International Journal of Environment and Climate Change

Volume 13, Issue 8, Page 728-739, 2023; Article no.IJECC.100974
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Evaluation of Changes in Temperature Extremes in Vamsadhara River Basin, Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i82004

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/100974

Original Research Article

Received: 01/04/2023
Accepted: 01/06/2023
Published: 03/06/2023

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 severely prone to extreme events. With climate change, extreme events are also increasing in the world especially in coastal regions. Vamsadhara 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 concerns about extremes which have an impact on numerous natural and human systems" [1]. "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" [2]. "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). 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 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" [3]. "A study on global scale by Alexander et al. [4] have shown that throughout 20th 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.* [5] 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 Ghats regions of India". Pant et al. [6] 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. Several other studies in India and other countries are conducted on extreme indices to find out the occurrence and frequency of extreme events [8-22]. The purpose of this study was to analyze the ETCCDI recommended extreme temperature indices and to assess the trends of indices".

1.1 Study Area and Data Used

The study location falls in Odisha state and Andhra Pradesh in India. Vamsadhara 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.

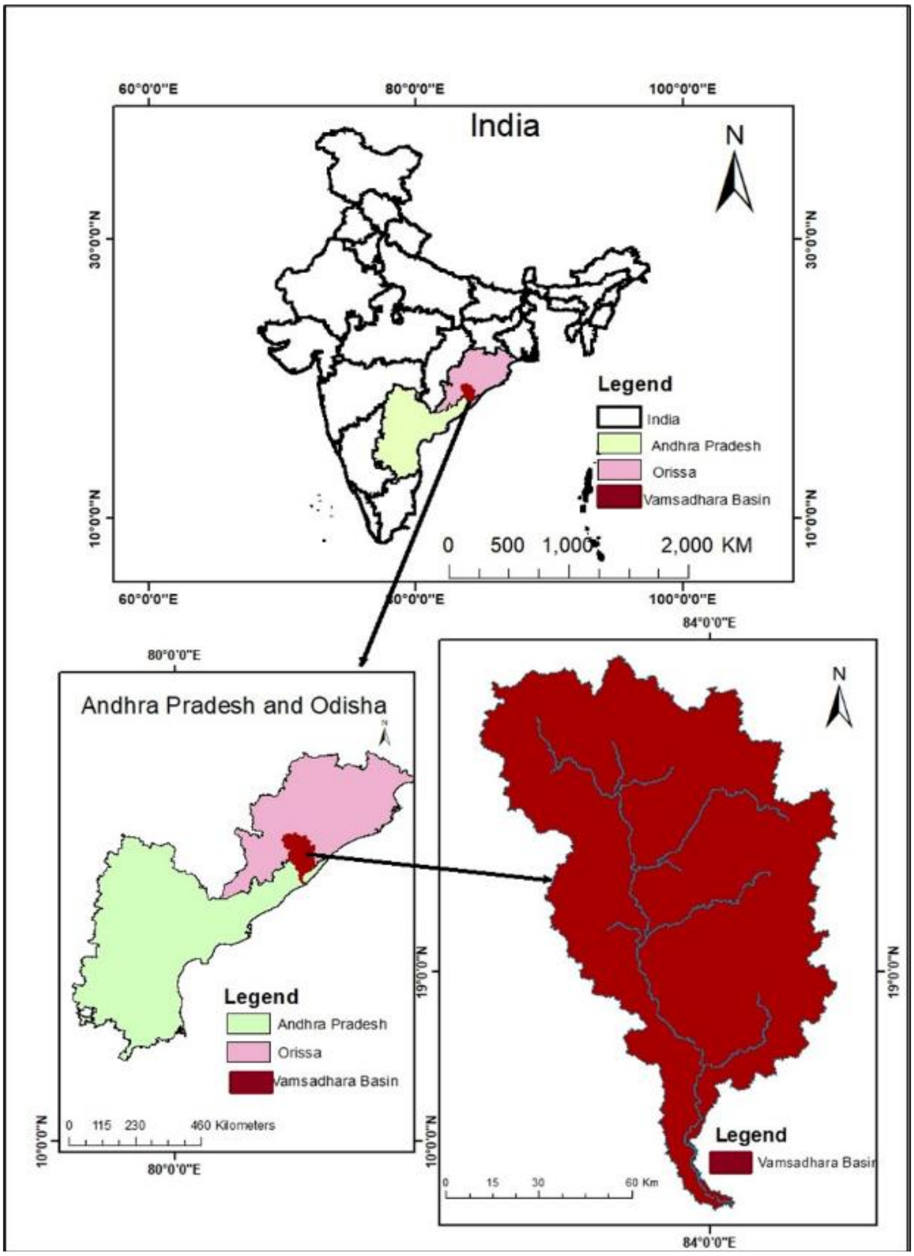


Fig. 1. Location map of study area

2. 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 [1]. 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 [7]. 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/).

Table 1. Definitions of selected indices used for analysis of extreme temperature in Vamsadhara 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).

2.1 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.

2.1.1 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:

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

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:

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

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:

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

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 of sample 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:

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

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

2.1.2 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:

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

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:

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

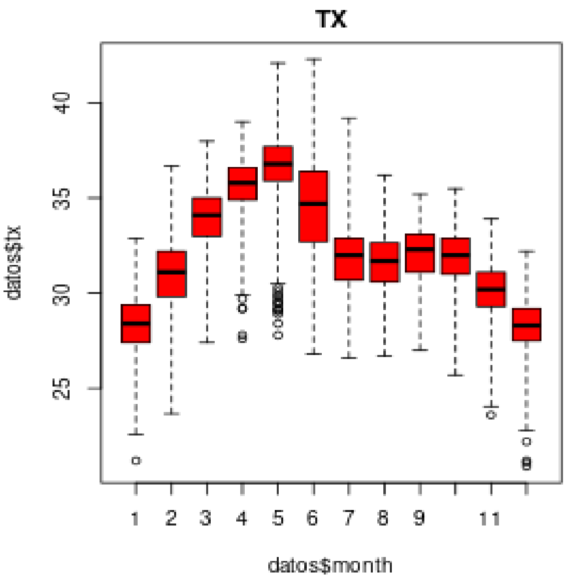
3. RESULTS

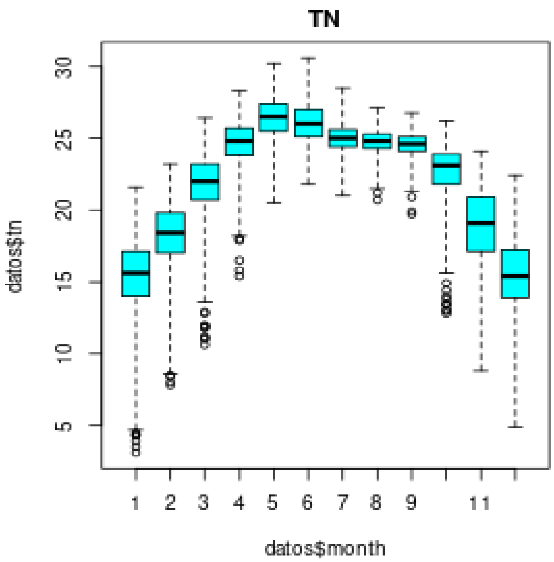
3.1 Quality Control

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.

3.2 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.





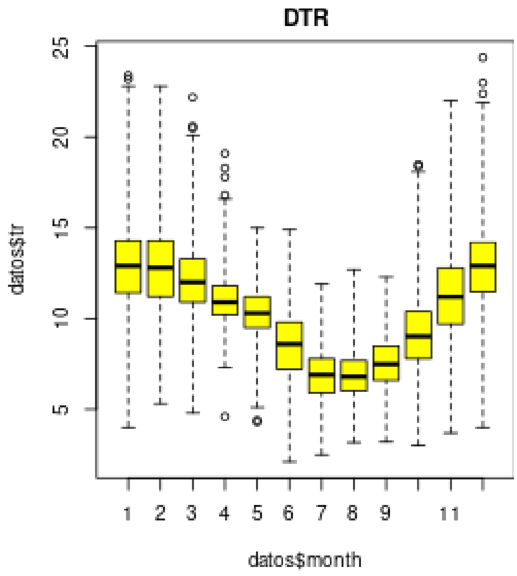


Fig. 2. Outliers per calendar month (a) T_{max}, (b) T_{min} and (c) DTR

Table 2. Linear trend statistics of selected temperature ETCCDI Indices

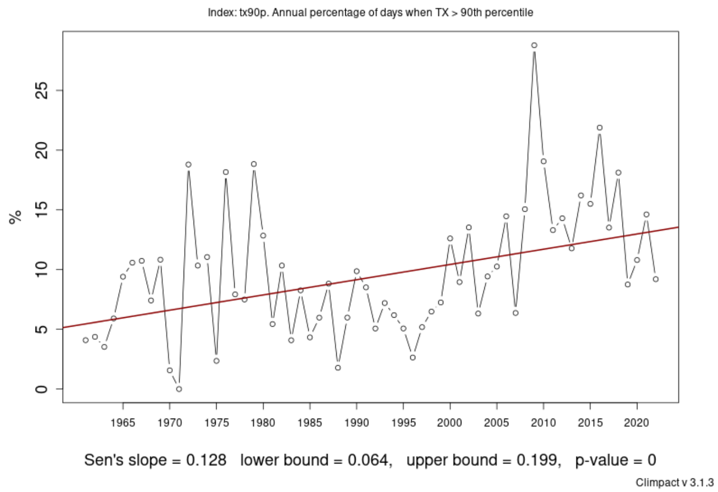
Index	Frequency	Start Year	End Year	Slope	MK
TX10	Annual	1961	2022	-0.06114	**-1.847***
TX90	Annual	1961	2022	0.127603	**3.626*****
TN10	Annual	1961	2022	-0.04063	-1.3
TN90	Annual	1961	2022	0.024539	0.462
TXx	Annual	1961	2022	-0.00934	-1.172
TNn	Annual	1961	2022	0	0.061
TNx	Annual	1961	2022	-0.01458	**-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***

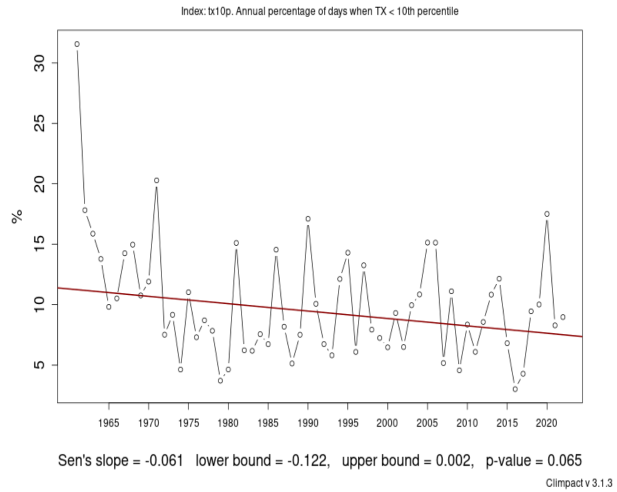
**Statistically significant at α = 10% (critical Z = ± 1.645), **Statistically significant at α = 5% (critical Z = ± 1.96), ***Statistically significant at α = 1% (critical Z = ± 2.33).*

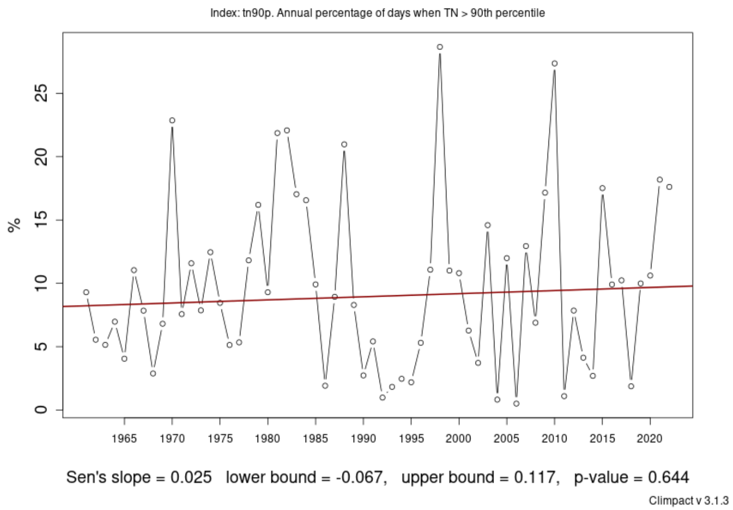
For percentile-based indices, only maximum temperature indices TX10 (cold night) and TX90 (warm night) indices showed negative and positive indices respectively at 10% and 1% level of significance. No significant trends were shown in minimum temperature indices. For absolute indices, TNx showed significant 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.

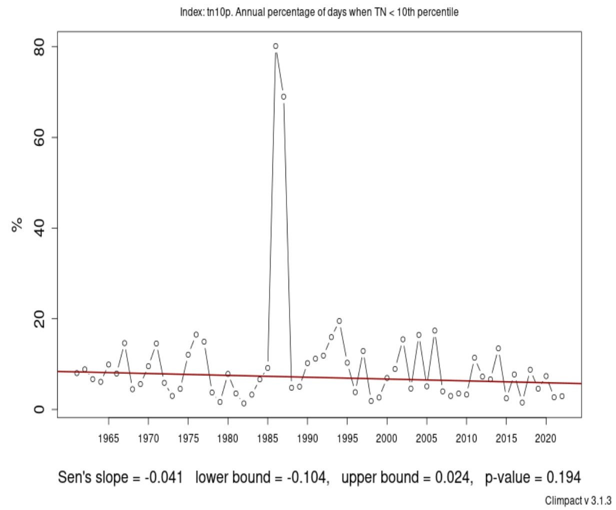
4. DISCUSSION

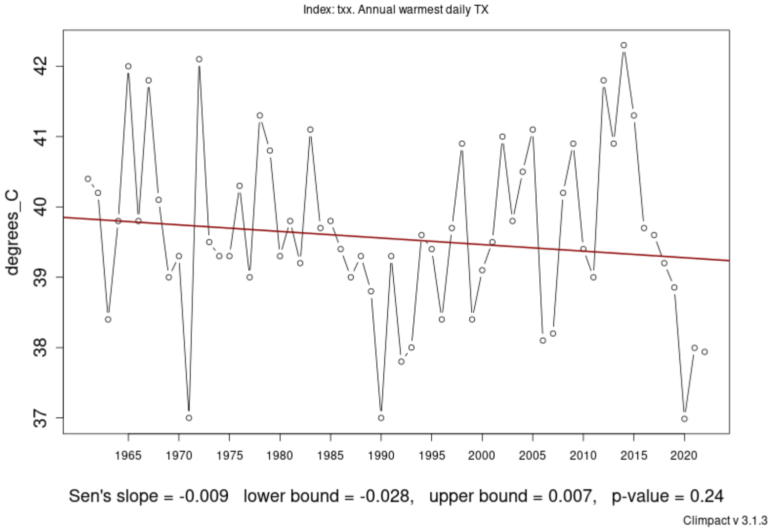
In the present study, annual extreme temperature indices for the Vamsadhara river basin in Odisha were estimated for the period 1961 to 2022. The extreme indices were evaluated using the Climpact model. The MK test was used to calculate trends, and the (TSS) test was used to determine the trend's magnitude. 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 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.

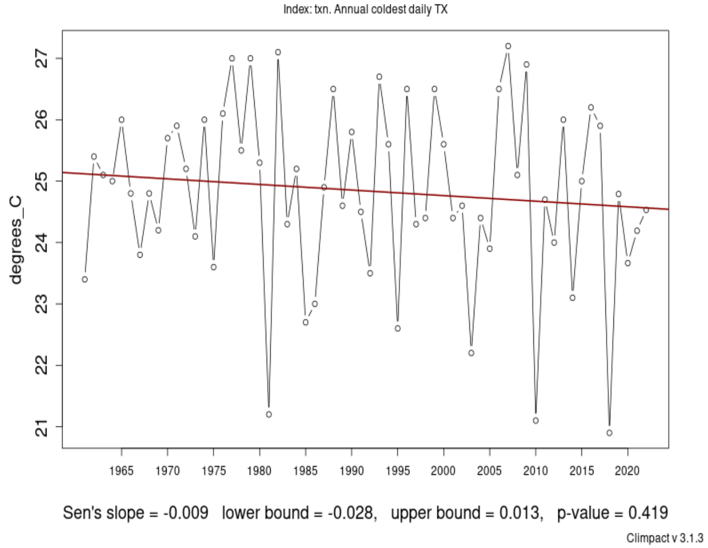

Index: tx90p. Annual percentage of days when TX > 90th percentile
%
Sen's slope = 0.128   lower bound = 0.064,   upper bound = 0.199,   p-value = 0
Climpact v 3.1.3

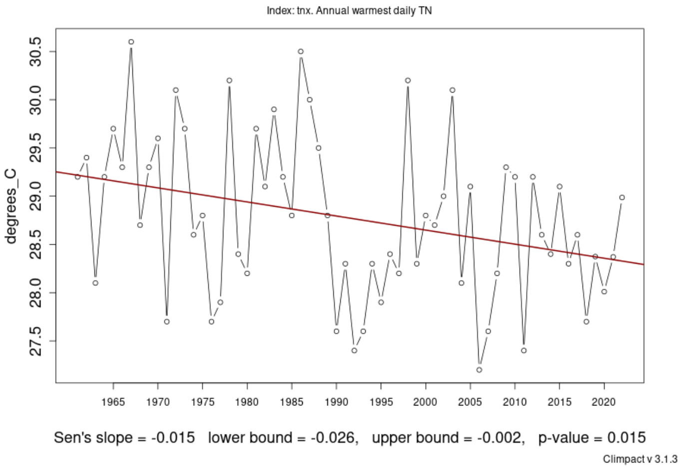

Index: tx10p. Annual percentage of days when TX < 10th percentile
%
Sen's slope = -0.061   lower bound = -0.122,   upper bound = 0.002,   p-value = 0.065
Climpact v 3.1.3

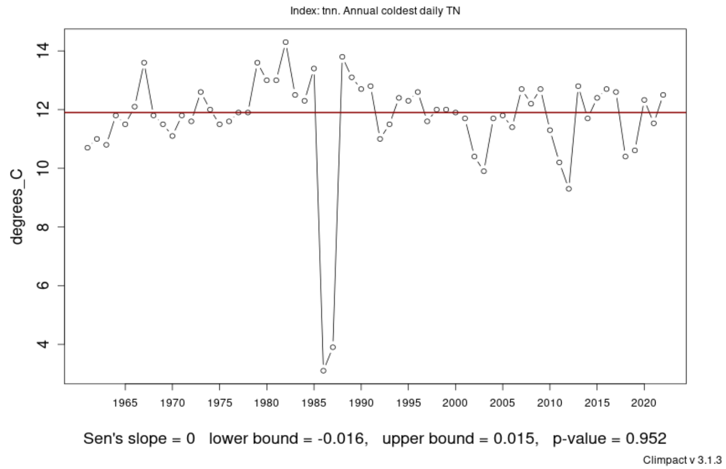

Index: tn90p. Annual percentage of days when TN > 90th percentile
%
Sen's slope = 0.025   lower bound = -0.067,   upper bound = 0.117,   p-value = 0.644
Climpact v 3.1.3

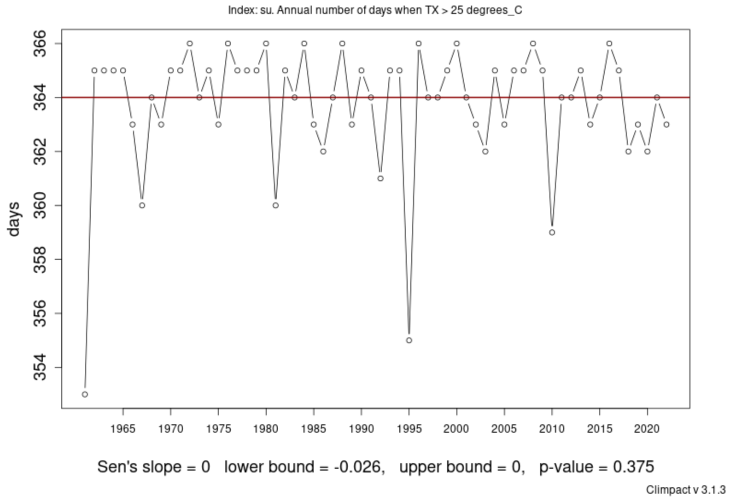

Index: tn10p. Annual percentage of days when TN < 10th percentile
%
Sen's slope = -0.041   lower bound = -0.104,   upper bound = 0.024,   p-value = 0.194
Climpact v 3.1.3

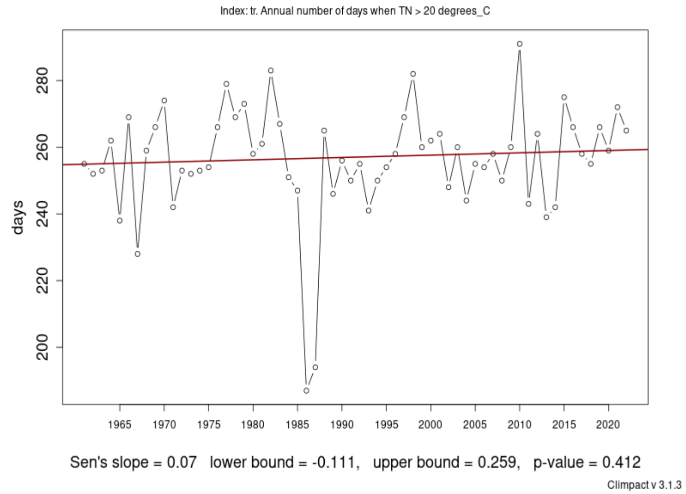

Index: txx. Annual warmest daily TX
degrees_C
37
38
39
40
41
42
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Sen's slope = -0.009   lower bound = -0.028,   upper bound = 0.007,   p-value = 0.24
Climpact v 3.1.3

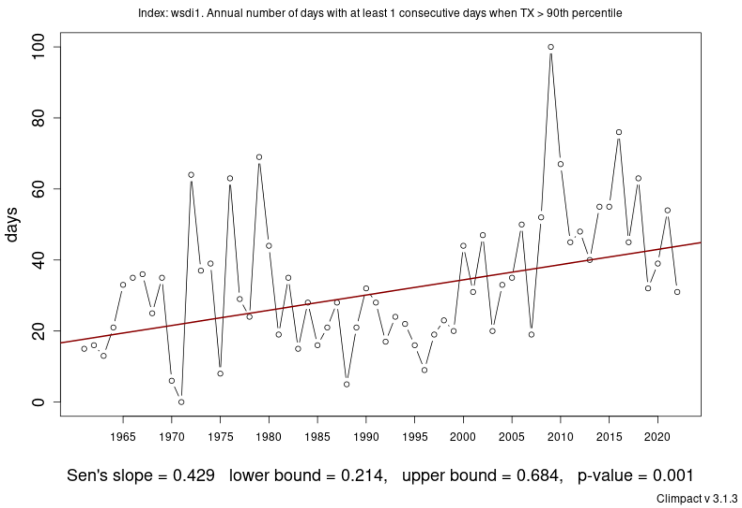

Index: txn. Annual coldest daily TX
degrees_C
21
22
23
24
25
26
27
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Sen's slope = -0.009   lower bound = -0.028,   upper bound = 0.013,   p-value = 0.419
Climpact v 3.1.3

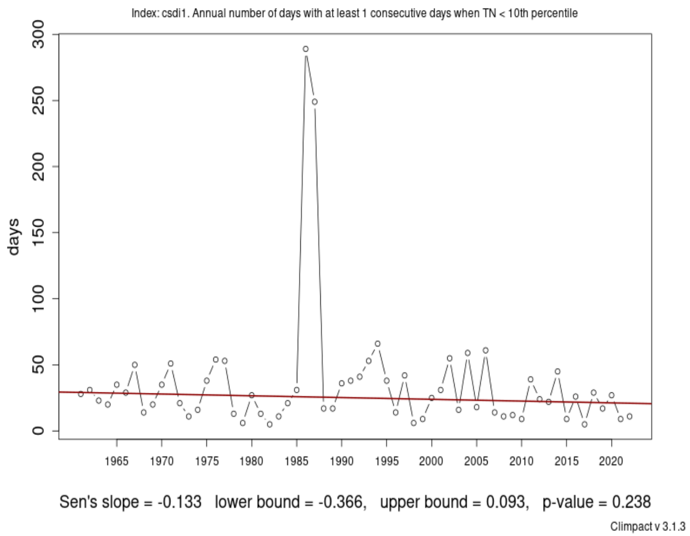

Index: tnx. Annual warmest daily TN
degrees_C
27.5
28.0
28.5
29.0
29.5
30.0
30.5
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Sen's slope = -0.015   lower bound = -0.026,   upper bound = -0.002,   p-value = 0.015
Climpact v 3.1.3

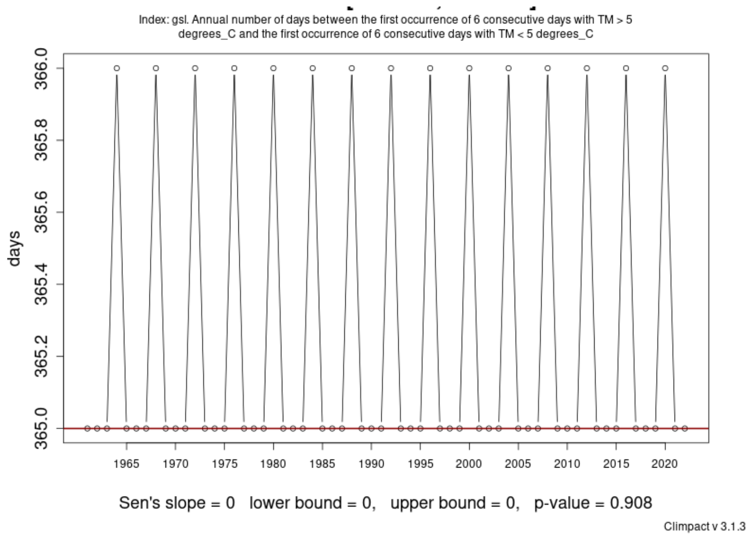

Index: tnn. Annual coldest daily TN
degrees_C
4
6
8
10
12
14
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Sen's slope = 0   lower bound = -0.016,   upper bound = 0.015,   p-value = 0.952
Climpact v 3.1.3


Index: su. Annual number of days when TX > 25 degrees_C
days
Sen's slope = 0   lower bound = -0.026,   upper bound = 0,   p-value = 0.375
Climpact v 3.1.3


Index: tr. Annual number of days when TN > 20 degrees_C
days
Sen's slope = 0.07   lower bound = -0.111,   upper bound = 0.259,   p-value = 0.412
Climpact v 3.1.3


Index: wsdi1. Annual number of days with at least 1 consecutive days when TX > 90th percentile
days
Sen's slope = 0.429   lower bound = 0.214,   upper bound = 0.684,   p-value = 0.001
Climpact v 3.1.3


Index: csdi1. Annual number of days with at least 1 consecutive days when TN < 10th percentile
days
Sen's slope = -0.133   lower bound = -0.366,   upper bound = 0.093,   p-value = 0.238
Climpact v 3.1.3



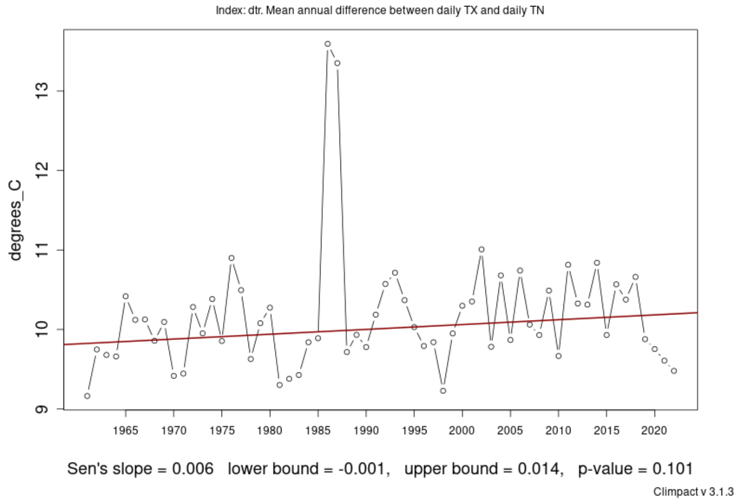


Fig. 3. Annual temperature indices with Sen's slope estimate for the Vamsadhara River Basin, India

5. CONCLUSION

The study concluded that on the basis of extreme indices of temperature, extreme events in basin are increasing. Hence, policy makers should build the strategy to mitigate and adapt the impact of climate change in the basin.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Zhang X, Alexander L, Jones Hegerl GC, P, Tank AK, Peterson TC et al. Indices for monitoring changes in extremes based on daily temperature and precipitation data. Wiley Interdiscip Rev Clim Change. 2011; 2(6):851-70.
   DOI: 10.1002/wcc.147.
2. Aguilar E, Aziz Barry A, Brunet M, Ekang L, Fernandes A, Massoukina M et al. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955-2006. J Geophys Res. 2009;114(D2).
   DOI: 10.1029/2008JD011010.
3. Brown PJ, Bradley RS, Keimig FT. Changes in extreme climate indices for the northeastern United States,1870-2005. J Clim. 2010;23(24):6555-72.
   DOI: 10.1175/2010JCLI3363.1.
4. Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG et al. Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res. 2006; 111(D5).
   DOI: 10.1029/2005JD006290.
5. Reddy NM, Saravanan S. Extreme precipitation indices over India using CMIP6: a special emphasis on the SSP585 scenario. Environ Sci Pollut Res Int. 2023;30(16):47119-43.
   DOI: 10.1007/s11356-023-25649-7
6. Pant M, Bhatla R, Ghosh S, Das S, Mall RK. Will warming climate affect the characteristics of summer monsoon rainfall and associated extremes over the gangetic plains in India? Earth Space Sci. 2023;10(2):EA002741:e2022.
7. Santos JA, Fraga H, Malheiro AC, Moutinho-Pereira J, Dinis L-T, Correia C et al. A review of the potential climate change impacts and adaptation options for European viticulture. Appl Sci. 2020; 10(9):3092.
8. Alexander LV, Fowler HJ, Bador M, Behrangi A, Donat MG, Dunn R et al. On the use of indices to study extreme precipitation on sub-daily and daily timescales. Environ Res Lett. 2019;14(12):125008.
9. Alexander LV, Herold N. Climpact user guide.
   Available: https://github.com/ARCCSS-extremes/climpact/blob/master/www/user_guide/Climpact_user_guide.md.
10. Balmaceda-Huarte R, Olmo ME, Bettolli ML, Poggi MM. Evaluation of multiple reanalyses in reproducing the spatio-temporal variability of temperature and precipitation indices over southern South America. Int J Climatol. 2021;41(12):5572-95.
    DOI: 10.1002/joc.7142.
11. Chattopadhyay S, Edwards DR. Long-term trend analysis of precipitation and air temperature for Kentucky, United States. Climate. 2016;4(1):10.
    DOI: 10.3390/cli4010010.
12. Kalita R, Kalita D, Saxena A. Trends in extreme climate indices in Cherrapunji for the period 1979 to 2020. J Earth Syst Sci. 2023;132(2):1-13.
    DOI: 10.1007/s12040-023-02087-0.
13. Li Z, Shi Y, Argiriou AA, Ioannidis P, Mamara A, Yan Z. A comparative analysis of changes in temperature and precipitation extremes since 1960 between China and Greece. Atmosphere. 2022; 13(11):1824.
    DOI: 10.3390/atmos13111824.
14. Nairn J, Fawcett R. Defining heatwaves: heatwave defined as a heat-impact event servicing all. Europe. 2011;220:224.
15. Nassaji Zavareh M, Ghermezcheshmeh B. Assessment of spatial and temporal variability of extreme temperature by ETCCDI indices (north and west of Iran). Environ Water Eng. 2023;9(1):95-108.
16. Patel SK, Mathew B, Nanda A, Pati S, Nayak H. A review on extreme weather events and livelihood in Odisha, India. Mausam. 2019;70(3):551-60.
    DOI: 10.54302/mausam.v70i3.258.
17. Pervin L, Khan MSM. Variability and trends of climate extremes indices from the observed and downscaled GCMs data over 1950-2020 period in Chattogram City,

Bangladesh. J Water Clim Change. 2022; 13(2):975-98.
DOI: 10.2166/wcc.2021.331.

18. Ramos AM, Trigo RM, Santo FE. Evolution of extreme temperatures over Portugal: recent changes and future scenarios. Clim Res. 2011;48(2):177-92.
DOI: 10.3354/cr00934.
19. Villa-Falfán C, Valdés-Rodríguez OA, Vázquez-Aguirre JL, Salas-Martínez F. Climate indices and their impact on maize yield in Veracruz, Mexico. Atmosphere. 2023;14(5):778.
DOI: 10.3390/atmos14050778.
20. Wu H, Qian H. Innovative trend analysis of annual and seasonal rainfall and extreme values in Shaanxi, China, since the 1950s. Int J Climatol. 2017;37(5):2582-92.
DOI: 10.1002/joc.4866.
21. Zhang X, Yang F. RClimDex (1.0) user manual; Climate Research Branch Environment Canada Downsview, Ontario, Canada. 2004;23.
22. Zhang X, Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N et al. Trends in Middle East climate extreme indices from 1950 to 2003. J Geophys Res. 2005; 110(D22):104.
DOI: https://doi.org/10.1029/2005jd006181

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