07 lower bound = -0.111, upper bound = 0.259, p-value = 0.412

Climpact v 3.1.3



Sen's slope = 0.429 lower bound = 0.214, upper bound = 0.684, p-value = 0.001

Climpact v 3.1.3



Sen's slope = -0.133 lower bound = -0.366, upper bound = 0.093, p-value = 0.238

Climpact v 3.1.3

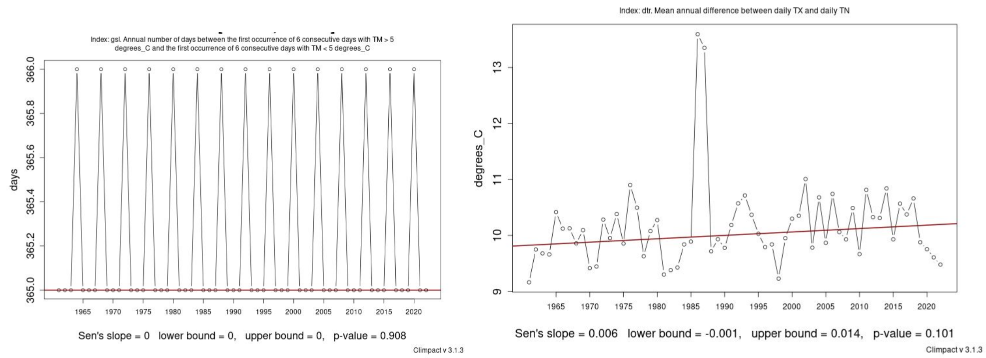


Fig (3). Annual temperature indices with Sen's slope estimate for the Vamsdhara River Basin, India

5. Conclusion

In present study, extreme temperature indices on annual basis were calculated for the period 1961-2022 for the Vamsdhara river basin, Odisha. Climpact model was used to evaluate the extreme indices. Trends were computed using MK test for the magnitude of the trend, (TSS) test was used. From the results, it is concluded that warm days (TX90) are increasing at higher level of significance(1%) and cold nights (TX10) are decreasing at 10% level of significance (1%) in the basin.Maximum value of daily T_{min} (TNx) is found to be decreasing at 10% level of significance. WSDI and DTR are also found to be significantly increasing over the period 1961-2022. This shows that in the study area, extreme events of are increasing which reflects the climate change impact on the basin.

Comment [U8]: Adjust grammer and paraphase

6. References

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