# Analysis of rainfall trend using non-parametric methods and innovative trend analysis during 1901–2020 in seven states of North East India

**Shyam Lochan Bora[1,2,*], Kalyan Bhuyan[2], Partha Jyoti Hazarika[3], Junmi Gogoi[2] and Kuldeep Goswami[3]**

[1]Department of Physics, DDR College, Chabua, Dibrugarh 786 184, India
[2]Department of Physics and [3]Department of Statistics, Dibrugarh University, Dibrugarh 786 004, India

**In this study, we analysed the variability and trends in annual as well as seasonal rainfall in the seven states of North East India for the period 1901–2020, using non-parametric tests like Mann–Kendall, trend-free pre-whitening Mann–Kendall, modified Mann–Kendall (MMK), as well as using the innovative trend analysis (ITA). The study revealed the variabilities in annual and seasonal rainfall in these seven states. In most cases, the results of all the tests were identical. However, significant differences were observed in the case of post-monsoon rainfall of Assam and Meghalaya, pre-monsoon rainfall of Arunachal Pradesh, Mizoram and Tripura, as well as in winter rainfall of Arunachal Pradesh and monsoon rainfall of Tripura. Compared to the other states of NE India and other tests, ITA detected no significant annual trend for Tripura; however, the winter season exhibited a decreasing trend. It was observed that only the MMK test could predict such changes in rainfall distribution across seasons to a certain extent at varying significance levels in comparison to the other three methods. Since these states are vulnerable to water-related disasters, this study could help policymakers arrive at valuable climatic and water resource management decisions.**

**Keywords:** Climate change, innovative trend analysis, non-parametric tests, rainfall patterns, water resource management.

CLIMATE change has become one of the most significant challenges for sustainable development. In 2018, Intergovernmental Panel on Climate Change (IPCC) reported that it would significantly impact human lives and ecosystems. Although climate change has been an extensive field of research, the changing precipitation pattern demands immediate and systematic consideration, as it is a significant component of the hydrological cycle. Studies on rainfall patterns will lead to a better knowledge of flood, drought-related problems, extreme weather conditions, etc.[1,2]. Studies have been carried out worldwide to explore the variability and changes in rainfall patterns and the existing trends in rainfall over different spatial horizons using parametric and non-parametric tests[3,4]. Non-parametric methods have the advantage of non-sensitiveness to the outliers present in the data[5].

In India, many regions receive considerable rainfall during the monsoon season, while some regions receive significantly less rainfall, thus experiencing water scarcity; and climate change accelerates this rainfall variability to a considerable extent[6]. A complete understanding of rainfall patterns in this changing environment will help in better decision-making and improving the adaptive capabilities of communities to sustain extreme weather events. Therefore, several attempts have already been made in India to detect rainfall trends at both national and regional levels[6–8]. However, there are minimal local or regional studies in North East India compared to the developments in climatological studies in other parts of the country and the world. Therefore, analysis of trends at the local and regional levels is much more relevant for specific development and adaptation plans to mitigate the effects of climate change.

The study of rainfall trends in NE India is significant as it is amongst the country's highest rainfall receiving regions, covering 0.26 million sq. km which can be considered as a separate macro-region within the Indian landmass[9,10]. This region is vulnerable to water-induced disasters because of its geographical location. Several studies have been carried out in the past to analyse rainfall trends in NE India using Mann–Kendall (MK) test[11–13].

Although this test is being widely used for trend detection, it has some flaws regarding serial correlation in the time-series data. To overcome this problem modified Mann–Kendall (MMK) and trend free pre-whitening Mann–Kendall (TFPW–MK) tests have been introduced, which provide more reliable results than the MK test; however, they are also highly dependent on sample size and data distribution[14]. Therefore, innovative trend analysis (ITA) was introduced to solve the issues in the MK test[15]. Recently, Serinaldi *et al.*[16] have reported that ITA is also dependent on sample size and data distribution.

*For correspondence. (e-mail: shyamlochan04@gmail.com)

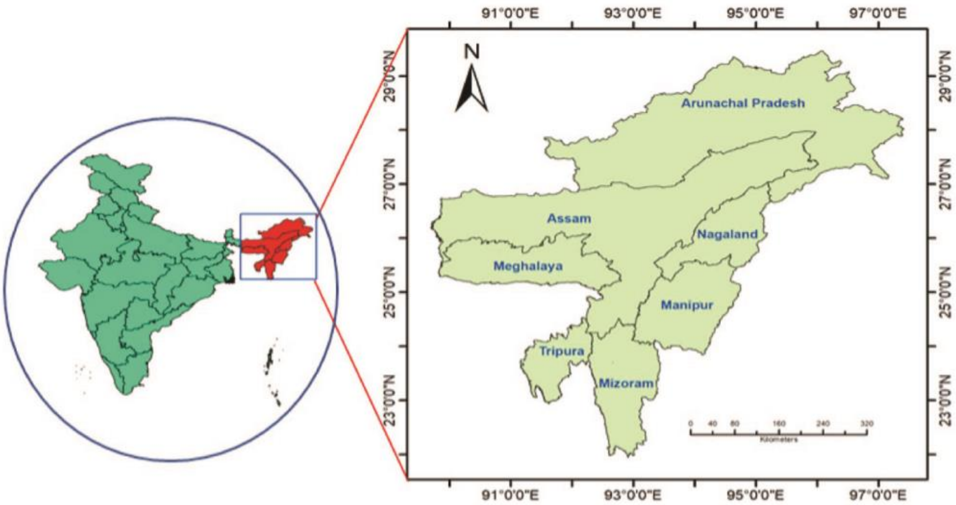


**Figure 1.** Study area.

Despite being limited by these drawbacks, ITA has become popular due to its capability to delineate hidden trends while using other methods and thus going a step further in analysing the trends[17–19]. It may be noted that the use of such advanced techniques of trend detection is sporadic in NE India. Thus, it becomes significant to study the rainfall trends using non-parametric methods and the ITA method to better understand rainfall variability in the study region by comparing the results with those obtained using other techniques.

## Study area and data

The study region is located between 89°46′–97°30′E long. and 21°57′ to 29°30′N lat., consisting of Arunachal Pradesh, Assam, Manipur, Meghalaya, Nagaland, Mizoram, Tripura and Sikkim (Figure 1). The Barak and Brahmaputra river basins are important physiographic components of NE India. The area has a rich biodiversity, high rainfall and high seismic activities. The climate of the region is subtropical, and it is known for its wide range of weather and climate. In the present study, monthly rainfall data for 120 years (1901–2020) have been collected for the seven states of NE India from India's Water Resources and Information System (https://indiawris.gov.in).

## Methodology

This study analyses rainfall data in the area to find the annual and seasonal trends using the MK, TFPW and MMK test and ITA. For analysis of seasonal trends, each year has been divided into four climatic seasons, viz. winter (January–February), pre-monsoon (March–May), southwest monsoon (June–October) and post-monsoon (November and December)[20].

### *Mann–Kendall test*

This test is a non-parametric test used worldwide to detect trends in hydrological as well as in climatic data. In this method, the test statistic $S$ is defined as

$$S = \sum_{i=2}^{n}\sum_{j=1}^{i-1} \text{sign}(x_i - x_j), \tag{1}$$

where $n$ is the length of the data series, $x_i$ and $x_j$ are the sequential data in the series and

$$\text{sign}(x_i - x_j) = \begin{cases} -1 \text{ for } (x_i - x_j) < 0 \\ 0 \text{ for } (x_i - x_j) = 0 \\ 1 \text{ for } (x_i - x_j) > 0 \end{cases}. \tag{2}$$

The mean of $S$ is $E(S) = 0$ and the variance of $S$ is given by

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{P-1}^{q} t_P(t_P - 1)(2t_P + 5)}{18}, \tag{3}$$

where $t_P$ is the number of ties for the $P$th value and $q$ is the number of tied values. The second term in the variance formula is for tied censored data. The standardized test statistic $Z$ is calculated by

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0. \\ \dfrac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{4}$$

**Table 1.** Descriptive statistics of annual rainfall (1901–2020)

| State | Minimum (mm) | Maximum (mm) | Mean (mm) | Standard deviation | Coefficient of variation (%) | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Arunachal Pradesh | 1323.01 | 4479.54 | 2788.25 | 592.88 | 21.26 | 0.37 | 0.26 |
| Assam | 1476.36 | 2725.47 | 2204.35 | 228.86 | 10.38 | –0.46 | 0.34 |
| Manipur | 879.11 | 2356.03 | 1589.87 | 267.95 | 16.85 | 0.25 | 0.23 |
| Meghalaya | 1322.62 | 6883.27 | 2930.70 | 926.17 | 31.60 | 1.29 | 2.03 |
| Mizoram | 989.13 | 3816.20 | 1881.42 | 389.29 | 20.69 | 1.22 | 4.64 |
| Nagaland | 1126.40 | 2540.71 | 1935.48 | 277.32 | 14.33 | –0.46 | 0.03 |
| Tripura | 1315.85 | 3711.52 | 2409.73 | 400.93 | 16.64 | 0.53 | 0.58 |

To test for monotonic trend at $\alpha$ significance level, the null hypothesis of no trend is rejected if the absolute value of $Z$ is greater than $Z_{1-\alpha/2}$, which is obtained from the standard normal cumulative distribution tables[21,22].

### *Sen's slope estimator*

The MK test shows that there is a positive or negative trend. Sen's slope calculates the strength of a trend and is given by

$$b_{\text{Sen}} = \text{Median}\left[\frac{Y_i - Y_j}{i - j}\right] \text{ for all } j < i, \tag{5}$$

where $Y_i$ and $Y_j$ are data at the time $i$ and $j$ respectively. If the total number of data points in the series is $n$, then there will be $n(n-1)/2$ slope estimates, and the test statistic $b_{\text{Sen}}$ is the median of all the slope estimates. The positive and negative sign of the test statistic indicates increasing and decreasing trends respectively[23].

### *Trend free pre-whitening with MK test*

In this method, the slope of the time series is determined using Sen's slope method. Next, the time series is detrended (with the assumption of linear trend), and the lag-1 correlation coefficient from the detrended series is found with some pre-defined significance level $\alpha$. Suppose the lag-1 correlation coefficient is significant within the considered significance level. In that case, the MK test is applied to the detrended pre-whitened series recombined with the estimated slope of trend using Sen's slope method. Else, the MK test is applied to the original series[14,24].

### *Modified Mann–Kendall test*

Serial correlation is an issue in time-series data. The MMK test is used to detect trends in hydrological and climatic data, and addresses the issue of serial correlation using a variance correction approach. The modified variance of $S$ statistic $V^*(S)$ is as follows

$$V^*(S) = V(S)\frac{n}{n^*}, \tag{6}$$

where $n/n^*$ is e correction factor. $V(S)$ is calculated as in the original MK test[14,24].

### *Innovative trend analysis method*

ITA is not sensitive to the serial correlation present in the data[15]. This method is based on dividing the data series into two halves and comparing them. The two halves are arranged in ascending order, and the first and second halves are plotted on $X$-axis and $Y$-axis respectively, with a 1 : 1 (45°) straight line on them. If the data are gathered on the straight line, then they show no trend, and gathering of data points above and below the straight line represents increasing and decreasing trend respectively. The trend slope is calculated by

$$S_{\text{ITA}} = \frac{10(\bar{x} - \bar{y})}{n}. \tag{7}$$

The confidence limits of the trend slope are given by

$$\text{CL}_{(1-\alpha)} = 0 \pm S_{\text{cri}} \times \sigma_S, \tag{8}$$

where $\alpha$ is the significance level, $S_{\text{cri}}$ the critical value and $\sigma_S$ is the standard deviation of the slope[15]. The slope $S_{\text{ITA}}$ of time series is statistically significant if it falls outside the confidence limits[15,25].

## Results

### *Descriptive analysis of annual rainfall*

Table 1 presents some of the statistical parameters of annual rainfall for the seven states of NE India, such as minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis. The mean annual rainfall was found to vary from 1589 ± 267.95 (Manipur) to 2930 ± 926.17 mm (Meghalaya), with the

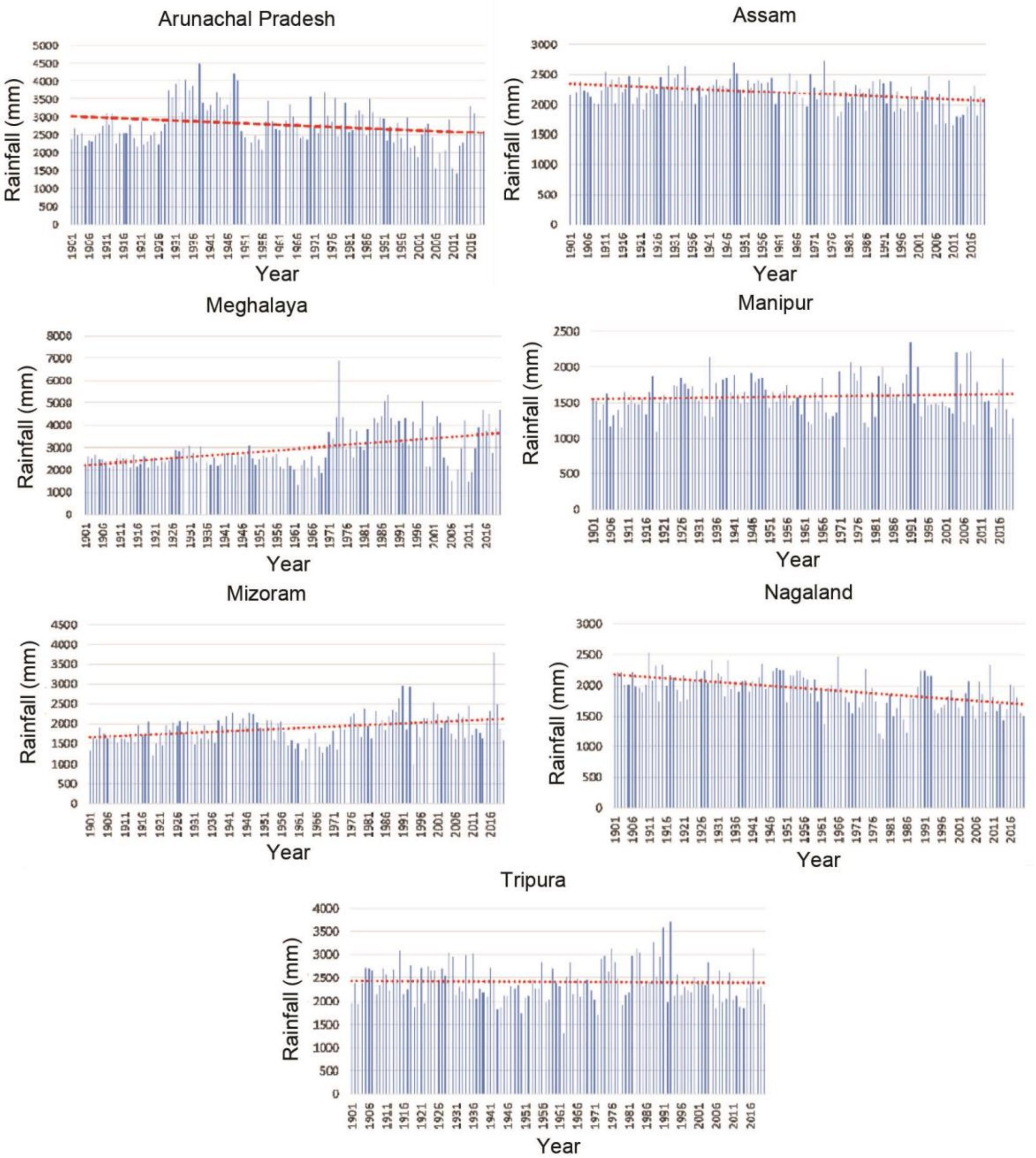


**Figure 2.** Actual time series plot of annual rainfall with linear trend line for the seven states in North East India.

CV of 16.85% and 31.60% respectively. SD of annual rainfall varied from 228.86 (Assam) to 926.17 (Meghalaya), with CV of 10.38% and 31.60% respectively. The mean minimum rainfall varied from 879.11 (Manipur) to 1476.36 mm (Assam) and the mean maximum rainfall from 2356.03 (Manipur) to 6883.27 mm (Meghalaya). The variability of rainfall in the study area is indicated by CV of 10.38% (Assam) to 31.60% (Meghalaya). Skewness is a parameter that gives the measure of symmetry or asymmetry of a given dataset. The skewness of annual rainfall in the study area varied from –0.46 (Assam and Nagaland) to 1.29 (Meghalaya). Also, kurtosis varied from 0.03 (Nagaland) to 4.64 (Mizoram).

## *Trends in rainfall pattern*

In this study, trend analyses of annual and seasonal rainfall in the seven states of NE India were carried out using the MK, TFPW–MK and MMK tests and ITA to detect long-term (1901–2020) trends in rainfall data. Figure 2 presents the annual rainfall data for the seven states fitted with linear trends.

*Annual rainfall trends using MK, TFPW–MK and MMK tests:* The state-wise annual rainfall trends were analysed for 1901–2020 using MK, TFPW–MK and MMK tests. The MK test revealed that Assam and Nagaland showed

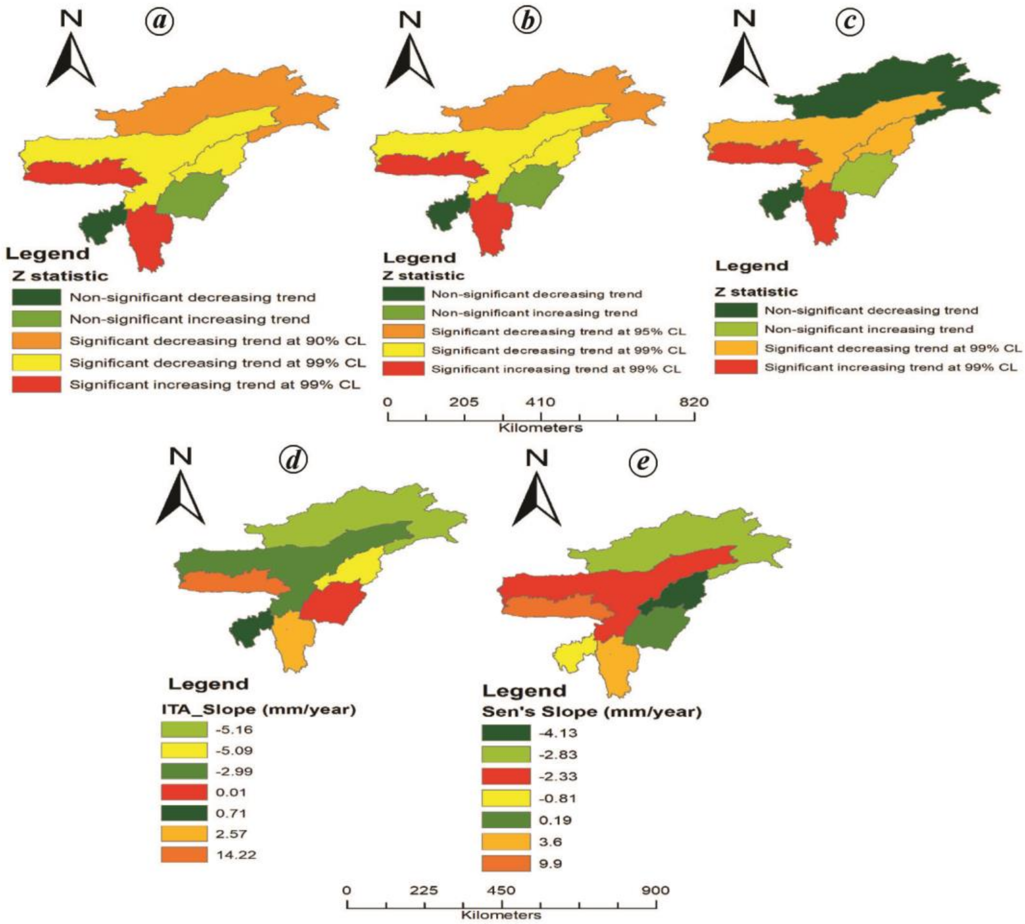


**Figure 3.** *Z* statistics of (***a***) MK test, (***b***) TFPW–MK test, (***c***) MMK test, (***d***) slope of ITA and (***e***) Sen's slope for annual rainfall for the seven states.

decreasing or negative trends at 99% ($P < 0.01$) significance level; Meghalaya and Mizoram showed increasing or positive trends at 99% ($P < 0.01$) significance level and Arunachal Pradesh showed a negative trend at 90% ($P < 0.1$) significance level. The remaining two states, i.e. Manipur and Tripura showed no significant trends.

Results of the TFPW–MK test revealed Assam and Nagaland showed negative trends at 99% significance level and Arunachal Pradesh showed a negative trend at 95% ($P < 0.05$) significance level. On the other hand, Meghalaya and Mizoram showed positive trends at a 99% significance level, whereas Manipur and Tripura showed no significant trends.

The MMK test revealed that the annual rainfall in Assam and Nagaland showed negative trends at a 99% significance level. Conversely, Meghalaya and Mizoram showed a positive trend at a 99% significance level, while Arunachal Pradesh, Manipur and Tripura showed no significant trends.

The statistical parameters of importance for the three tests for annual rainfall are shown in Supplementary Table 1.

*Annual rainfall trends using ITA:* The trend indicator, slope of the trend, upper confidence level (UCL), and lower confidence level (LCL) at 99%, 95% and 90% of annual rainfall of the states are shown in Supplementary Table 2.

The results revealed that Arunachal Pradesh, Assam and Nagaland showed decreasing trends at a 99% significance level for annual rainfall. Meghalaya and Mizoram showed increasing trends at a 99% significance level, while Manipur and Tripura showed no significant trends.

Figure 3 shows the *Z* statistics of the MK, TFPW–MK and MMK tests, Slope of ITA and Sen's slope for annual rainfall for the seven states.

*Seasonal rainfall trends using MK, TFPW–MK and MMK test:* The results of the seasonal trend analysis of rainfall data for 1901–2020 are shown in Supplementary Table 3.

In the case of winter rainfall, the MK test revealed that Arunachal Pradesh, Meghalaya and Mizoram showed no significant trends, while Nagaland showed a negative trend at a 99% significance level. Assam also showed a negative trend at a 95% significance level, while Manipur and

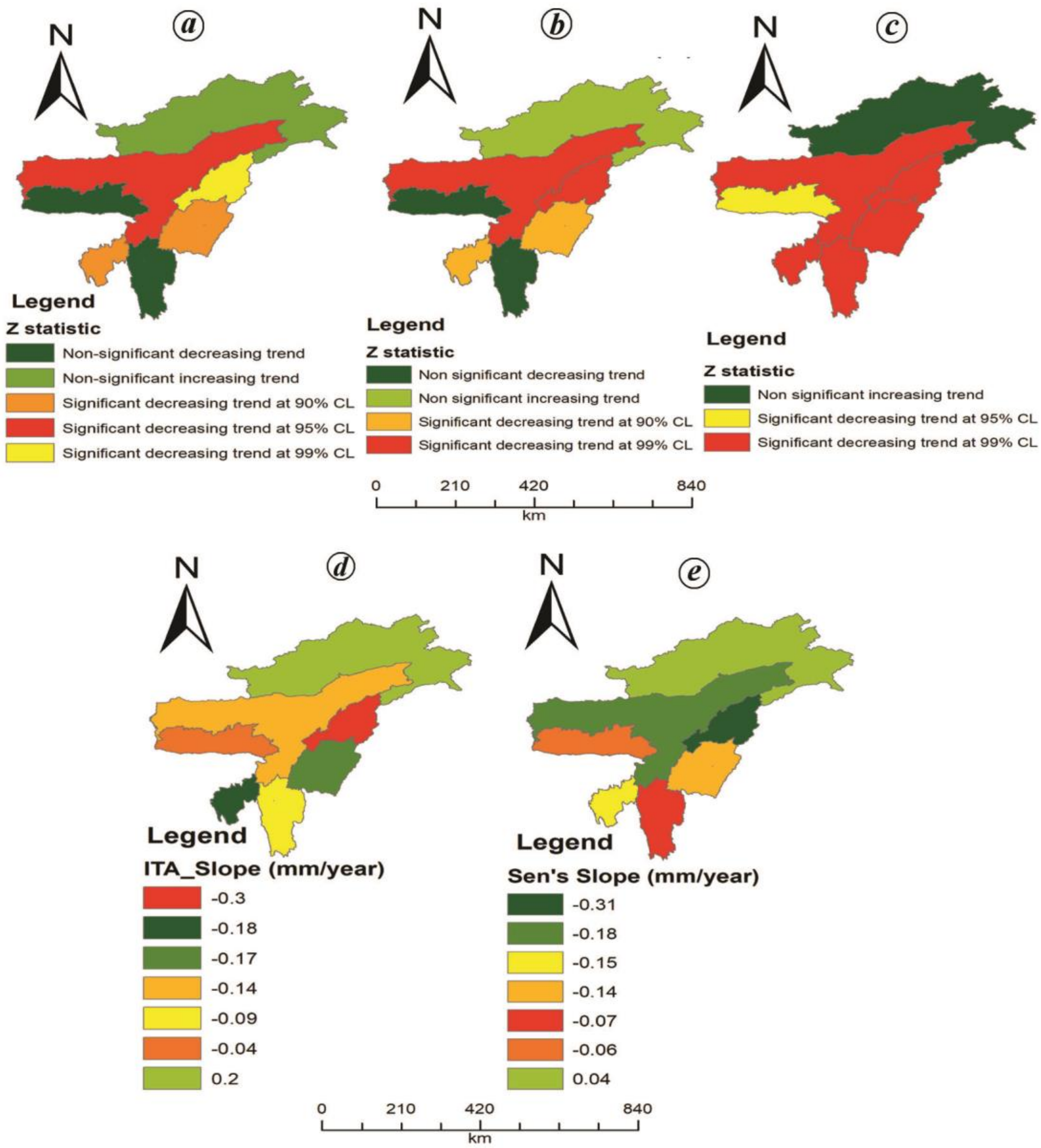


**Figure 4.** *Z* statistics of (***a***) MK test, (***b***) TFPW–MK test, (***c***) MMK test, (***d***) slope of ITA and (***e***) Sen's slope for winter rainfall for the seven states.

Tripura showed a negative trend at a 90% significance level. Arunachal Pradesh, Meghalaya and Mizoram showed no significant trends according to the results of the TFPW–MK test. Assam and Nagaland showed a negative trend at a 99% significance level, while Tripura and Manipur showed a negative trend at a 90% significance level. The MMK test revealed that Arunachal Pradesh showed no significant trends, whereas Assam, Manipur, Mizoram, Nagaland and Tripura showed decreasing trends at a 99% significance level. Meghalaya showed a negative trend at a 95% significance level.

For the pre-monsoon rainfall, the MK test revealed that Arunachal Pradesh, Assam, Manipur, Mizoram and Tripura showed no significant trends in the pre-monsoon season. On the other hand, Meghalaya and Nagaland showed increasing and decreasing trends at a 99% significance level. The TFPW–MK test revealed that Arunachal Pradesh, Assam, Manipur, Mizoram and Tripura showed no significant trends. On the other hand, Meghalaya and Nagaland showed increasing and decreasing trends at a 99% significance level. The MMK test revealed that Arunachal Pradesh, Mizoram and Tripura showed no significant trends. Assam and Nagaland showed decreasing trends at 99% significance level, while Meghalaya showed an increasing trend at 99% significance level and Manipur showed an increasing trend at a 90% significance level.

In the case of monsoon rainfall, the MK test revealed that Manipur and Tripura showed no significant trends in the monsoon season. Arunachal Pradesh, Assam and Nagaland showed negative trends at a 99% significance

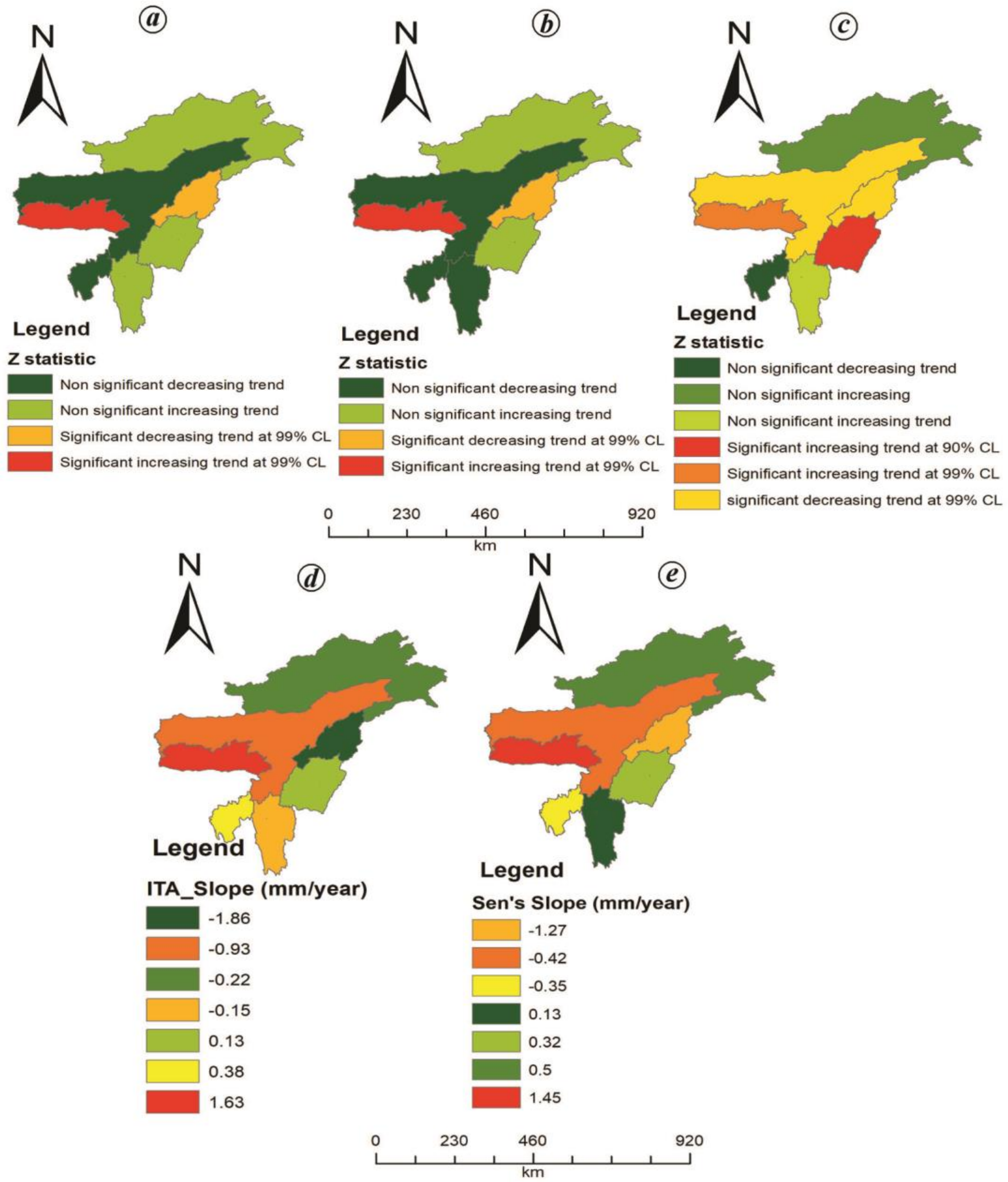


**Figure 5.** *Z* statistics of (***a***) MK test, (***b***) TFPW–MK test, (***c***) MMK test, (***d***) slope of ITA and (***e***) Sen's slope for pre-monsoon rainfall for the seven states.

level. On the other hand, Meghalaya and Mizoram showed a positive trend at a 99% significance level. The TFPW–MK test revealed that Arunachal Pradesh, Assam and Nagaland showed decreasing trends at a 99% significance level, while Meghalaya and Mizoram showed an increasing trend at a 99% significance level. Manipur and Tripura showed no significant trends. The MMK test reported that Arunachal Pradesh, Assam and Nagaland showed decreasing trends at a 99% significance level, while Mizoram and Meghalaya showed increasing trends at a 99% significance level. Manipur and Tripura showed no significant trends.

For post-monsoon rainfall, the MK test revealed that Arunachal Pradesh, Assam, Manipur, Meghalaya and Tripura showed no significant trends. Mizoram showed an increasing trend at a 95% significance level, while Nagaland showed a decreasing trend at a 90% significance level. The TFPW–MK test revealed that Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram and Tripura showed no significant trends. A decreasing trend at 90% significance level was noted for Nagaland. The MMK test revealed that Arunachal Pradesh, Assam, Meghalaya, Mizoram and Tripura showed no significant trends. Nagaland showed a decreasing trend at a 99% significance level, whereas Manipur showed a decreasing trend at a 90% significance level.

*Seasonal rainfall trends using ITA:* The trend indicator, slope of the trend, UCL and LCL at 99%, 95% and 90%

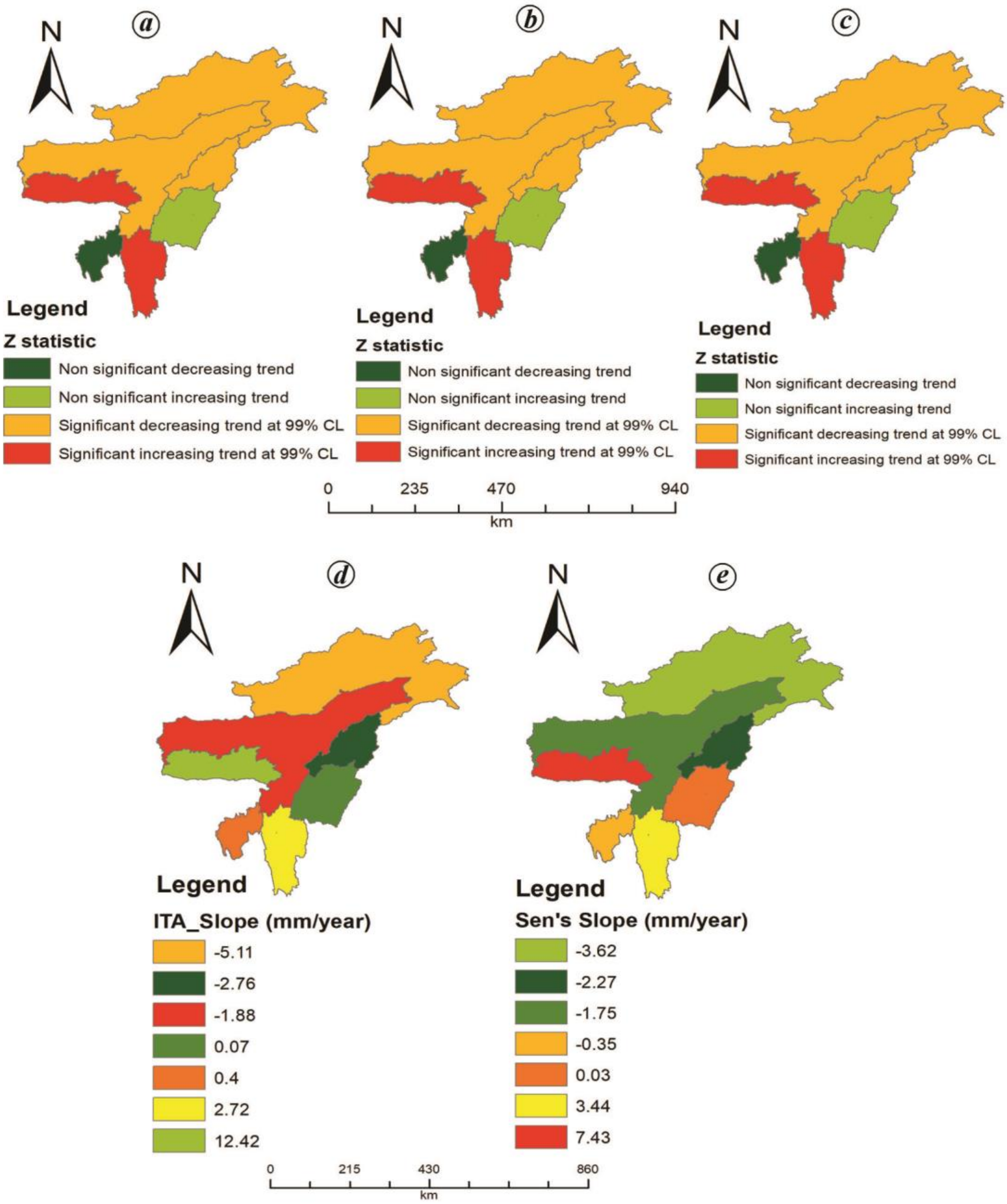


**Figure 6.** *Z* statistics of (***a***) MK test, (***b***) TFPW–MK test, (***c***) MMK test, (***d***) slope of ITA and (***e***) Sen's slope for monsoon rainfall for the seven states.

of the seasonal rainfall of the states are shown in Supplementary Table 4.

The results indicate that Arunachal Pradesh shows an increasing trend at a 99% significance level in the case of winter rainfall. On the other hand, Assam, Manipur, Mizoram, Nagaland and Tripura show decreasing trends at a 99% significance level, while Meghalaya shows a decreasing trend at a 90% significance level. In the case of pre-monsoon rainfall, Arunachal Pradesh, Assam, Mizoram and Nagaland show decreasing trends at a 99% significance level. Conversely, Manipur, Meghalaya and Tripura show increasing trends at a 99% significance level, while Arunachal Pradesh, Assam and Nagaland show decreasing trends in monsoon rainfall at a 99% significance level. Meghalaya, Mizoram and Tripura show increasing trends at a 99% significant level, while Manipur shows no significant trends. For post-monsoon rainfall, Arunachal Pradesh and Manipur show no significant trends, while Assam and Nagaland show decreasing trends at a 99% significance level. On the other hand, Meghalaya, Mizoram and Tripura show increasing trends at a 99% significance level.

Figures 4–7 show the *Z* statistics of MK, TFPW–MK and MMK tests, slope of ITA and Sen's slope for the

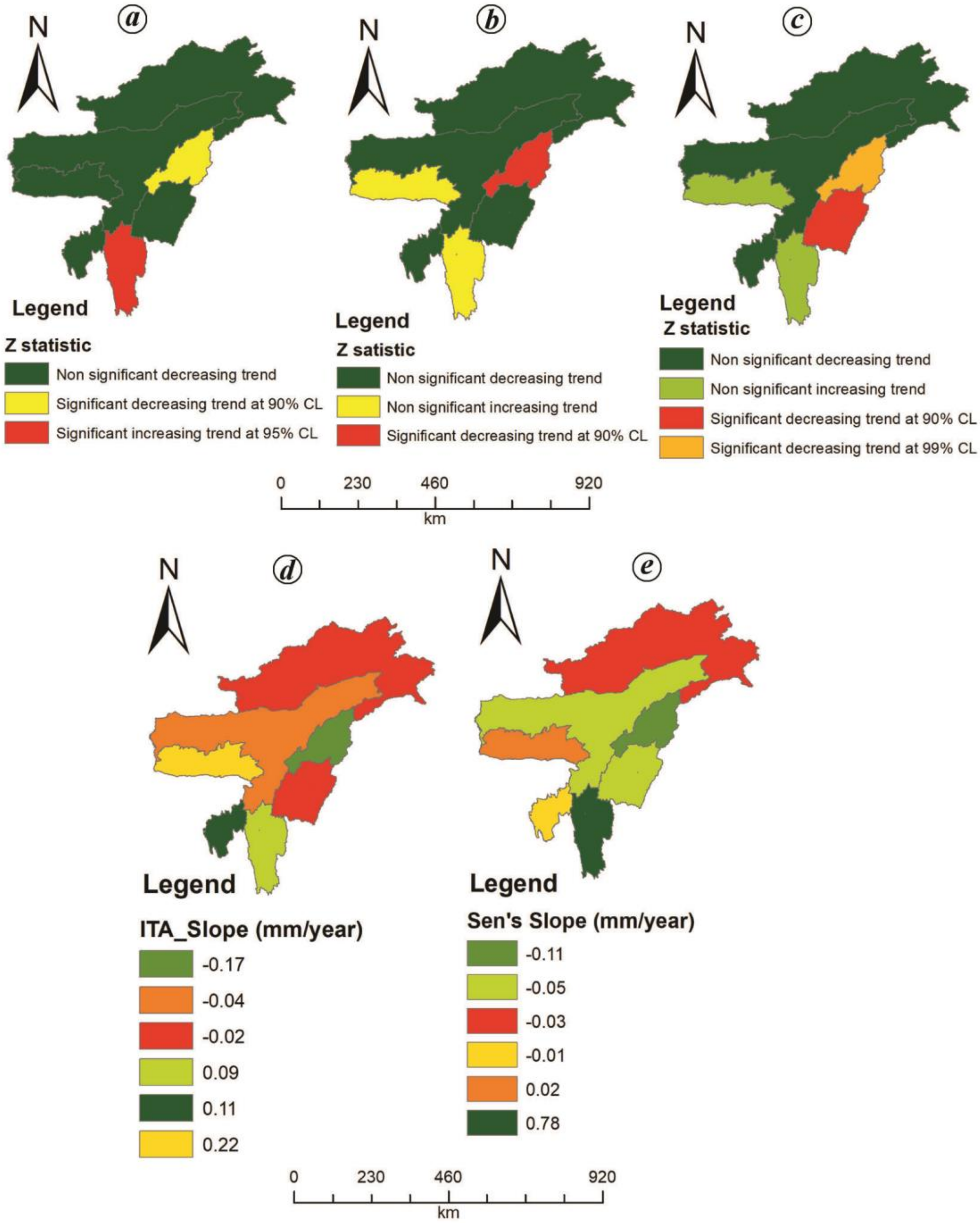


**Figure 7.** *Z* statistics of (***a***) MK test, (***b***) TFPW–MK test, (***c***) MMK test, (***d***) slope of ITA and (***e***) Sen's slope for post-monsoon rainfall for the seven states.

winter, pre-monsoon, monsoon and post-monsoon rainfall for the seven states.

## Discussion

The present study was carried out to analyse seasonal and annual rainfall data of the seven states in NE India using non-parametric methods and ITA. The latter method detected a change in rainfall patterns across season in most of these states. The rainfall trend of Assam and Nagaland was observed to decrease during seasons. However, in the case of Arunachal Pradesh, the winter season experienced an increasing trend, while the pre-monsoon and monsoon seasons experienced decreasing trends. No significant annual trend was observed for Manipur. However, significant decreasing and increasing trends were observed in the winter and pre-monsoon season respectively. The analysed rainfall trends of NE India were not so prominent for the other two seasons (monsoon and post-monsoon). Meghalaya experienced an increasing trend annually and seasonally, except during winter when there was a decrease. The annual trend of Mizoram was found to increase. For this state, the winter and pre-monsoon seasons showed decreasing trends while the other two seasons showed increasing trends. Compared to the other states of NE India and the other tests, ITA detected no significant annual trends for Tripura. However, the winter season exhibited a decreasing trend. All the detected trends had 99% significance level. It was observed that only the MMK test can predict such changes in rainfall distribution across seasons to a certain extent at varying significance levels in comparison to the other three methods. Notably, this study highlights the role of seasonal trends in shadowing the annual trends.

The proper prediction of rainfall trends is of utmost importance in drought protection, sustainable agricultural production, executing resilience plans, etc. Rainfall also affects urban water supply and water uses for industrial and residential purposes. It may be noted that the present study indicates the shifting of rainfall patterns seasonally, which may adversely affect agricultural production as well as availability of groundwater in the seven states of NE India. An increase in rainfall may lead to floods causing loss of properties and human lives, and affecting human health due to various vector-borne diseases after the flood event. As such, change in rainfall needs to be considered carefully for water management in the long-term catchment scale[26]. The rapid change in climatic conditions around the world is a new challenge. The adaptation and execution of policies are highly dependent on climatic conditions, and therefore detection and understanding of rainfall patterns are necessary. According to an IPCC report, upcoming climate changes are likely to distress agriculture which will amplify hunger and water paucity. Studies have also noted that large-scale ocean–atmospheric changes derived from the ECMWF ERA5 re-analysis data depict that an increasing/decreasing convective precipitation rate, enhanced low cloud cover and inadequate moisture variance in the Indian Ocean being transported to the northwest direction might have highly influenced the rainfall trend in India between the periods 1979–2000 and 2001–2015 (refs 27, 28). To conclude, the present study on the analysis of rainfall trends of NE India would help in water resource management, sustainable agricultural planning, ecosystem management and management of the health sector over the region.

## Conclusion

This study analysed annual and seasonal rainfall in the seven states of NE India using the classical non-parametric methods and ITA method to detect long-term trends (1901–2020). ITA is a relatively new method and several studies have reported that it could detect trends effectively compared to the other non-parametric tests[18,19,27,28]. It has been observed that there is variability in annual and seasonal rainfall patterns in the seven states of NE India. The results using these methods are similar in most cases, but there are inconsistencies in some cases. These may be due to the limitations of the classical non-parametric tests, as mentioned earlier. NE India is a subtropical region of the great Himalayan range. It faces heavy precipitation, which causes severe natural calamities such as sporadic floods, erosion, etc. These natural calamities are a barrier to agricultural growth, economic development and industrial growth. The proper identification of rainfall trends over the region may be beneficial to create awareness and minimize risks of different sectors (agriculture and industries), which are directly related to the economic development of the nation. This study will help policymakers develop a robust framework for overall development.


1. Myhre, G. *et al.*, Frequency of extreme precipitation increases extensively with event rareness under global warming. *Sci. Rep. 9*, 2019, **9**, 16063; https://doi.org/10.1038/s41598-019-52277-4.
2. Papalexiou, S. M. and Montanari, A., Global and regional increase of precipitation extremes under global warming. *Water Resour. Res.*, 2019, **55**; https://doi.org/10.1029/2018WR024067.
3. Pal, I. and Al-Tabbaa, A., Assessing seasonal precipitation trends in India using parametric and non-parametric statistical techniques. *Theor. Appl. Climatol.*, 2011, **103**; https://doi.org/10.1007/s00704-010-0277-8.
4. Tabari, H. *et al.*, Trend analysis of reference evapotranspiration in the western half of Iran. *Agric. For. Meteorol.*, 2011, **151**; https://doi.org/10.1016/j.agrformet.2010.09.009.
5. Mondal, A., Khare, D. and Kundu, S., Spatial and temporal analysis of rainfall and temperature trend of India. *Theor. Appl. Climatol.*, 2015, **122**; https://doi.org/10.1007/s00704-014-1283-z.
6. Goswami, B. N. *et al.*, Increasing trend of extreme rain events over India in a warming environment. *Science*, 2006, **314**, 1442–1445; https://doi.org/10.1126/science.1132027.
7. Nikumbh, A. C., Chakraborty, A. and Bhat, G. S., Recent spatial aggregation tendency of rainfall extremes over India. *Sci. Rep.*, 2019, **9**; https://doi.org/10.1038/s41598-019-46719-2.
8. Varikoden, H., Revadekar, J. V., Kuttippurath, J. and Babu, C. A., Contrasting trends in southwest monsoon rainfall over the Western Ghats region of India. *Climate Dyn.*, 2019, **52**; https://doi.org/10.1007/s00382-018-4397-7.
9. Winstanley, D., Recent rainfall trends in Africa, the Middle East and India. *Nature*, 1973, **243**; https://doi.org/10.1038/243464a0.
10. Parthasarathy, B., Sontakke, N. A., Monot, A. A. and Kothawale, D. R., Droughts/floods in the summer monsoon season over different meteorological subdivisions of India for the period 1871–1984. *J. Climatol.*, 1987, **7**; https://doi.org/10.1002/joc.3370070106.
11. Laskar, S. I., Kotal, S. D. and Bhowmik, S. K. R., Analysis of rainfall and temperature trends of selected stations over North East India during last century. *Mausam*, 2014, **65**.
12. Das, S. *et al.*, Trends in rainfall patterns over North-East India during 1961–2010. *Int. J. Earth Atmos. Sci*., 2015, **2**.
13. Prokop, P. and Walanus, A., Variation in the orographic extreme rain events over the Meghalaya Hills in northeast India in the two halves of the twentieth century. *Theor. Appl. Climatol.*, 2015, 121; https://doi.org/10.1007/s00704-014-1224-x.
14. Yue, S. and Wang, C. Y., The Mann–Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resour. Manage.*, 2004, **18**; https://doi.org/10.1023/B:WARM.0000043140.61082.60.

15. Şen, Z., Innovative trend analysis methodology. *J. Hydrol. Eng.*, 2012, **17**; https://doi.org/10.1061/(asce)he.1943-5584.0000556.
16. Serinaldi, F., Chebana, F. and Kilsby, C. G., Dissecting innovative trend analysis. *Stoch Environ. Res. Risk Assess.*, 2020, **34**, 733–754; https://doi.org/10.1007/s00477-020-01797-x.
17. Girma, A. *et al.*, Study on recent trends of climate variability using innovative trend analysis: the case of the Upper Huai River Basin. *Polish. J. Environ. Stud.*, 2020, **29**; https://doi.org/10.15244/pjoes/103448.
18. Wang, Y. *et al.*, Innovative trend analysis of annual and seasonal rainfall in the Yangtze River Delta, eastern China. *Atmos. Res.*, 2020, **231**; https://doi.org/10.1016/j.atmosres.2019.104673.
19. Mallick, J. *et al.*, Analysing the trend of rainfall in Asir region of Saudi Arabia using the family of Mann–Kendall tests, innovative trend analysis, and detrended fluctuation analysis. *Theor. Appl. Climatol.*, 2021, **143**; https://doi.org/10.1007/s00704-020-03448-1.
20. Jain, S. K., Kumar, V. and Saharia, M., Analysis of rainfall and temperature trends in northeast India. *Int. J. Climatol.*, 2013, **33**; https://doi.org/10.1002/joc.3483.
21. Kendall, M. G., A new measure of rank correlation. *Biometrika*, 1938, **30**; https://doi.org/10.2307/2332226.
22. Mann, H. B., Nonparametric tests against trend. *Econometrica*, 1945, **13**; https://doi.org/10.2307/1907187.
23. Sen, P. K., Estimates of the regression coefficient based on Kendall's tau. *J. Am. Stat. Assoc.*, 1968, **63**; https://doi.org/10.1080/01621459.1968.10480934.
24. Sonali, P. and Nagesh Kumar, D., Review of trend detection methods and their application to detect temperature changes in India. *J. Hydrol.*, 2013, **476**; https://doi.org/10.1016/j.jhydrol.2012.10.034.
25. Şen, Z., Innovative trend significance test and applications. *Theor. Appl. Climatol.*, 2017, **127**; https://doi.org/10.1007/s00704-015-1681-x.
26. Khan, N. *et al*., Performance assessment of general circulation model in simulating daily precipitation and temperature using multiple gridded datasets. *Water*, 2018, **10**(12).
27. Praveen, B. *et al.*, Analyzing trend and forecasting of rainfall changes in India using non-parametrical and machine learning approaches. *Sci. Rep.*, 2020, **10**; https://doi.org/10.1038/s41598-020-67228-7.
28. Kisi, O. and Ay, M., Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. *J. Hydrol.*, 2014, **513**; https://doi.org/10.1016/j.jhydrol.2014.03.005.

ACKNOWLEDGEMENTS. We thank the National Water Informatics Centre India, New Delhi (https://indiawris.gov.in) for the monthly rainfall data used in this work. We also thank the reviewers for their valuable comments that helped improve the manuscript.

Received 25 July 2021; re-revised accepted 19 January 2022

doi: 10.18520/cs/v122/i7/801-811