Trend and Change point Analysis of Extreme Temperature over India using Non-Parametric Methods and Empirical Mode Decomposition

Drisya S Dharan, Anuja PK, Govindan Unnithan, Anand Vishnu B, Adarsh S

Abstract*:. This paper presents the trend and change point analyses of extreme temperature (T_{max} and T_{min}) datasets of annual and seasonal series of seven homogeneous regions of India for the period 1901-2007. The study used Mann-Kendall (MK) test for detection of trend, Cumulative Sum (CUSUM) test for detection of change point and Empirical Mode Decomposition (EMD) for extracting non-linear trend of all the 70 time series. The results of MK test showed that at all the seven regions except North-West, T_{max} series of winter season showed a significant increase at 5 % significance level. The MK test detected a significantly increasing trend on annual and all seasonal T_{max} series of West Coast (WC) and North East (NE) regions. The CUSUM test detected a change point within 1975-77 for minimum temperature series of East Coast (EC) region for all the seasons except monsoon, which is in agreement with the well debated climate shift of 1976-77 period. The test detected a change point in 1950 for T_{max} series of winter season in all homogeneous regions except northwest (NW). The study also found that change point year estimated in the non linear trend fitting by EMD may differ from that based on statistical estimations

***Index Terms*: Trend, Change Point, Non-linear, Temperature**

I. INTRODUCTION

Temperature is one of the important meteorological variables, which is of direct influence on the hydrological process. The changes in extreme (maximum and minimum) temperature significantly affect the hydrology of the geographical domain of interest. High temperature may affect drought conditions, damage of crops; while low temperature may affect the yield of cereal crops. Many studies have been conducted on the changes in temperature regime of India in the past, out of which some studies focused on extreme temperature. For example, Rupakumar et al. [1] performed linear trend analysis of extreme temperature data of 121 stations over India of the period 1901–1987 and it was found that mean temperature trends over India were similar to the global and hemispheric trends. They showed that the increase in the mean temperatures over India is mainly contributed by the maximum temperatures, with the minimum temperatures were practically trendless. Krishnakumar et al. [2] found the association of extreme temperatures in the pre-monsoon season with Indian summer monsoon rainfall. Kothawale and Rupakumar [3] reported a significant warming trend of 0.05^{o}C per decade during the period 1901–2003, and for 1971–2003 the study noted a relatively accelerated warming of 0.22^{o}C per decade. Kumari et al. [4] analyzed the relation between solar radiation and extreme temperature for twelve different locations in India for the period of 1981-2004 and found that spatial averaged surface extreme air temperatures of India have been increasing, and the change in minimum temperature has been doubled while change in maximum temperature is marginal. Kothawale et al. [5] found trends in extreme temperature events for the pre-monsoon season using daily data on maximum and minimum temperatures from all the seven temperature homogenous regions in India. Pal and Al Tabbaa [6] performed a detailed trend analysis study of extreme temperature dataset from different temperature homogeneous regions in India, at monthly and seasonal scale. It was found that monthly maximum temperature increased over the last century and minimum temperature changes have high variability than maximum temperature changes (both temporally and spatially) with lesser degree of significance. Sonali and Nagesh Kumar [7] performed trend analysis of temperature records from the temperature homogeneous regions of India during 1901-2003 using thirteen different methods. Eventhough many studies were performed for analyzing the trend (mainly by using Mann-Kendall (MK) and Sen's slope methods), studies on estimation of change point is rarely attempted by researchers. Due to the changing climate and the induced non-stationarity, it is important to extract the inherent non-linear trend in the datasets [8]. For the extraction of inherent non-linear trend, the techniques like singular spectrum analysis, empirical mode decomposition (EMD) or its variants, wavelet transform etc. have been used by the researchers [9-13]. The next section presents the details of methodologies used, section 3 presents the study area and data details, section 4 presents results and discussion and in the final section important findings are concluded.

Revised Manuscript Received on June 23, 2018.

Drisya S Dharan, TKM College of Engineering, Kollam 691005, India
Anuja PK, TKM College of Engineering, Kollam 691005, India.
Govindan Unnithan, TKM College of Engineering, Kollam ,India
Anand Vishnu B, TKM College of Engineering, Kollam ,India.
Adarsh S, Assistant Professor,, TKM College of Engineering, Kollam ,India.

II. Methodology

A. CUSUM test

CUSUM test originally proposed by E.S. Page (stated in [14]) involves the calculation of cumulative sum of the differences. After computing the mean $(\bar{x})$ of a time series, the cumulative sum S_i is computed recursively as

$$S_i = S_{i-1} + (x_i - \bar{x}) \quad (1)$$

B. Mann -Kendall Test

1) Mann-Kendall test [15, 16] is one popular non-parametric test used for the trend analysis and statistical significance. In this method, the test statistics is computed directly based on the values of the random variable and the expression for the same is

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i) \quad (2)$$

2) where N is the number of data points, xj and xi are data values at time j and i (j>i), respectively. This statistics represents the number of positive differences minus the number of negative differences for all the differences considered.

3) Denoting $(x_j - x_i) = \delta$

4)
$$\operatorname{sgn}(\delta) = \begin{cases} 1 & if \quad \delta > 0 \\ 0 & if \quad \delta = 0 \\ -1 & if \quad \delta < 0 \end{cases} \quad (3)$$

5) For large samples (N>10), the sampling distribution of S is assumed to be normally distributed with zero mean and variance as follows:

6)
$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k - 1)(2t_k + 5)}{18} \quad (4)$$

7) where N is the number of tied (zero difference between compared values) groups and tk the number of data points in the kth tied group.

8) The Z-statistic or standard normal deviate is then computed by using equation:

9)
$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \quad (5)$$

10) Here, if the computed value of $|Z| > Z_{\alpha/2}$, then the null hypothesis of no trend is rejected at α level of significance in a two-sided test (i.e., the trend is significant). A positive value of Z indicates an increasing trend and a negative value of Z indicates a decreasing trend.

C. Empirical Mode Decomposition

Empirical Mode Decomposition (EMD) is a non-parametric signal decomposition method proposed by Huang et al. [17], which decomposes a time series signal X(t) into different oscillatory modes in purely empirical and data adaptive manner. The flow chart of EMD is provided below:

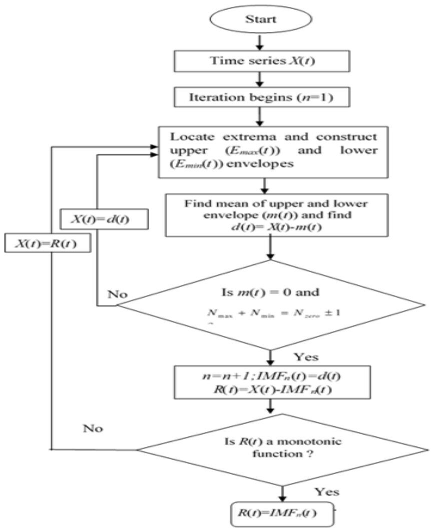

Fig. 1 Flowchart of EMD algorithm [18]

III. Study Area and Data

Indian Institute of Tropical Meteorology (IITM) Pune grouped different parts of India into seven temperature homogenous regions as shown in Fig. 2. The maximum and minimum temperature (T_{max} and T_{min}) data for the period 1901-2007 for the seven regions are collected from IITM Pune (http://www.tropmet.res.in) and used for trend and change point analysis.

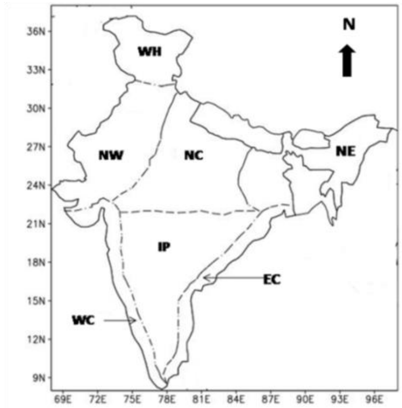

Fig. 2 Map showing temperature homogeneous regions of India. EC-East Coast; WC-West Coast; IP-Interior Peninsula; NE-North East; NC-Noth Central; NW-North West; WH-Western Himalaya

IV. Results and Discussion

. First the trend analysis of T_{max} and T_{min} series at annual and seasonal temporal scale are performed using MK test by considering significance level of 5 %. The results are presented in Table 1.

Then the CUSUM method is used for the detection of change point. The results of CUSUM test are presented in Table 2. If you must use mixed units, clearly state the units for each quantity in an equation.

The SI unit for magnetic field strength *H* is A/m. However, if you wish to use units of T, either refer to magnetic flux density *B* or magnetic field strength symbolized as $\mu_0 H$. Use the center dot to separate compound units, e.g., "A·m^2."

Table 1. Results of MK test of different temperature time series (A-Annual; M-Monsoon PoM-Post Monsoon;W-Winter; PrM-Pre Monsoon) the bold and italic figures show that trend is staistically significant at 5 % level

Region	Maximum Temperature				
	A	M	PoM	W	Pr M
EC	0.791	0.11	1.018	***5.586***	1.02
IP	1.042	-0.002	1.053	***4.554***	1.042
NC	0.065	-0.097	***2.312***	***2.711***	***3.61***
NE	***2.143***	***2.377***	***5.19***	***4.148***	***2.121***
NW	-1.3	-0.555	1.236	1.734	-0.67
WC	***5.75***	***3.613***	***6.2***	***7.551***	***5.75***
WH	-0.371	-0.323	**2.337**	**3.551**	0.495
	Minimum Temperature				
EC	***2.781***	1.922	***3.042***	1.551	***4.046***
IP	-0.116	***4.294***	***2.167***	1.02	***4.216***
NC	***2.086***	-0.783	***3.726***	0.215	**1.976**
NE	0.703	***-3.268***	***4.272***	0.1	1.195
NW	-1.171	0.027	-0.345	**-1.971**	0.961
WC	0.215	***3.766***	1.769	-0.53	1.715
WH	**2.983**	1.225	**2.872**	**2.42**	**2.415**

Table 2 Change points of extreme temperature datasets by CUSUM method. The bold figures show temperature change happened at climate shift of 1976/77 period

Region	Type	W	PrM	M	PoM	A
EC	Max	1965	1995	1995	**1977**	1983
	Min	**1977**	**1976**	1985	**1975**	**1977**
WC	Max	1950	1968	1961	1959	1968
	Min	1992	1919	1991	1956	1991
IP	Max	1950	1982	1963	1963	1982
	Min	**1978**	1968	1994	**1977**	2006
WH	Max	1991	1949	1996	1930	1996
	Min	**1978**	1940	1986	**1976**	**1978**
NW	Max	1950	1962	1986	1962	1962
	Min	1932	1983	1994	1999	1932
NC	Max	1950	1933	1969	1962	1962
	Min	**1976**	2000	1961	1975	**1978**
NE	Max	1950	1949	1963	1963	**1978**
	Min	2003	1917	1963	1984	1952

From Table 1 it is noticed that except for few cases, the different the extreme temperature time series show an increasing trend. Many of the T_{max} series show statistically significant change while a significant reduction is noted only for monsoon minimum temperature of NE region and winter minimum temperature of NW region. None of the T_{max} series of NW region displayed a significant trend. Annual and all of the four seasonal maximum temperature series showed a statistically significant increasing trend for the WC and NE regions. In the minimum temperature series of WH region annual series and seasonal series except monsoon showed an increasing trend. This study found that winter maximum temperature series of all regions except NW showed a statistically significant increasing trend. The CUSUM method helped in detecting the change point year of different temperature series and Table 2 show that there is no definite pattern or uniqueness in change point years of different series. However it is noted that in winter maximum temperature series, the change point is 1950 for all series except that of EC and WH regions. One can notice the possible harmony of the well debated climate shift year 1976/77[20] (with a deviation of 1 year) in the change point years of certain series. Interestingly, all the regions except NW and NE, the change point year of minimum temperature series coincides with the climate shift year. Also all the four seasonal minimum series and annual minimum series of EC region showed a change point year between 1975 and 1977.

The linear trend fitting is done for all the 70 time series and the non-linear trend of different series is determined by EMD method. The plots of trend analysis of maximum temperature series for winter season of all regions except NW are presented in Fig. 3.

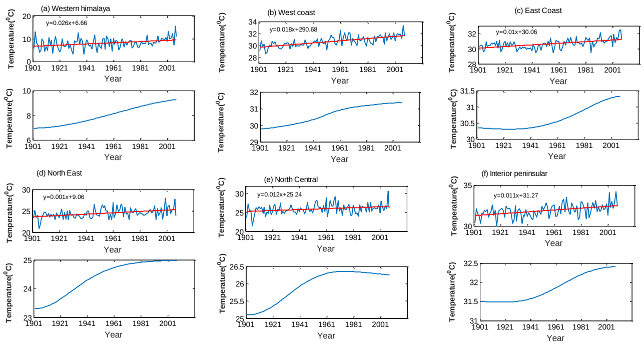

Fig. 3 Linear fitting and EMD of winter maximum temperature series of different homogeneous regions

From Fig.3 it is clear that the non- linear trend is increasing and it resembles with the character noticed by MK test. However on recollecting the fact that the change point year was ~1950s, the change point year is expected around ~ 1950s in non-linear trend, which is found to be absent in all these series. The non-linear trend of T_{min} series of EC region captured by EMD are presented in Fig. 4. It shows a diametric change in the winter series about 1950s with an increase in the latter half and an opposite nature for monsoon series with a difference in change point years (1950s). For rest of the series the trend is monotonically increasing in practice. Further, the trends of T_{min} series of WH region are presented in Fig. 5. The EMD analysis detected an increasing trend for all the seasonal and annual series. Here the increasing trend starts during the beginning of last century for all of the time series except that of winter season. Thus from different analysis it is noticed that the change point year (in non-linear trend) is not coinciding with the climatic shift year which again signifies the importance of capturing non-linear trends in series. Capturing the true shape of non-linear trend and the changing year by EMD method is helpful in non-stationary modeling of hydrological variables under the changing climate scenario, which eventually help for sustainable management of water resources of the country.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

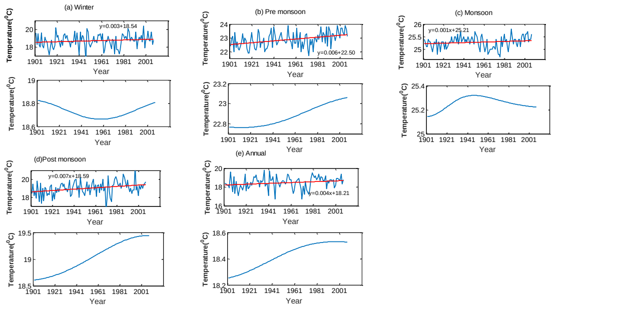

Fig. 4 Linear fitting of annual and seasonal T_{min} series of EC region

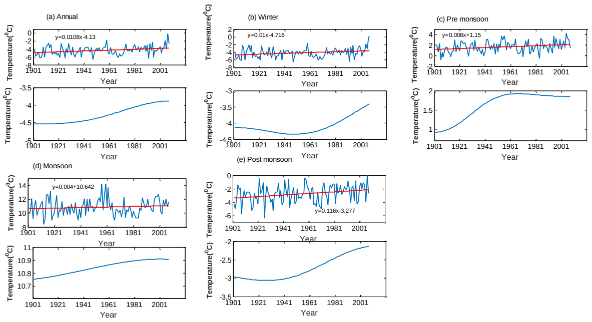

Fig. 5 Linear fitting of annual and seasonal T_{min} series of Western Himalaya

V. CONCLUSIONS

This paper performed the trend and change point analyses of extreme temperature (T_{max} and T_{min}) datasets of annual and seasonal temperature of seven homogeneous regions of India for the period 1901-2007. The major conclusions of the study are:

- The results of MK test showed that T_{max} series of WC and NE region displays an increasing trend irrespective of season
- The MK test showed that at all the seven regions except NW, maximum temperature of winter season is significantly increasing
- The CUSUM test detected a change point within 1975-77 for minimum temperature series of East Coast (EC) region for all the seasons except monsoon, which is in agreement with the well debated climate shift of 1976-77 period.
- The CUSUM test detected a change point in 1950s for maximum temperature series of winter season in all homogeneous regions except Western Himalaya (WH)
- The CUSUM test detected a change point during 1975-77 in the T_{min} series of winter season in all regions except the coastal belts of EC, EC and the NE
- The non-linear trend need not be in agreement with the linear trend of the time series and it may comprise a change point year about which an asymmetric change may be present
- The change point year estimated in the non- linear trend fitting may differ from that based on statistical estimations.

REFERENCES

1. Rupa Kumar K,Krishna Kumar K., Pant G.B.: Diurnal asymmetry of surface temperature trends over India. Geophysical Research Letters, 21, 677-680 (1994)
2. Krishnakumar K, Rupakumar K Pant G.B.: Pre-monsoon maximum and minimum temperatures over India in relation to the summer monsoon rainfall. International Journal of Climatology, Geophysical. Research Letters, 17, 1115-1127 (1997)
3. Kothawale D.R., Rupa Kumar K.: On the recent changes in surface temperature trends over India. Geophysical Research Letters, 32, L18714, DOI: 10.1029/2005GL023528, (2005)
4. Kumari P.B., Londhe A.L., Daniel S, Jadhav D.B.: Observational evidence of solar dimming: offsetting surface warming over India. Geophysical Research Letters, 34, DOI:10.1029/2007GL031133 (2007)
5. Kothawale D.R., Revadekar J.V., Rupa Kumar K.: Recent trends in pre-monsoon daily temperature extremes over India. Journal of Earth System Science, 119,. 51–65 (2010)
6. Pal I, Al Tabbaa A.L: Long-term changes and variability of monthly extreme temperatures in India. Theoretical and Applied Climatology, 100, 45–56 (2011)
7. Sonali P., Nagesh Kumar D.: Review of trend detection methods and their application to detect temperature change in India. Journal of Hydrology, 476, 212–227 (2013)
8. Franske C.L.: Non-linear climate change. Nature of Climate Change 4, 423-424 (2014)
9. Wu Z, Huang N.E., Long S.R., Peng C.K. On the trend, detrending and variability of nonlinear and non-stationary time series. Proceedings Nattional Academy of Science USA, 104 (38), 14889-14894 (2007)
10. Sang Y-F., Wang Z., Liu C.: Comparison of the MK test and EMD method for trend identification in hydrological time series. Journal of Hydrology 510, 293–298 (2014)
11. Unnikrishnan P., Jothiprakash V.: Extraction of nonlinear trends using singular spectrum analysis. Journal of Hydrologic Engineering,10.1061/(ASCE)HE.1943-5584.0001237, 05015007, (2015)
12. Carmona A.M., Poveda G.: Detection of long-term trends in monthly hydro-climatic series of Colombia through Empirical Mode Decomposition. Climatic Change 123(4), 301-31 (2013)
13. Sang Y-F., Sun F., Singh V-P., Xie P., Sun J.: A discrete wavelet spectrum approach to identifying non-monotonic trend pattern of hydro-climate data. Hydrology and Earth. System Science Discussions doi:10.5194/hess-2017-6 (2017)
14. Taylor W.: Change-Point Analysis: A Powerful Tool for Detecting Changes. Taylor Enterprises, Libertyville. 2000, http://www.variation.com/cpa/tech/changepoint.html
15. Mann H.B.:Non-parametric tests against trend. Econometrica, 13(3), 245–259 (1945)
16. Kendall M.G.: Rank Correlation Methods, 4th Ed., Charles Griffin, London, UK, 1975.
17. Huang N.E., Shen Z., Long S.R., Wu M.C., Shih H.H., Zheng, Q., Yen N.C., Tung C.C., Liu H.H.: The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proceedinngs of Royal Society London, Series A. 454, 903–995 (1998)
18. Adarsh S. Multiscale characterization of hydrological time series using mathematical transforms. Ph.D thesis, Indian Institute of Technoloy Bombay (2017)

Sahana A.S., Ghosh S., Ganguly A., Murtugudde R.: Shift in Indian summer monsoon onset during 1976/1977.Environmental Research Letters 10(5), 10.054006, doi:10.1088/1748-9326/10/5/054006, (2015)