Assessing Spatiotemporal Trends of Long Term Temperature Variable over Kharun Watershed Chhattisgarh, India

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Abstract

Study and investigation of temperature trends are quite essential for a country like India, whose economy is largely dependent on agriculture as temperature greatly influences rainfall and evapotranspiration processes. Temperature along with other meteorological parameters largely affect the water availability over a region. Almost 83% of water is used in agriculture, 12% is consumed by industries and merely 5% is used for domestic purposes. In the present study, the long-term trend with temperature data of 64 years (1951-2014) was analyzed for maximum, minimum and mean temperature values. After removal of all significant correlation in the data, Mann-Kendall test (MK) was applied. To identify the trends Sen's slope estimator was used and the overall percent change for the temperature over the study area was determined. To interpolate the spatial pattern an inverse distance weighted interpolation method (IDW) was used using ArcGIS 10.2.2. The analysis showed a significant increase in the trend of temperature for annual and seasonal series during the entire period over the study area i.e. Kharun watershed, Chhattisgarh, India. These results will be quite helpful and play an important role in managing water resources in the basin and will be useful for future planning of irrigation and agricultural practices.

Keywords: Temperature; Mann-Kendall; Sen's slope; IDW; ArcGIS;

Motivation behind the study

- Numerous studies in the past have proved that planet Earth is warming day by day and at a faster rate in the past few decades (Tilman et al. 2011, IPCC 2014).
- As this rampant climate change has severely altered ecological balance of the planet, it has causes a significant damage to infrastructure and agricultural sector (Min et al. 2011).
- For a developing country like India, which is still largely dependent on precipitation for the purpose of irrigation, it is a must to quantify the changes in rainfall patterns/intensities due to climate change.

Research Objective

- Evaluation of changes in the extremes indices subjective to the temperature (minimum and maximum) data.
- Identification of trends and their magnitude based on historical datasets of minimum and maximum temperature.
- Develop a correlation between the extreme indices dependent on temperature with various rainfall intensities suggested by Indian Meteorological Department (IMD), Pune.

Study area and data description

Study area

Kharun watershed, which is the focus of this study is at the heart of Chhattisgarh and passes directly through the state capital. Kharun River is the major tributary of the Seonath River which is a major tributary of Mahanadi River. The index map showing the study area and its cutoff from Mahanadi River is shown in Fig.1. Kharun River originates at Petechua in Balod district and lies between the geographical coordinates of 20° 33′ 30″N – 21° 33′ 38″ N latitude and 81° 17′ 51″ E – 81° 55′ 25″ E longitude. The study area exhibits a relatively flat topography and does not have much of elevation difference throughout its stretch. The total length of the river is 164 Km and its catchment area is approximately 4191 km².

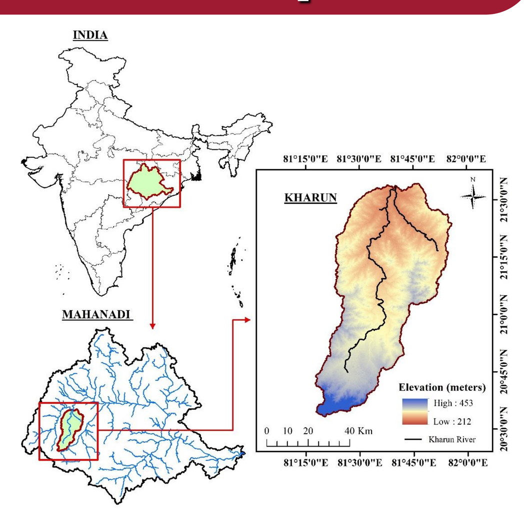

Fig. 1 Index map of the study area

Data description

Daily temperature (minimum and maximum) 1º × 1º gridded datasets was provided by IMD, Pune. The data was further interpolated using kriging (Gaussian process regression), and was resampled at 0.25º × 0.25º. 22 stations (or grids) were selected for the watershed as shown in Fig. 2.

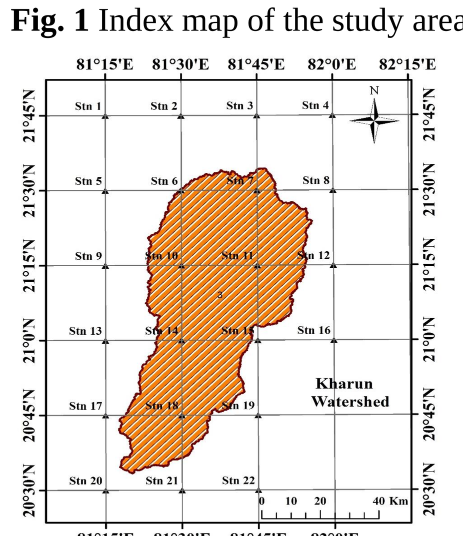

Fig. 2 Selected stations (grids)

Methodology

For this study, 9 extreme indices depended on minimum and maximum temperature were used, out of the 23 extreme indices generated by the joint (ETCCDMI) (http://etccdi.pacificclimate.org/list_27_indices) as shown in Table-1.

Table 1 List of indices used for the analysis

S. No.	Index ID	Index name	Description	Units
1	TN10P	Cool nights	Percentage of days when TN < 10^{th} percentile	%
2	TX90P	Hot days	Percentage of days when TX > 90^{th} percentile	%
3	TX10P	Cool days	Percentage of days when TX < 10^{th} percentile	%
4	TN90P	Warm nights	Percentage of days when TN > 90^{th} percentile	%
5	TR	Number of tropical nights	Annual count when TN > 24 °C	Days
6	SU	Number of summer days	Annual count when TX > 40 °C	Days
7	WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
8	CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
9	DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC

Identification of trend

Linear regression

In any regression line β refers to the slope while intercept is denoted by λ, as shown in eq. (1)

$$y = \beta x + \lambda \qquad (1)$$

Mann-Kendall (MK) test

Mann-Kendall's test statistic is given as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_k) \qquad (2)$$

$$Sign(X_j - X_k) = \begin{cases} +1, \ldots\ldots\ldots if\ (X_j - X_k) > 0 \\ 0, \ldots\ldots\ldots if\ (X_j - X_k) = 0 \\ -1, \ldots\ldots\ldots if\ (X_j - X_k) < 0 \end{cases} \qquad (3)$$

$$E(S) = 0\ ,\ Vars(S) = \frac{n(n-1)(2n+5)}{18} \qquad (4)$$

$$Vars(S) = \frac{\left\{ n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5) \right\}}{18} \qquad (5)$$

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \qquad (6)$$

- Positive values of ***Z*** signify positive trend while negative value signifies negative trend

In case of data with correlation, **Modified Mann Kendall (MMK)** is used, Var(S) is modified in such cases

$$Var(S)^* = V(S)\frac{n}{n^*} \qquad (7)$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1(n-2)} \sum_{i=1}^{n-1} (n-1)(n-i-1)(n-1-2)r_i \qquad (8)$$

Magnitude of trend

Sen's method was used to compute magnitude of trend in various extreme value indices, Slopes (Ti) of entire data pairs are computed by:

$$T_i = \frac{x_j - x_k}{j-k} \quad \text{for } i = 1,2,\ldots N \qquad (9)$$

$$\beta = \left(\frac{T_{N+1}}{2}\right) \quad \text{if } N \text{ is even} \qquad (10)$$

$$\beta = \frac{1}{2}\left(\frac{T_N}{2} + \frac{T_{N+2}}{2}\right) \quad \text{if } N \text{ is odd} \qquad (11)$$

- Positive value of ***β*** signify upward trend, while negative values represent negative rend

Rate of change

Rate of change (change in magnitude) is calculate by:

$$ROC = \frac{N \times \beta \times 100}{\bar{X}} \qquad (12)$$

Spatial analysis of temperature series

The Spatial distribution plots of MMK statistics were obtained using ArcGIS.

- Yearly temperature aberrations of study area were also computed as shown in Fig. 3.

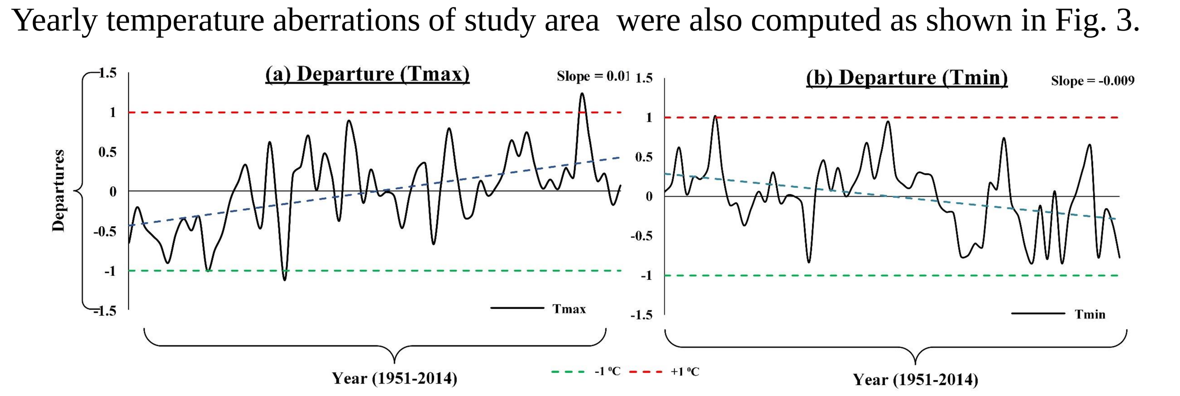

Fig. 3 Departure of minimum/maximum temperature from normal is +1 ºC to -1 ºC)

Results

Trend identification using linear regression and MMK

- Significant negative trends were observed in the case of TN10P and TR across all the stations.
- Significant positive trends were across most of the stations observed in the case of TN90P, WSDI, CSDI and DTR.
- Increase in the number of summer days (SU) and reduced tropical nights (TR) can be seen in Fig. 4, which further highlights the point that the days are getting hotter and the nights are getting cooler.

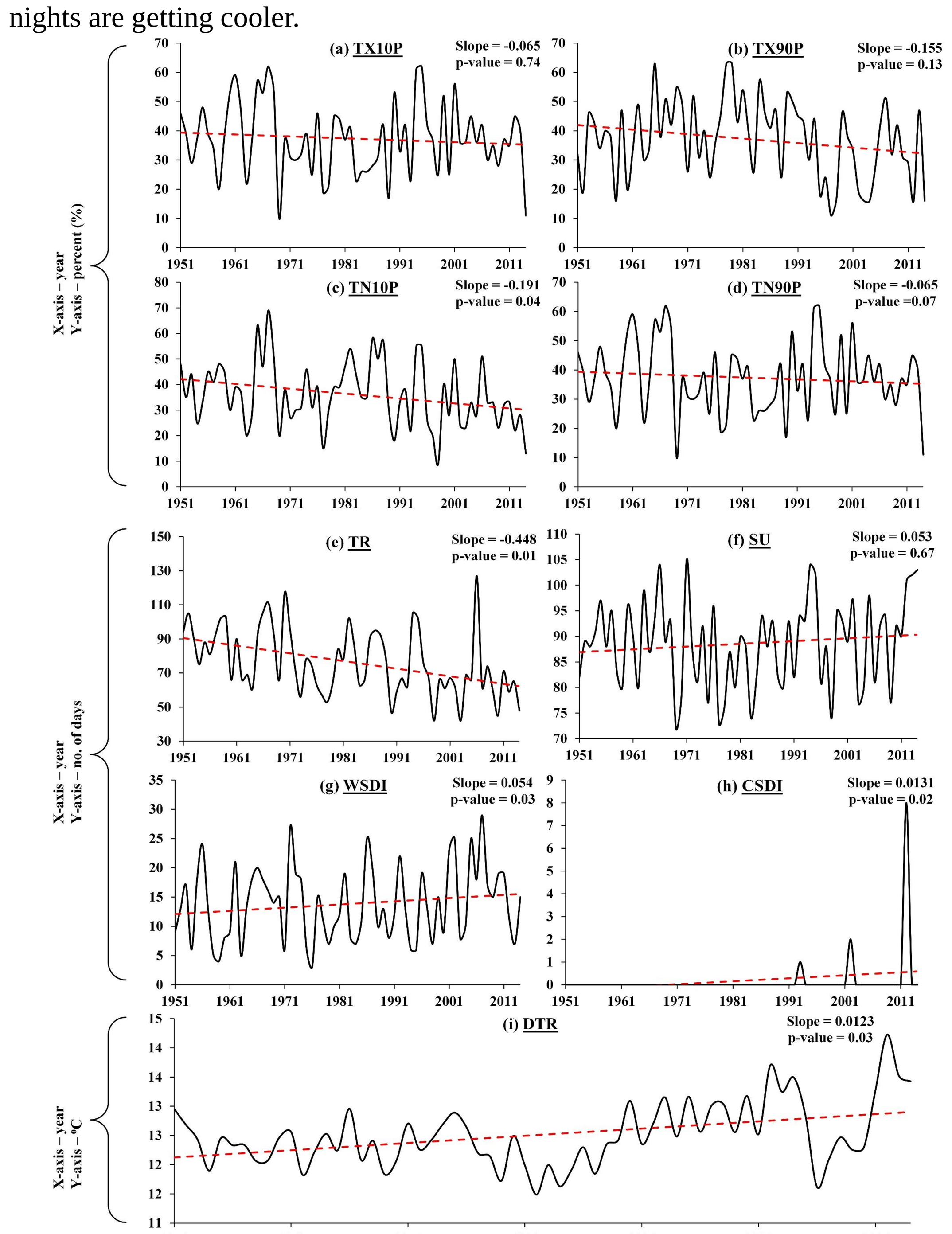

Fig. 4 Linear trends for extreme value indices of long term temperature series

Impact on precipitation intensities

- There was a considerable reduction seen in the number of rainy/wet days, while number of heavy to very heavy rainy days have increased (Fig. 5).

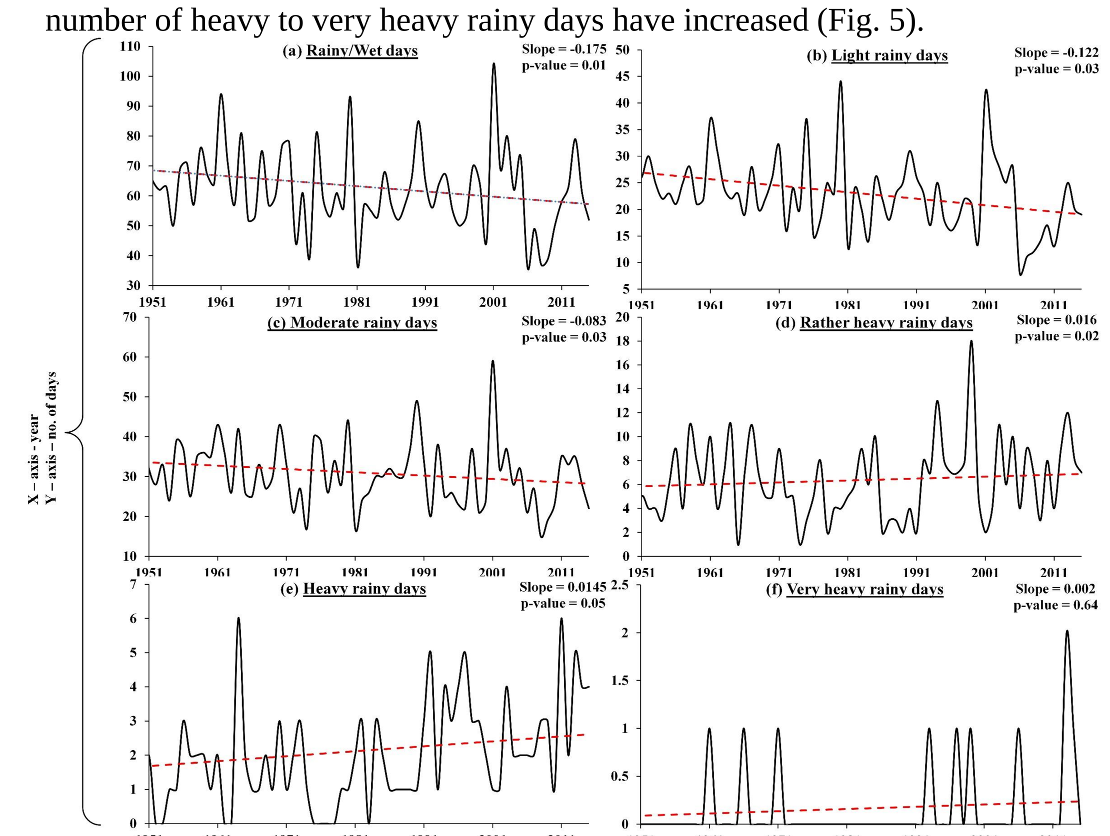

Fig. 5 Changes in various precipitation intensities

Spatial Plots

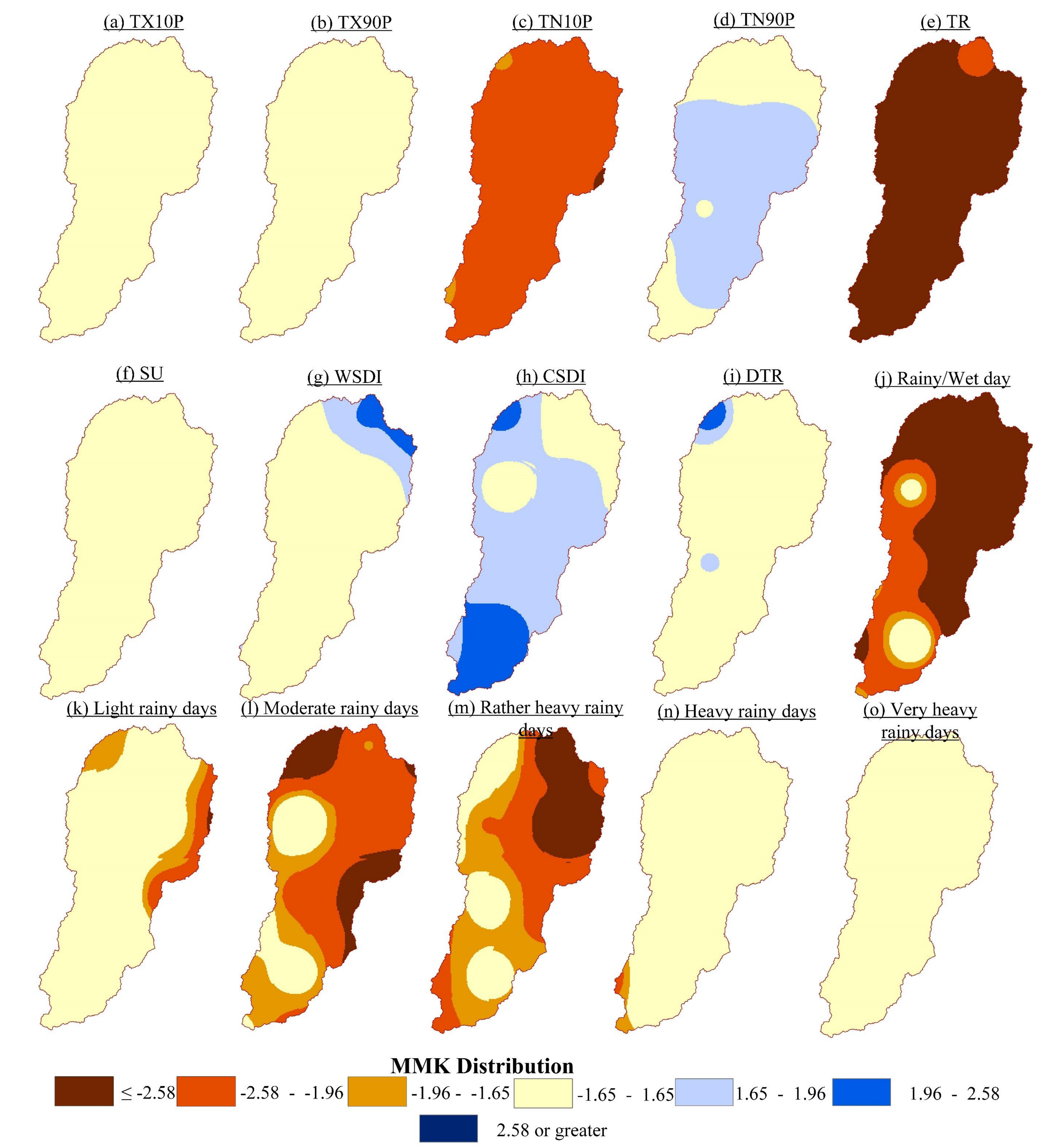

Fig. 6 Spatial distribution plot of MMK test statistics

- No significant trends were observed in case of TX10P, TX90P, SU and very heavy rain days across the study area.
- Significantly negative trend were obtained in case of TN90P, WSDI, CSDI and DTR across all or some parts of study area.
- Significantly negative trend were observed for TN10P, TR and for all rainfall intensities except very heavy rainy days.

Conclusions

- Increase in Diurnal Temperature Range (DTR) was observed, which gives indication of increasing gap between minimum and maximum temperature, this phenomenon has increased number of hot summer days and reduced warm tropical nights.
- As a result of which number of rainy/wet days have reduced along with increase in very heavy and heavy rainy days, which will directly affect the agricultural activities in this area, since the area still practices traditional methods of irrigation.
- Phenomenon of urban flash flooding can be a faced by the people in the future, especially those who are living in the urban pockets in the study area.

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