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Innovative trend analysis of long-term rainfall variation over West Bengal, India

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सार – यह अध्ययन पूरे पश्चिम बंगाल, भारत में वार्षिक और मौसमी वर्षा में दीर्घकालिक परिवर्तनों का निरीक्षण करने के लिए 121 गेज स्टेशनों से 115 वर्षों के ग्रिडेड वर्षा डेटा का उपयोग करता है। इन परिवर्तनों और समग्र रुझानों के महत्व और आयाम का आकलन 1901 से 2015 की अवधि के लिए भारत मौसम विज्ञान विभाग से एकत्र किए गए ऐसे ग्रिडेड डेटा के उपयोग से किया जाता है, जिसमें अभिनव प्रवृत्ति विश्लेषण लागू होता है। अध्ययन के निष्कर्षों के अनुसार, अध्ययन क्षेत्र में वर्षा सर्दियों के मौसम और प्री-मानसून सीजन के दौरान काफी कम हो जाती है, जबकि मानसून के मौसम और मानसून के बाद के मौसम में काफी बढ़ जाती है। मानसून की वर्षा में सबसे अधिक वृद्धि 4.68 मिमी/वर्ष और सबसे कम कमी 2.95 मिमी/वर्ष का अनुभव करती है। प्री-मानसून, मानसून और मानसून के बाद की वर्षा के लिए कुछ जिलों को छोड़कर मौसमी वर्षा के समग्र रुझान 5% महत्व के स्तर पर सांख्यिकीय रूप से महत्वपूर्ण पाए जाते हैं।

ABSTRACT. This study uses 115 years' gridded rainfall data from 121 gauge stations to observe long-term changes in annual and seasonal rainfall in the entire West Bengal, India. The significance and amplitude of these changes and overall trends are assessed with the use of such gridded data for the period from 1901 to 2015 collected from the India Meteorological Department, by applying innovative trend analysis. According to the findings of the study, rainfall in the study area decreases significantly during the winter season and pre-monsoon season, while increases significantly during the monsoon season and post-monsoon season. The monsoon rainfall experiences the largest increase at 4.68 mm/year and the smallest decrease at 2.95 mm/year. The overall trends of seasonal rainfalls are found to be statistically significant at the 5% significance level except for a few districts for pre-monsoon, monsoon, and post-monsoon rainfalls. This work aims to provide scientific support to recognize and strategically mitigate the impact of climatic changes on water management in West Bengal and thereby reduce the risk of climate change.

Key words – Innovative trend analysis, Gridded data, West Bengal, Climate change, Rainfall.

1. Introduction

In the past few years, people around the world have gradually become aware of the consequences of climate change (IPCC, 2021; Cook *et al.*, 2014). These consequences cause many climate hazards, such as strong thunderstorms, floods, wildfires, extreme weather events, dry spells and strong winds (Hajani, 2020). Furthermore, it was confirmed that rainfall is one of the primary climatic factors influencing regional and temporal patterns of water supply (Trenberth, 2011). Rainfall significantly affects global hydrology, groundwater, water quality parameters and vegetation. Rainfall is an important part of the hydrological cycle and although climate change has been studied extensively, long-term changes in patterns require urgent and sustained attention. The study of rainfall patterns is important to gain insights into various weather-related problems such as flooding, droughts and other meteorological challenges. Global warming is contributing to both the intensity and frequency of extreme rainfall events. To fully characterize the impact of extreme rainfall on global warming, it is necessary to communicate both their total amount and the individual contributions of intensity and frequency. In addition, the duration and extent of these extreme rainfall events can be influenced by climate change, which has a wide impact on weather patterns and ecosystems. Understanding these interrelated factors is essential to develop informed strategies to mitigate and adapt to increased risks associated with extreme rainfall in a changing climate (Myhre *et al.*, 2019). The climatic landscape of West Bengal, India, is experiencing significant changes, with rainfall patterns playing an important role in shaping the hydrology of this region. Therefore, this study explores innovative trend analysis to detect long-term changes in rainfall. In a world grappling with the effects of climate change, understanding the complexity of rainfall trends is critical for decision-making and strategic planning.

Many regions in India receive significantly high rainfall during the monsoon season, while others receive significantly less, resulting in water scarcity. Climate change is accelerating this change in rainfall significantly. Rainfall studies at the regional level are important because they help predict issues affecting regional resources and economic activity. Analysis of changes in historical rainfall patterns can be used to predict future climate patterns. At a regional scale, spatiotemporal trends in rainfall should be identified and considered as indicators of climate change. Floods are aggravated by heavy rainfall, while droughts reduce agricultural production due to insufficient rainfall. Examining the historical evolution of rainfall provides a comprehensive understanding of the different climates of different regions. It can inform more effective drought and flood mitigation and water resource management policies. The global discourse on climate change has highlighted the urgency of studying rainfall patterns, especially in regional locations. Although the issues of climate change have been widely studied, recent changes in rainfall patterns require a fresh and systematic review. Global warming is the driving force behind these changes, increasing the intensity and frequency of extreme rainfall events, requiring a comprehensive analysis.

Many researchers working in different geophysical fields studied and analyzed the effects of climate change and variability (Dash and Maity, 2019; Malik *et al.*, 2019; Marak *et al.*, 2020; Amiri and Gocić, 2021; Das *et al.*, 2021; Singh *et al.*, 2021). On the other hand, most previous studies of long-term trends in climatology have focused on the surface air temperature and rainfall. Trend analysis has been shown to be a useful tool for water resources planning, design and management. Because identifying trends in hydrologic variables such as discharge, direct runoff and rainfall provides useful information about how those variables may change in the future. Both parametric and non-parametric tests were used to analyse climatic parameters of temperature and rainfall trends. Non-parametric tests can be used in discrete data sets and are strong enough to account for outlying observations (Hamed and Rao, 1998). The Mann-Kendall test is one of the most widely used methods in the world to determine trends in rainfall, temperature and stream flow due to climate change. Nasker (2022) explain the rainfall trend over Kolkata in recent decade using Mann-Kendall test and found that none of the seasons shows a significant trend in rainfall pattern. Halder *et al*. (2022) studied the rainfall patterns at the Shali water reservoir in West Bengal's Bankura district over the past decade. They used the Mann-Kendall test to analyze the trends and found that there is a positive trend in rainfall during the monsoon season, but a negative trend in annual rainfall.

This study uses an innovative and powerful technique called Innovative Trend Analysis (ITA) to identify and quantify trends in terms of hydro-meteorological variables. ITA is chosen for its ability to work without requiring assumptions such as non-linearity, serial correlation, or specific sample sizes. Notably, no prior studies have applied ITA to analyze hydro-meteorological trends in West Bengal, a study that is very important to understand the regional scenario. Using advanced trend analysis techniques, this study aims to analyze the distribution of long-term rainfall data throughout West Bengal. Advanced statistical tools are used to identify trends and potential changes in rainfall patterns. Using an innovative approach, this research seeks to provide a more nuanced understanding of evolving climate dynamics, facilitating the development of forecasting and adaptation strategies.

The focus is to explore long-term, yearly, and seasonal patterns and variability of rainfall in the entire West Bengal, India. Using data collected from 121 grid-wise monitoring stations covering a time series of 115 years, this study aims to assess spatial and temporal changes in rainfall patterns from 1901 to 2015. The overall objective of this study involves a comprehensive analysis of seasonal and annual rainfall trends in West Bengal at a grid-based meteorological scale. The main objective includes a comparative evaluation of trend detection methods such as Mann-Kendall and Innovative Trend Analysis (ITA) to determine their effectiveness, sensitivity, and reliability in capturing the nuances of hydro-meteorological patterns. Confirmation of trends and identification of seasonal variations, including winter, pre-monsoon, monsoon and post-monsoon, are important elements. In addition, the study attempts to map the spatial distribution of rainfall trends, assess their statistical significance, and evaluate their implications for water resources, agriculture, and climate adaptation strategies all over West Bengal. Understanding long-term rainfall patterns is essential for developing effective strategies to

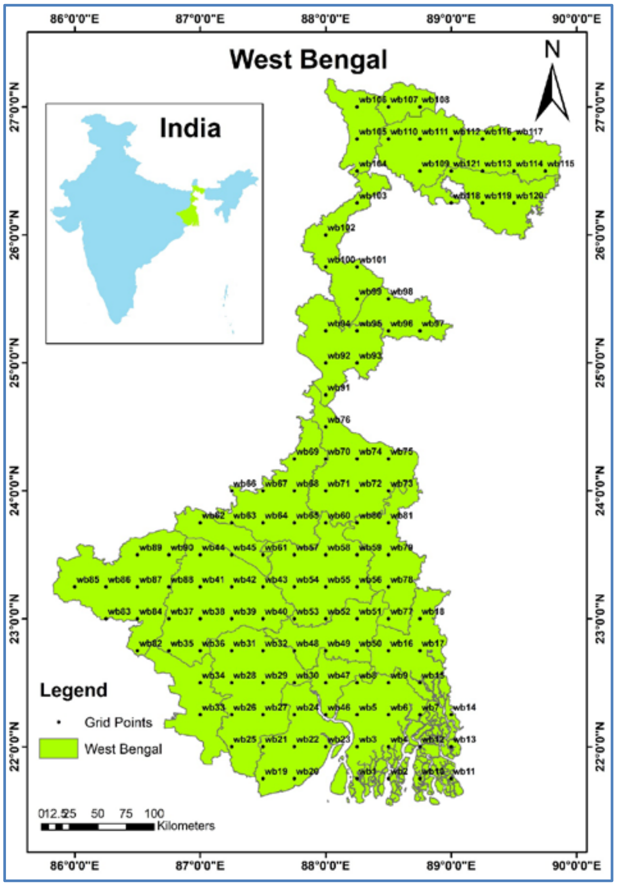

Fig. 1. Distribution of grid points over West Bengal, India

mitigate and adapt to the increased risks associated with extreme rainfall events in a changing climate. Insights from this innovative trend analysis may guide policymakers, environmentalists and climate scientists in designing sustainable approaches to address the challenges posed by dynamic rainfall patterns.

2. Study area and data used

2.1. *Study area*

West Bengal, a key Indian state, has a diverse landscape and a complex socio-economic fabric. Stretching from the Himalayas in the north to the Bay of Bengal in the south, it borders Bangladesh, Nepal and Bhutan. Covering an area of 88,752 sq km, it experiences a variety of climates from humid subtropical to tropical savanna influenced by the northern highlands and the Sundarban mangrove forests. With 23 districts, including 19 flood-prone ones, West Bengal stands out for its geographical uniqueness in the Indian context. Map of the study area can be seen in Fig. 1.

2.2. *Data used*

This study analyzes rainfall patterns in four seasons such as pre-monsoon, monsoon, post-monsoon and winter using interpolated daily grid-wise rainfall data from 121 grid points as shown in Fig. 1. The grids, covering mainland India with 0.25º latitude and 0.25º longitude intervals, have been developed by the India Meteorological Department (IMD) based on readings of 6955 rain gauges operating in the interval between 1901 and 2015 (Pai *et al.*, 2014). Qualitative assessments and comparisons have been made to address variable measurement uncertainty. This database is widely used in India for climate related research and applications (Anil and Raj, 2022; Buri *et al.*, 2022; Swain *et al.*, 2022).

3. Methodology

The long-term time series rainfall data of West Bengal has been analyzed using a new trend method proposed by Şen (2012). Compared to other statistical tests, the most important advantage of the new trend analysis is that it does not require any assumptions, such as nonlinearity, serial correlation and sample size.

3.1. *Innovative trend analysis*

A novel approach to the concept of trend detection was proposed by Şen (2012). It enables the recognition of patterns in rainfall time series. Using this procedure, the statistics are first arranged in descending order, then split down the middle into two equal halves. The first half (fh) and the second half (sh) of the series are represented on the graph by moving along the X-axis and the Y-axis, respectively. The trend in the series is determined by the no trend line of 1:1; if it lies on the line, it indicates that there is no trend. If it is located above the line, then it indicates a positive trend, and if it is located below the line, then it indicates a negative trend. Şen (2017) conducted an experiment using ITA methodology at different levels of statistical significance to provide a comprehensive understanding of trend analysis. The slope of ITA is evaluated using the following Equation (1):

$$s = \frac{y_2 - y_1}{n} \tag{1}$$

where s is the slope of ITA, n is the total number of sample data and y_1, y_2 are the mean of the first and second half respectively. The standard deviation of the slope is calculated as follows (Equation 2):

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1-\rho_{\bar{y}_1\bar{y}_2}} \tag{2}$$

where σ_s the standard slope; σ is the standard deviation of the data series and $\rho_{\bar{y}_1\bar{y}_2}$ is the cross-correlation coefficient between the first half and second half.

Finally, the confidence limit (*CL*) of the trend at *α* significance level is as follows (Equation 3):

$$CL = 0 \pm S_c\sigma_s \tag{3}$$

where *CL* is the lower and upper confidence limit at a 5% significance level, and *Sc* is the confidence limit of standard normal distribution.

3.2. *Mann-Kendall test*

The Mann-Kendall test, a non-parametric statistical method, is commonly applied to assess significant trends in hydrometeorological data. In this test, the null hypothesis (H_o) is employed to examine the presence of a trend in a time series. The statistic *S* (Equation 4) of the Mann-Kendall test is

$$S = \sum_{k=1}^{n-1} \sum_{i=1}^{n} \text{sign}\left(x_j - x_k\right) \tag{4}$$

where *n* is the total number of observations of the time series, *xj* and $x_k$are the observations for the j^{th} and k^{th} observations, and sign(x_j – x_k) is the sign function that varies as -1, 0, or +1; if the argument (x_j – x_k) < 0 then sign(x_j – x_k) = -1, if (x_j – x_k) = 0 then sign(x_j – x_k) = 0 and if (x_j – x_k) > 0 then sign (x_j – x_k) = 1, respectively.

For the number of observations in the time series $n \geq 10$, the statistic *S* is approximately distributed normally by Kendall (1938) and Mann (1945) with the mean (*S*) = 0 and the variance Var(*S*) defined as (Equation 5)

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^{p}\left(t_j - 1\right)\left(2t_j + 5\right)}{18} \tag{5}$$

where *p* denotes the number of arbitrarily designated groups *j*=1 to *p* in the time series and *tj*denotes the number of observations of group *j*. The Mann-Kendall statistic *Z* is given in Equation (6).

$$Z = \begin{bmatrix} \dfrac{S-1}{\sqrt{\text{Var}(S)}} \text{for } S > 0 \\ 0 \text{ for S} = 0 \\ \dfrac{S+1}{\sqrt{\text{Var}(S)}} \text{for } S < 0 \end{bmatrix} \tag{6}$$

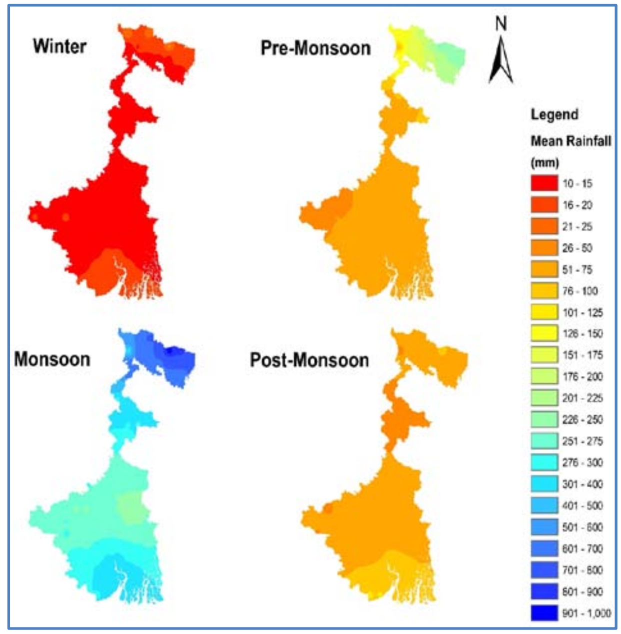

Fig. 2. Mean rainfall distribution over West Bengal during four different seasons 1901 to 2015

where *Z* takes positive values for increasing trends, negative values for decreasing trends, and approaches zero in the absence of any significant trend.

4. Results and discussion

Extreme weather events and changes in rainfall patterns have serious consequences on human well-being. Long-term monthly rainfall is useful for determining the availability of water in large river catchments and assessing the regional impact of water resource systems in climate change. Due to the monsoon rains from June to September, the river basins of West Bengal are prone to floods in some years and drought in others. In order to improve disaster and water management and planning, it is important for the state government to have district-level rainfall climatology and important data related to the temporal variability of district level rainfall due to the increasing frequency and severity of such disasters. In view of this, efforts have been made to use rainfall data for all districts from 1901 to 2015 to investigate the temporal and spatial variability of monsoon rainfall on a seasonal and annual scale as well as rainfall patterns that make up the state of West Bengal.

4.1. *Rainfall statistics*

4.1.1. *Seasonal rainfall*

When analyzing the impacts of rainfall on hydrology, ecology, agriculture and water use, the overall

TABLE 1

Significance of ITA results and remarks for different districts of West Bengal

Districts	Non-significant Grids	Significance remarks
Kolkata	wb9, wb16, wb50	During winter, there is a significant negative trend, while the pre-monsoon period shows no significant trends in the eastern region. Monsoon season exhibits a strong positive trend across the district, and the post-monsoon period also demonstrates a significant positive trend
South 24 Parganas	wb6, wb7, wb9	The northeastern region of the district shows a non-significant trend only during the pre-monsoon season
North 24 Parganas	wb11, wb12, wb13, wb14, wb15, wb16, wb17, wb18	The entire region shows a non-significant trend in the pre-monsoon season
Paschim Medinipur	wb26, wb29, wb30	The eastern region of the district shows a non-significant trend during the monsoon season
Bankura	wb38, wb41	A non-significant trend was observed in the middle of the district during the pre-monsoon season
Hooghly	wb50, wb51	The eastern region of the district shows a non-significant trend in the pre-monsoon season
Paschim Bardhhaman	wb61	The eastern region shows a non-significant trend for both the winter and pre-monsoon seasons
Birbhum	wb66, wb68	The western and eastern regions show a non-significant trend during the monsoon season
Purulia	wb83	The southern part of the district shows a non-significant trend for all seasons except the winter season
Malda	wb93, wb94, wb95	The northern part of the district shows a non-significant trend in the post-monsoon season
Kalimpong, Cooch Behar	wb108, wb120	The eastern portion of the district shows a non-significant trend for both winter and monsoon seasons

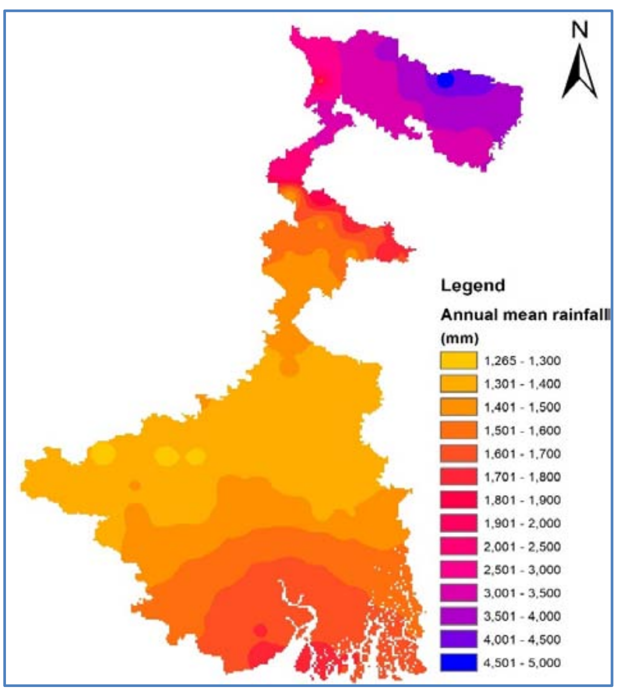

Fig. 3. Mean annual rainfall distribution in West Bengal for during 1901-2015

annual amount of monthly, annual and seasonal rainfall is as important as the pattern of rainfall occurring in the seasonal cycle. The southern region of West Bengal is characterized by a tropical wet-dry climate while the northern region is characterized by a humid subtropical climate. The seasonal rainfall pattern of West Bengal is shown in Fig. 2 illustrating its regional distribution. The distribution of winter rainfall shows that the average rainfall in West Bengal is 10-20 mm. The spatial distribution for the pre-monsoon season ranges from 20 to 200 mm. It can be seen from the figure that the distribution increases from the south to the north side of the map. For the monsoon season, rainfall ranges from around 250-1000 mm and for post-monsoon, it ranges from 20-100 mm.

4.1.2. *Annual rainfall*

The annual mean rainfall distribution in West Bengal is shown in Fig. 3. The mean rainfall in the state is about 1625 mm. The Southern part of West Bengal receives about 1700 mm of rainfall, while the northern part receives the highest among all the parts, around 4000 mm of mean rainfall. The distribution pattern of mean rainfall

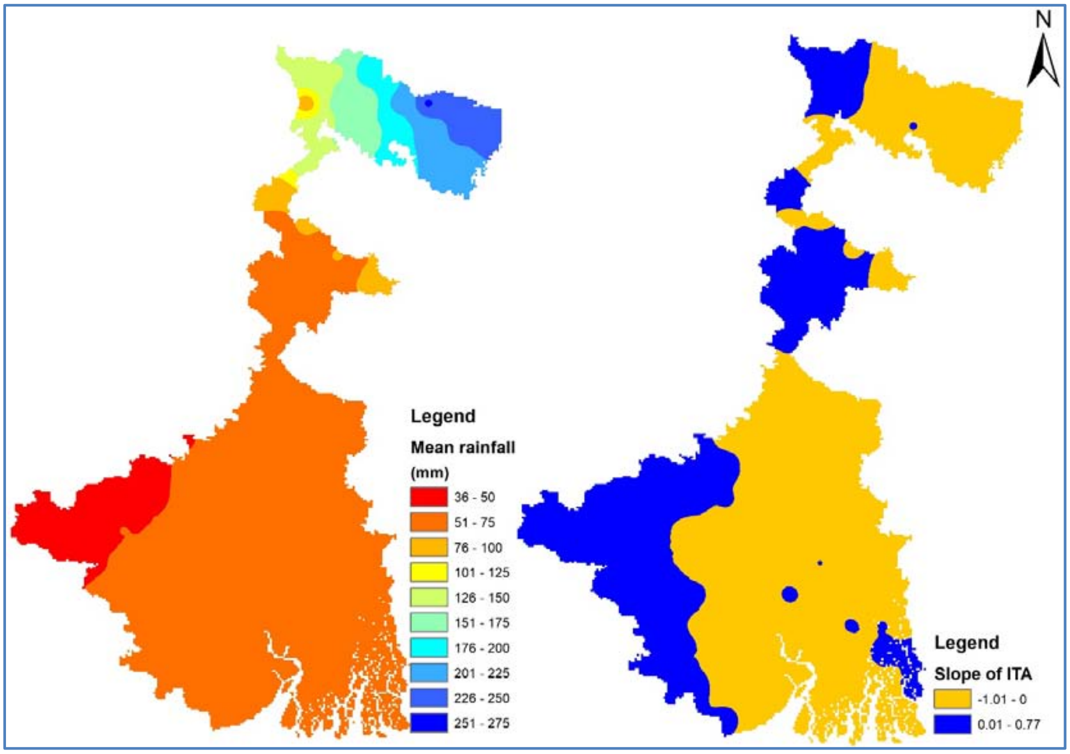

Fig. 4. Variation of mean rainfall and slope of ITA for pre-monsoon season from 1901-2015

varies in an increasing pattern from the middle part to the northern part of the state. A similar pattern is seen from the middle part to the southern part of the state. The highest and lowest rainfall receiving districts are Alipurduar in the northern part and Birbhum in the western part, respectively. The range of mean rainfall across the state ranges from1295 mm to 4895 mm. The annual rainfall data reveals an interesting pattern in the middle region of the state, with both the upper and lower portions displaying an upward trend.

4.2. *Trend analysis*

The pattern of rainfall that occurred during each season is found to be different according to the trend analysis performed on rainfall data of West Bengal for 115 years from 1901 to 2015. Table 1 presents the district-wise ITA significance, providing insight into rainfall pattern variations across West Bengal. Over 98% of grids show a significant trend in winter, while approximately 85% exhibit this trend in the pre-monsoon season. For the monsoon season, more than 89% of grids indicate a significant trend, and in the post-monsoon season, over 90% of grids show a significant trend. These findings highlight the seasonal variability in rainfall trends, with winter showing the most pronounced trends and the pre-monsoon season exhibiting slightly lower but still substantial levels of trend significance.

4.2.1. *Pre-monsoon trend*

Fig. 4 provides insights into the distribution of mean rainfall and the slope of ITA across West Bengal. During the pre-monsoon season, mean rainfall ranges from 30 mm to 250 mm, with lower levels in the southern and eastern regions compared to the northern and western regions. The Fig. 4 reveals that the western and northern parts of the state exhibit positive ITA slopes, indicating an increasing trend in rainfall. In contrast, the rest of the state shows negative trends, with these negative slopes being more pronounced than the positive ones. This suggests an overall decreasing trend in pre-monsoon rainfall across West Bengal. The distribution pattern highlights the regional variability in rainfall trends, with some areas experiencing significant changes over time. Understanding these trends are crucial for effective water resource management and agricultural planning in the region.

4.2.2. *Monsoon trend*

Fig. 5illustrates the normal distribution of mean rainfall and the slope of ITA during the monsoon season. The rainfall pattern observed during the monsoon season shows similar pattern as the pre-monsoon rainfall. The figure suggests that the northern region of the state experiences heavier rainfall. There is an overall positive

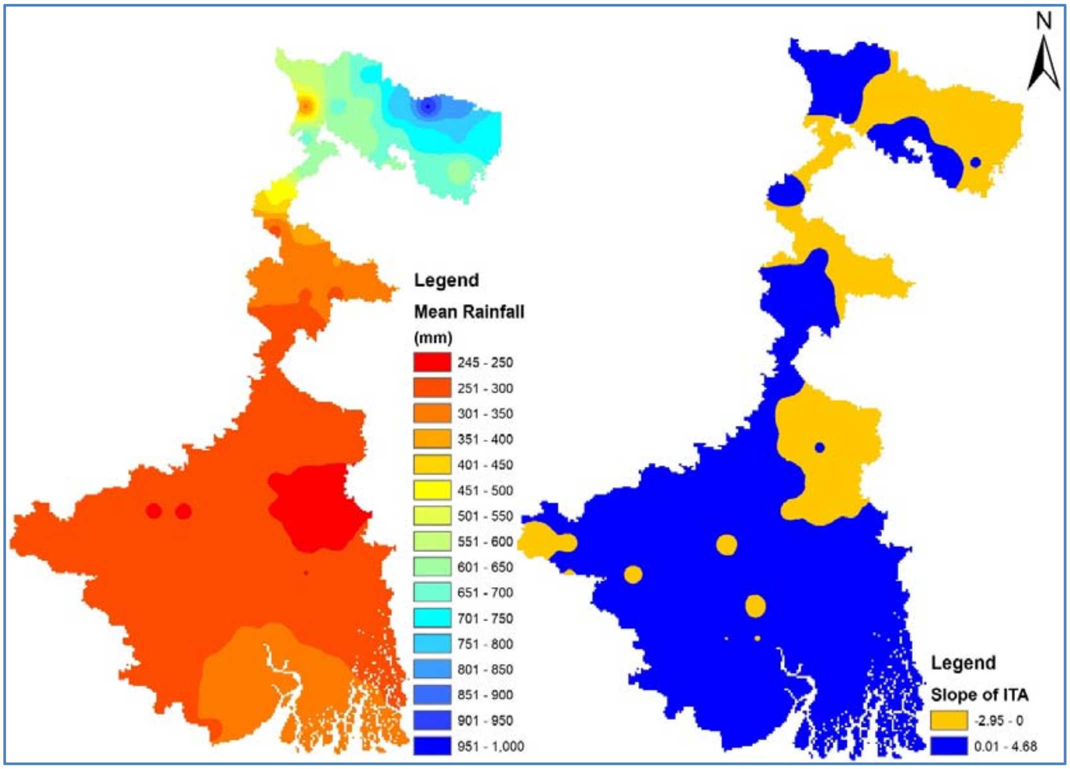

Fig. 5. Mean rainfall sub ranges and slopes of ITA for monsoon season for 1901-2015

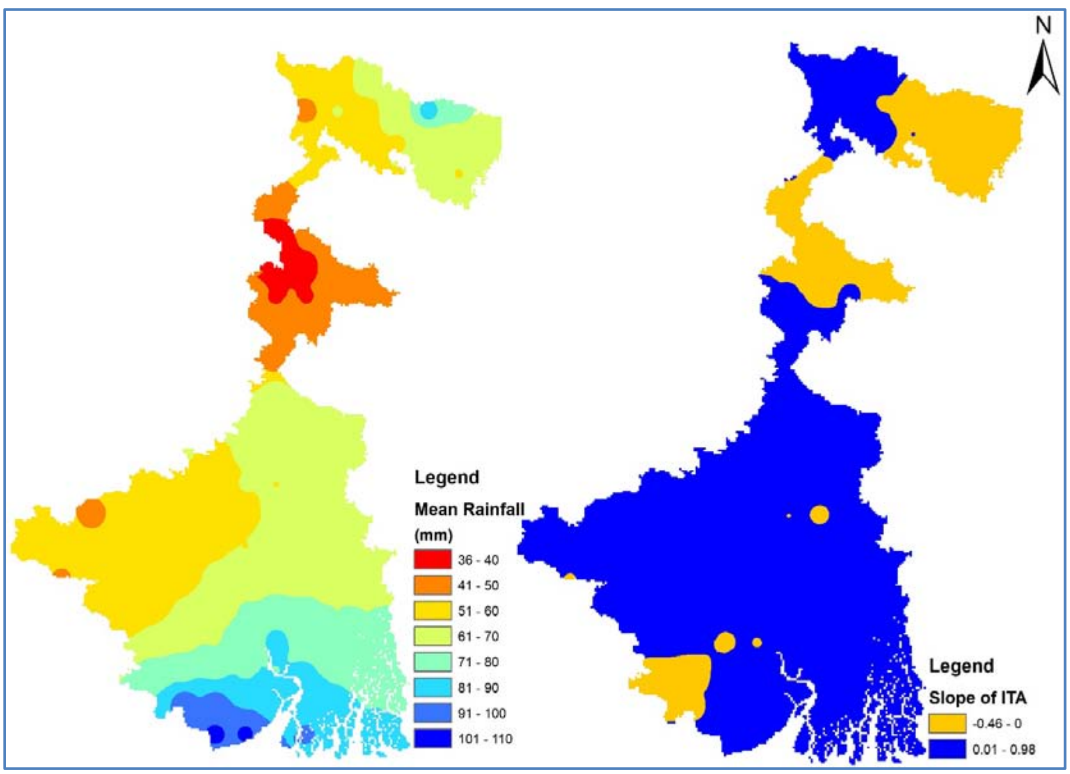

Fig. 6. Sub range wise pattern of mean rainfall and slopes of ITA for post-monsoon season for 1901-2015

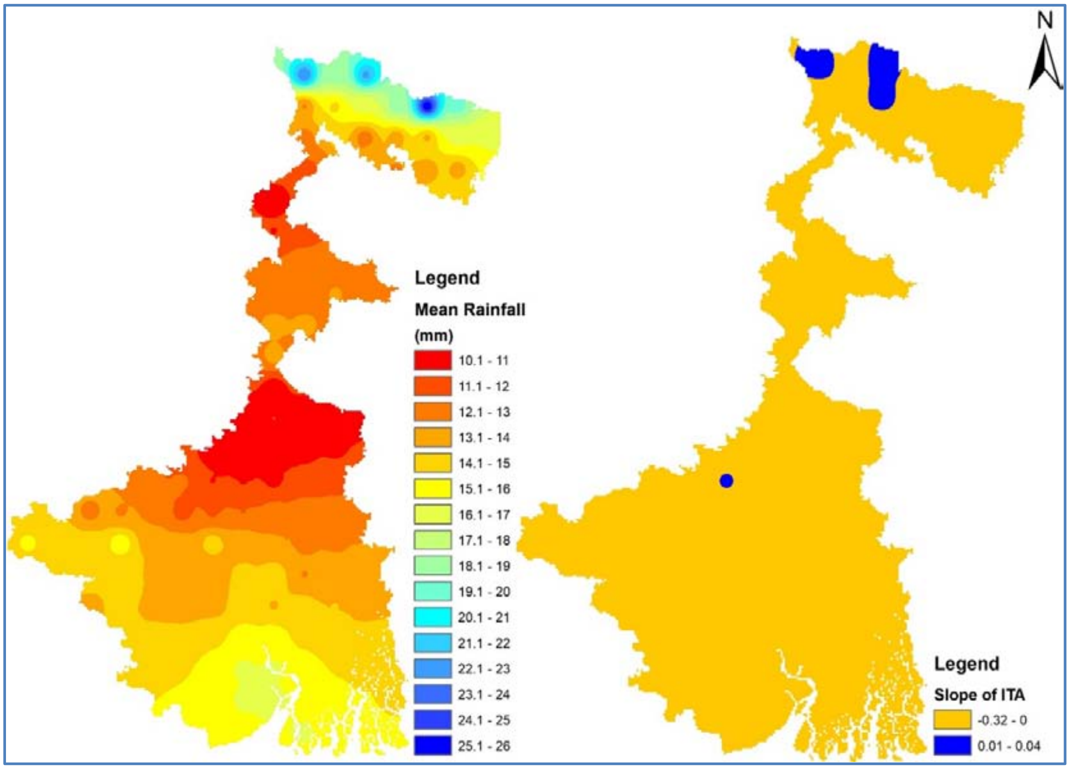

Fig. 7. Mean rainfall sub ranges and slopes of ITA for the winter season in the period from 1901 to 2015

trend in ITA slopes across West Bengal, except for the northern region, where strong negative ITA slopes were observed. During the monsoon season, mean rainfall ranges from 245 to 1000 mm, with detailed sub-ranges depicted in the figure. The steep negative and positive slopes indicate areas of significant concern for climate researchers, likely reflecting areas experiencing rapid changes in rainfall patterns. These findings underscore the importance of continued monitoring and analysis to understand and potentially mitigate the impacts of climate change on regional rainfall patterns. The overall monsoon trends in the entire state indicate an increasing trend in rainfall pattern during the monsoon season.

4.2.3. *Post-monsoon trend*

A typical rainfall pattern and slope of ITA are shown in Fig. 6. The mean rainfall typically ranges from 30 mm to 100 mm on average during the monsoon season. The distribution of rainfall in this season doesn't show similar pattern of rainfall as previous seasons. The figure indicates that most parts of the state exhibit positive ITA slopes, although with smaller magnitudes. The northern region, however, shows a mild negative magnitude of ITA slope in this period. The distribution of overall mean post-monsoon rainfall appears random across West Bengal. However, the southern region of the state receives higher rainfall compared to other parts. This variation in rainfall distribution underscores the complex nature of regional climate patterns and the need for detailed analysis to understand the factors driving these variations. The overall tendency of the post-monsoon season throughout the entire state reveals an increasing trend in mean rainfall during the post-monsoon season.

4.2.4. *Winter trend*

Fig. 7 illustrates the distribution of sub-ranges of mean rainfall and the slopes of ITA for the post-monsoon season from 1901 to 2015. The figure indicates that the majority of the state exhibits negative ITA slopes, suggesting a general decrease in mean rainfall during this season. Mean rainfall during the winter season ranges from 10 mm to 30 mm. The distribution of mean rainfall across the state shows an increasing trend from the central region towards the northern and southern parts. The negative ITA slopes indicate an overall downward trend in mean winter rainfall across the state, highlighting the importance of understanding and addressing these changing patterns in precipitation for effective water resource management.

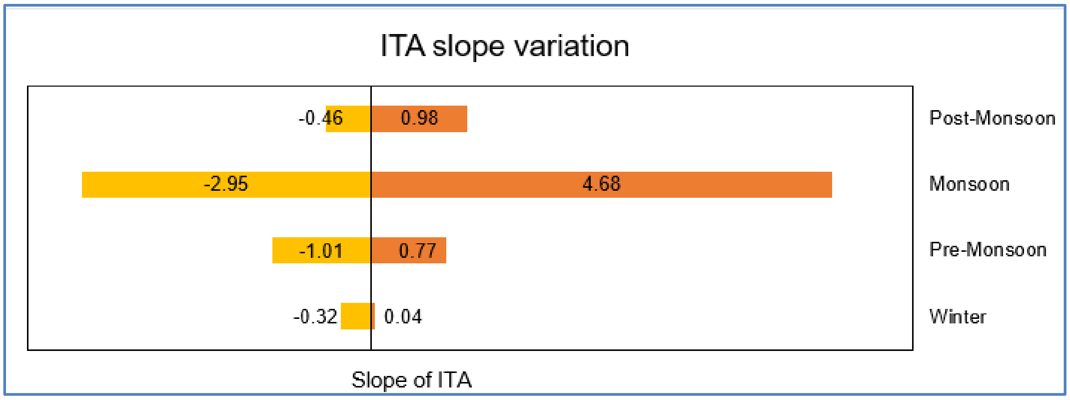

Fig. 8. ITA slope variation over West Bengal for different seasons for the period 1901 to 2015

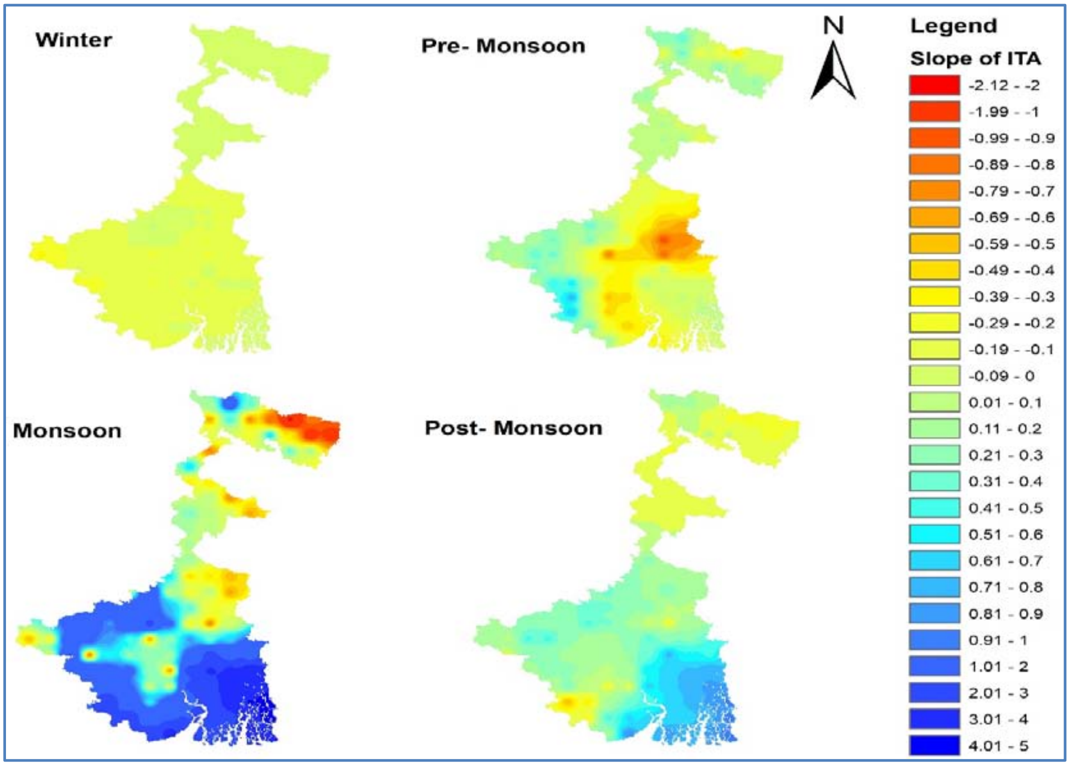

Fig. 9. ITA slope variations over West Bengal for different seasons for the period from 1901 to 2015

4.3. *Spatial distribution of ITA slope*

The spatial distribution of ITA slopes and their variation in four different seasons are displayed in Fig. 8 and Fig. 9. The ITA slope values range from -2.95 to 4.68, indicating the presence of both negative and positive trends. During the winter season, the distribution of ITA slopes exhibits minimal variation. However, significant fluctuations in the ITA slope values are observed across the remaining three seasons. In the pre-monsoon period, a larger magnitude of negative slopes is evident in the eastern part of the state, specifically in the Nadia district. This suggests a declining trend in the region during this period. The monsoon season presents contrasting trends, with the lower region exhibiting a positive trend of exceptionally high magnitude, while the upper region, particularly Alipurduar, displays a remarkably strong negative trend. This highlights the diverse climatic patterns within the state during the monsoon period.

Interestingly, the post-monsoon season does not exhibit significant changes in ITA slopes across most of the state, except for the lower region, where notable variations are observed. In contrast, the winter season

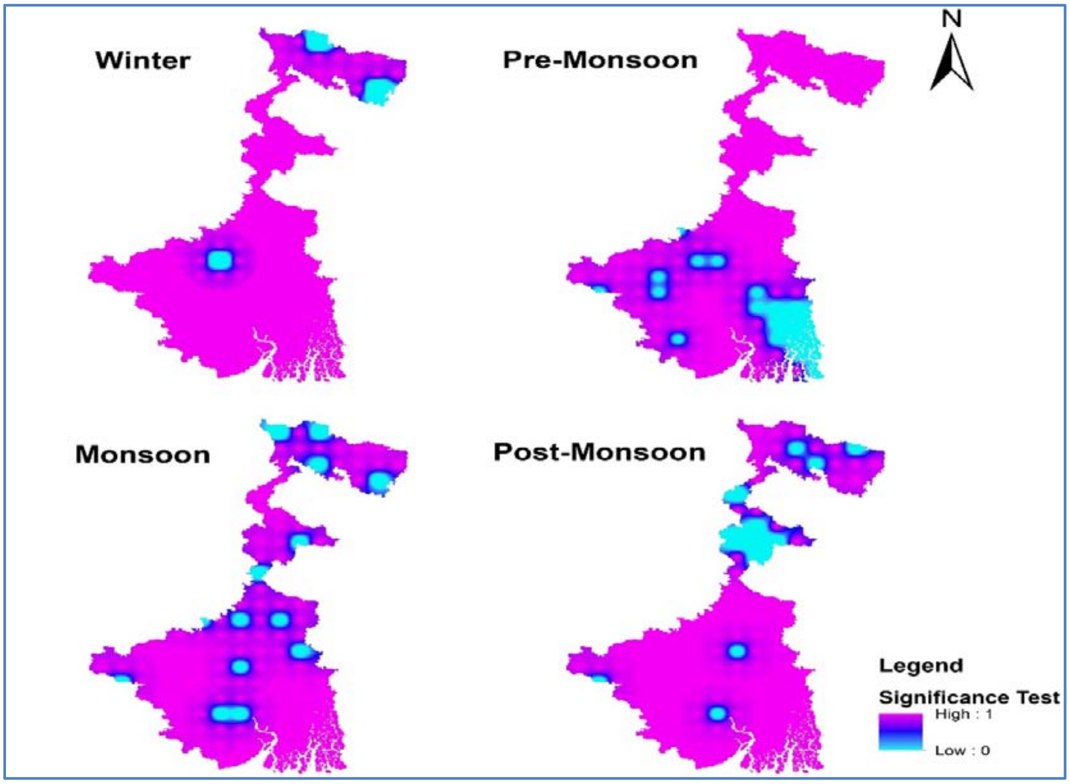

Fig. 10. Significance of ITA slope over West Bengal for four different seasons over the period of 1901 to 2015 (1: Significant trend; 0: non-significant trend)

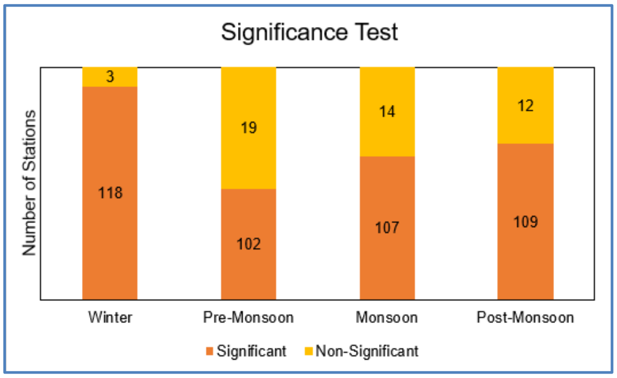

Fig. 11. Details of the significance of ITA slope based on stations

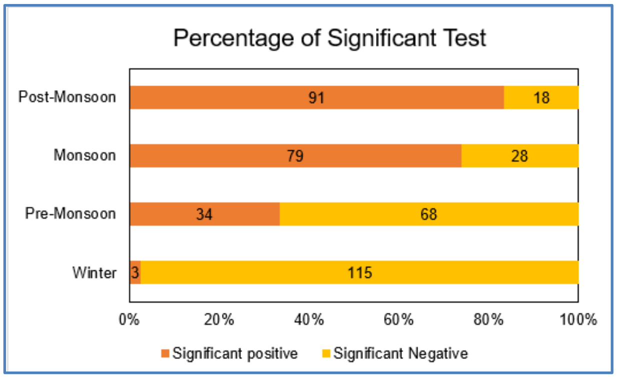

Fig. 12. Distribution of significant positive and negative slope

stands out as the only period without noticeable changes in ITA slopes, indicating a relatively stable climatic condition across West Bengal during this time.

4.4. *Significance of innovative trend*

The significance of the ITA slope is considered at the 5% significance level. The significance test for all seasons is shown in Fig. 10. During the winter season, almost all grids show a significant trend. In the pre-monsoon season, North 24 Parganas district in the south portion of the state shows a non-significant trend. In the winter season, a significant trend of ITA slopes is very randomly distributed all over West Bengal. In post-monsoon, the significance test shows the lower part of the state has a significant trend, but the upper northern part gives a non-significant trend. The purple color used in Fig. 10 indicates a significant trend, while the blue color indicates a non-significant trend. There are a total of 121 grid stations. In addition to all of these notable stations, Figs. 11 and 12 illustrate the percentage of significant positive and negative trends, respectively.

TABLE 2

Mann-Kendall trend significant results and remarks for different districts of West Bengal

Districts	Significant grids	Remarks
Kolkata	wb8, wb9, wb16, wb50	Entire district exhibits a strong positive trend during the monsoon season.
South 24 Parganas	wb1, wb2, wb3, wb4, wb5, wb6, wb7, wb8, wb9	The overall region shows a positive trend during the monsoon season, while the southeastern zone of the district exhibits a significant positive trend in the post-monsoon season.
North 24 Parganas	wb10,wb11, wb12, wb13, wb14, wb15 wb16, wb17, wb18	The entire district exhibits a significant positive trend during both the monsoon and post-monsoon seasons.
PurbaMedinipur	wb19, wb20, wb21, wb22, wb23	Only the monsoon season shows a significant trend for the entire region.
Jhargram	wb33, wb34	The southern portion of the district shows a significant positive trend during both the pre-monsoon and monsoon seasons.
Bankura	wb35, wb36 wb43, wb45	During the pre-monsoon and monsoon periods, the northeastern and southern regions show a significant trend.
Hooghly	wb50 wb51	The eastern region of the district shows a significant trend during the monsoon season.
Purba Bardhhaman, Nadia	wb54, wb55, wb56, wb58, wb59, wb60 wb78, wb79 wb80, wb81	The entire district shows a significant trend during the pre-monsoon season.
Dakshin Dinajpur	wb97, wb98	The northeastern part of the district exhibits a significant trend during the monsoon season.

4.5. *Comparative analysis with ITA and Mann-Kendall test*

When we compare the results of the Mann-Kendall test with the ITA, a notable decrease in the number of significant trends is noted across West Bengal. Table 2 illustrate the significant districts outcomes with spatial remarks related to MK trend. However, the other districts do not demonstrate the same degree of sensitivity to the ITA. According to ITA, rainfall in the Kolkata district exhibits a significant negative trend during the winter season and a positive trend in the remaining seasons. However, according to the Mann-Kendall analysis, only the monsoon season shows a positive trend. Similar pattern of results for Kolkata were reported using the Mann-Kendall test (Ghosh, 2018; Chakraborty *et al.*, 2019; Kundu and Mondal, 2019). Halder *et al.* (2023) describe the seasonal and annual rainfall trends in West Bengal using the Mann-Kendall (MK) test, the Sequential Mann-Kendall (SQMK) test, and Sen's slope. They found that, except for the winter season, the remaining seasons exhibit a significantly increasing positive trend in rainfall over Gangetic West Bengal (GWB). Nasker (2022) explain the rainfall trend over Kolkata in recent decade using Mann Kendall test and found that none of the seasons shows a significant trend in rainfall pattern. Saikh *et al.* (2023) conducted an analysis of monthly, yearly, and seasonal rainfall variations in the Kolkata district of

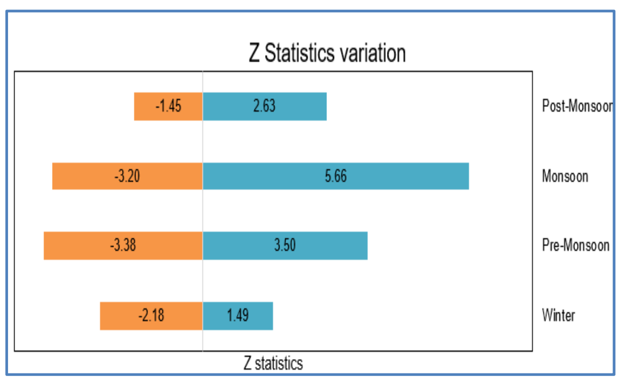

Fig. 13. Variation of Z statistics in West Bengal during different seasonsfrom 1901 to 2015

West Bengal from 1901 to 2019. They observed a positive trend in the data series for pre-monsoon, monsoon, post-monsoon, and annual rainfall. However, they noted a negative trend in winter rainfall. Their findings align with the results of this study. According to Fig. 13, the Z statistics show a considerable magnitude of variations: -1.45 to 2.63 in post-monsoon, -3.20 to 5.66 in monsoon, -3.38 to 3.50 in pre-monsoon, and -2.18 to 1.49 in winter. These intervals reflect the varied and distinct nature of trends across the respective seasons. Several districts exhibit no significant trend across all seasons. This could be because the Mann-Kendall test evaluates trends by

TABLE 3

Significance of trend analysis methods utilized for 121 grid points

Trend methods	Significance	Winter	Pre-monsoon	Monsoon	Post-monsoon
ITA	Significant	118	102	107	109
	Non- Significant	3	19	14	12
Mann-Kendall	Significant	1	20	46	15
	Non- Significant	120	100	75	106

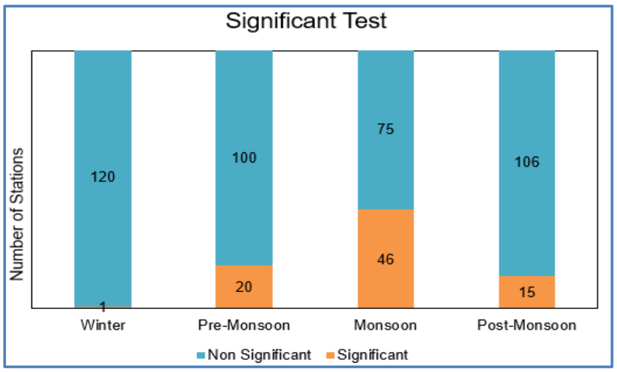

Fig. 14. Details of the significance of Mann-Kendall test

analyzing the ranks of data rather than the actual values. This approach makes the test less sensitive to small fluctuations or short-term variations in the data. As a result, if the changes in rainfall patterns within a district are not consistent or significant enough to alter the ranks of the data points significantly, the Mann-Kendall test may not detect a significant trend, even if there are slight changes occurring over time (Narayan *et al.*, 2016). Serial correlation can also impact the test's ability to detect trends accurately. If there is strong serial correlation in the data, it can inflate the variance of the Mann-Kendall test statistic, potentially leading to incorrect conclusions about the presence or absence of a trend.

Fig. 14 shows these stations, emphasizing the undervaluation of the significance test when compared to the ITA. The preference for adopting ITA over Mann-Kendall is due to the undervaluation as observed from the significance test. The disparity in results and the higher sensitivity of ITA show that it is suitable for trend analysis in this context. The Mann Kendall test evaluates trends based on the ranks of data, making it less sensitive to subtle changes or short-term trends, especially in datasets with high variability. In the context of pre-monsoon and winter rainfall, which may experience more localized and infrequent changes compared to monsoon rainfall, the Mann Kendall test may not always detect significant trends (Hamed, 2008; Narayan *et al.*, 2016; PZ & KV, 2021; Patel *et al.*, 2024). The sensitivity of detecting trend in ITA is very strong compare to Mann Kendall test. Sensitivity of Mann Kendall test can vary depending on the length of the time series, the presence of autocorrelation in the data, and the choice of significance level. These methodological considerations can influence the detection of significant trends. Other possible reason for non-significant trends are natural variation in rainfall pattern, land-use changes, urbanization, and irrigation practices can have a more pronounced impact on rainfall patterns during the monsoon and post-monsoon seasons compared to pre-monsoon and winter. These factors can introduce additional noise in the data, potentially complicating any underlying trends. The results in Table 3 indicate that the ITA method detects significantly more trends than the Mann-Kendall test.

The observed trends in West Bengal, with almost 80% of grids show a significant positive trend during post-monsoon and monsoon seasons. Over 60% of grids exhibit a significant negative trend during pre-monsoon and winter periods. These could be attributed to various factors. Possible reasons for these changes may include shifts in rainfall patterns influenced by climate change, alterations in land use practices, regional environmental modifications, or other local climate dynamics. Understanding the specific drivers behind these trends requires a more detailed analysis and consideration of local environmental factors. The non-significant trends observed in pre-monsoon, post-monsoon and winter rainfall patterns according to the Mann-Kendall statistical test can be attributed to the combination of the inherent natural variability and complex atmospheric conditions. The sensitivity of this test to detect small trends is as crucial as its ability to discern significant directional changes, with both factors contributing to challenges in identifying clear trends in the data. Marak *et al.* (2020) employed the ITA methodology to examine patterns in low, medium, and high precipitation levels in Meghalaya, India. Patel *et al.* (2023) also employed ITA to examine temperature pattern in West Bengal. Their findings suggest that the ITA method demonstrates more sensitive performance compared to the MK test in detecting trends across different categories.

5. Conclusions

This study examines a comprehensive analysis of seasonal and annual rainfall trends at a grid-based meteorological scale for West Bengal. Using a large dataset from 121 grid stations in a period of 115 years from 1901 to 2015, the aim is to show the complex pattern of rainfall dynamics in the region. Analysis of long-term rainfall trends reveals significant spatial and temporal variations in both annual and seasonal rainfall in West Bengal. However, the methodological approach plays an important role in the quality of the findings. The widely used Mann-Kendall method does not provide satisfactory results compared to Innovative Trend Analysis (ITA) while identifying trends at a 5% significance level. The key remarks are given below:-

(*i*) ITA has emerged as a reliable and sensitive tool showing superior performance in identifying trends in different seasons such as winter, pre-monsoon, monsoon, and post-monsoon.

(*ii*) A comparative analysis between Mann-Kendall and ITA reveals a significant difference in the significance test, indicating that ITA has greater sensitivity and a more nuanced understanding of hydro-meteorological patterns.

(*iii*) The adaptation of ITA to identify trends due to its superior sensitivity offers a comprehensive and accurate description of rainfall trends.

In conclusion, this study highlights the importance of methodological choices in trend analysis, with ITA emerging as a preferred tool for reliable performance. The comprehensive insights gained by ITA not only improve our understanding of rainfall trends in West Bengal but also provide a valuable basis for devising effective strategies to combat the hydro-meteorological landscape. This research makes a significant contribution to the broader conversation about the impacts of climate change and highlights the importance of using advanced analytical tools to identify trends in complex environmental systems.

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References

Amiri, M.A. and Gocić, M., 2021, "Innovative trend analysis of annual precipitation in Serbia during 1946-2019", *Environ. Earth Sci.*, **80**, 777, 1-15.

Anil, S. and Raj, P. A., 2022, "Deciphering the projected changes in CMIP-6 based precipitation simulations over the Krishna River Basin", *J. Water Clim. Chang.*, **13**, 3, 1389-1407.

Buri, E. S., Keesara, V. R., Loukika, K. N. and Sridhar, V., 2022, "Spatio-Temporal Analysis of Climatic Variables in the Munneru River Basin, India, Using NEX-GDDP Data and the REA Approach", *Sustainability*, **14,** 3, 1715.

Chakraborty, S., Chowdhury, B. R., Ghosh, S., Sen, P. K., De, U. K., 2019, "Statistical analysis of urban regional pre-monsoon rainfall in and around Kolkata, India", *J. Earth Syst. Sci.*, **128**, 57.

Cook, B. I., Smerdon, J. E., Seager, R. and Coats, S., 2014, "Global warming and 21st century drying", *Clim. Dyn.*, **43**, 2607-2627.

Das, J., Mandal, T., Rahman, A.T.M.S. and Saha, P., 2021, "Spatio-temporal characterization of rainfall in Bangladesh: an innovative trend and discrete wavelet transformation approaches", *Theor. Appl. Climatol.*, **143**, 1557-1579.

Dash, S. and Maity, R., 2019, "Temporal evolution of precipitation-based climate change indices across India: contrast between pre- and post-1975 features", *Theor. Appl. Climatol.*, **138**, 1667-1678.

Ghosh, K.G., 2018, "Analysis of Rainfall Trends and its Spatial Patterns During the Last Century over the Gangetic West Bengal, Eastern India", *J. Geovis. Spat. Anal.*, **2**, 15.

Halder, S., Das, S. and Basu, S., 2022, "Extreme rainfall pattern analysis for drought prone Shali reservoir area in West Bengal of India", *MAUSAM*, **73**, 4, 843-858.

Halder, P., Dey, R. K., Mandal, S., 2023, "Long-period trend analysis of annual and seasonal rainfall in West Bengal, India (1901–2020)", *Theor. Appl. Climatol*., **154**, 685-703.

Hamed, K.H., 2008, "Trend detection in hydrologic data: The Mann–Kendall trend test under the scaling hypothesis", *J. Hydrol*., **349**, 3-4, 350-363.

Hamed, K. H. and Rao, A. R., 1998, "A modified Mann-Kendall trend test for autocorrelated data" *J. Hydrol.*, **204**, 1-4, 182-196.

IPCC, 2021, "Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change", [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press

Kendall, M. G., 1938, "A New Measure of Rank Correlation", *Biometrika*, **30**, 1/2, 81-93.

Kundu, S.K. and Mondal, T.K., 2019, "Analysis of long-term rainfall trends and change point in West Bengal, India", *Theor. Appl. Climatol.***138**, 1647–1666.

Mann, H. B., 1945, "Nonparametric Tests Against Trend", *Econometrica*, **13**, 3, 245-259.

Malik, A., Kumar, A., Guhathakurta, P. and Kisi, O., 2019, "Spatial-temporal trend analysis of seasonal and annual rainfall (1966–2015) using innovative trend analysis method with significance test", *Arab. J. Geosci.*, **12**, 328.

Marak, J. D. K., Sarma, A. K. and Bhattacharjya, R. K., 2020, "Innovative trend analysis of spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India", *Theor. Appl. Climatol.*, **142**, 1397-1412.

Myhre, G., Alterskjær, K., Stjern, C.W.,*et al*., 2019, "Frequency of extreme precipitation increases extensively with event rareness under global warming", *Sci. Rep.*, **9**, 16063.

Narayanan, P., Sarkar, S., Basistha, A. and Sachdeva, K., 2016, "Trend analysis and forecast of pre-monsoon rainfall over India", *Weather*, **71**, 4, 94-99.

Naskar, P. R., 2022, "Variations in rainfall, temperatures and thunderstorm over Kolkata (India) in recent decades", *MAUSAM*, **73**, 1, 193-202.

Pai, D. S., Rajeevan, M., Sreejith, O. P., Mukhopadhyay, B. and Satbha, N. S., 2014, " Development of a new high spatial resolution (0.25° × 0.25°) long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region", *MAUSAM*, **65**, 1, 1-18.

Patel, G., Das, R. and Das, S., 2023, "Is the extreme temperature trend changed in last two decades compared to last seven decades? Case study from Eastern India", *J. Earth Syst. Sci*.,**132(3)**, 140.

Patel, G., Das, S. and Das, R., 2024, "Determine the best method for analysing long-term (120 years) annual and seasonal rainfall trends in four east India river basins", *J. Earth Syst. Sci*.,**133(2)**, 70.

Saikh, N. I., Saha, S., Sarkar, D., Mondal, P., 2023,"Rainfall trend and variability analysis of the past 119 (1901-2019) years using statistical techniques:A case study of Kolkata, India", *MAUSAM*, **74**, 4, 1193-1112.

Sen, P. K., 1968, "Estimates of the regression coefficient based on Kendall's tau", *J. Am. Stat. Assoc.*, **63**, 324, 1379-1389.

Şen, Z., 2012, "Innovative trend analysis methodology", *J. Hydrol. Eng.*, **17**, 9, 1042-1046.

Şen, Z., 2017, "Innovative trend significance test and applications", *Theor. Appl. Climatol.*, **127**, 939-947.

P Z, S., K V, J., 2021, "Comparative study of innovative trend analysis technique with Mann-Kendall tests for extreme rainfall", *Arab. J. Geosci*.,**14**, 536.

Singh, R., Sah, S., Das, B., Potekar, S., Chaudhary, A. and Pathak, H., 2021, "Innovative trend analysis of spatio-temporal variations of rainfall in India during 1901-2019", *Theor. Appl. Climatol.*, **145,** 821-838.

Swain, S., Mishra, S. K., Pandey, A. and Dayal, D., 2022, "Spatiotemporal assessment of precipitation variability, seasonality, and extreme characteristics over a Himalayan catchment", *Theor. Appl. Climatol.*, **147**, 817-833.

Trenberth, K.E., 2011, ”Changes in precipitation with climate change", *Clim. Res.*, **47**, 123-138.