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RESEARCH ARTICLE

Detection of rainfall trends using non-parametric method in the Himalayan Region of Sikkim, India in past 121 years

Mannu Wangsu[1*] and Salil K. Shrivastava[2]

Abstract

Changes in the timing and distribution of rainfall such as large rainfall events and unpredictable or delayed precipitation can seriously reduce agricultural output. These changes in rainfall patterns can lead to flooding or long-term water scarcity destroying livelihoods and property. Communities may therefore become more vulnerable, hence it is crucial to apply adaption strategies supporting local resilience and sustainable development. Using a high-resolution daily gridded dataset from the India meteorological department, the susceptibility of the study area to climate change was fully investigated spanning the years 1901–2021. The study area includes four districts viz. East, West, North, and South Sikkim. At a 5% significance level, pre-monsoon rainfall had showed significant increase in all districts except East Sikkim whereas monsoon rainfall sharply decreased. Throughout the study, the rainfall time series trend shift points were also found using the SQMK test. Maps showing the regional geographical variations in rainfall trend changes also produced by employing the interpolation technique known as inverse distance weighted (IDW). This research provides an in-depth understanding of the primary rainfall distribution patterns in relation to climate change, which will assist the state's resource planners in making informed decisions, developing mitigation strategies, and implementing water management practices for sustainable agriculture.

Keywords: Gridded data, Temporal and spatial change, SQMK test, Trend detection, Climate adaptation, Sikkim.

Introduction

The changes in several meteorological events might have a significant influence and disturb the possible agricultural yield, so causing social unrest in a specific region (Rahman *et al.*, 2017). Mukhopadhyay *et al.*, (2016) claim that most people agree climate change is the most significant global occurrence. Rising temperatures, glacier melting, extreme rainfall (drought and floods), agricultural food grains, and water resource management influence human lives as well as the worldwide biosphere (Kumar and Gautam 2014). Particularly in rainfed agricultural systems, rainfall is crucial, hence susceptible changes in climate have greatly affected farming with little adaptive ability (Lewis *et al.,* 2018). The fact that monsoon rainfall which accounts for 80% of all precipitation defines India's whole agricultural output, therefore influencing the country's economy. India's summer monsoon season gets the greatest rainfall; other seasons get the least. Any variation in the monsoon rainfall could significantly impact the overall condition of the country, water resource management, and agricultural productivity (Jain *et al.,* 2013). To evaluate the amount of water available to fit a range of purposes, including hydropower generation, agriculture, and the provision of water for households and businesses, it is therefore necessary to investigate the rainfall and how it varies with a region's changing climate. A trend analysis helps investigate the underlying long-term trends, variability, and probable changes over time in hydro-meteorological variables (Gajbhiyee *et al.*, 2016) at both temporal and spatial dimensions. Statistical tests, generally divided into parametric and non-parametric categories, are employed to identify trends in climate variables. In a non-parametric test, it is assumed that the data is normally distributed and is free from outliers (Bandyopadhyay *et al.,* 2011). Contrarily, parametric tests assume a specific data distribution. Numerous global studies have utilized Sen's slope method, modified Mann-Kendall test, and non-parametric Mann-Kendall test to examine the geographical and temporal patterns, along with their magnitude in long-term rainfall data (Sabziparvar and Shadmani 2011;

Department of Agricultural Engineering, North-Eastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh, India.

***Corresponding Author:** Mannu Wangsu, Department of Agricultural Engineering, North-Eastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh, India, E-Mail: mwangsu1990@gmail.com

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Choudhury *et al.,* 2012; Yang *et al.,* 2012; Chen *et al.,* 2014; Bari *et al.,* 2016; Khatiwada *et al.,* 2016; Chang *et al.,* 2018; Malik and Kumar 2020; Gadedjisso *et al.,* 2021; Singh *et al.*, 2020; Sah *et al.*, 2021). But there aren't many studies in Inida's North-Eastern Region (NER) (Oza and Kishtawal 2014; Bhagawati *et al.,* 2016; Deka *et al.,* 2016; Bora *et al.,* 2022; Gogoi and Rao 2022; Kakkar *et al.,* 2022; Singh and Kumar 2022; Kumar *et al.,* 2023). Depending on their geographic diversity, different locations experience different impacts from changes in the climate (Hamilton *et al.,* 2001). According to Bernard (2017) and Tse-ring *et al.,* (2010), even little changes in rainfall and temperature can negatively impact mountain ecosystems and increase the chances of adverse outcomes. of landslides, floods, and droughts. High susceptibility to climate change impacts (Immerzeel *et al.,* 2020). The bulk of rural residents (more than 80%) in states that rely heavily on agricultural and forest products for their livelihoods, such as Sikkim. In Sikkim, around 20% of the land is used for irrigation, where 98% of the water is used (Government of Sikkim, 2012). The state is recognized for its wealth of water resources, owing to its unique geographical setting and terrain. Despite the state's abundance of water resources, adequate conservation and management have been lacking, which has led to a growing demand for more sustainable management techniques to guarantee the state's resources are used wisely and preserved. Since the state is a popular tourist destination (Rai and Rai, 1994), water pressure rises during the busiest seasons of the year since dryness and moisture stress throughout the winter months results. If a trend study is done, investigating how the patterns of climatological variables especially precipitation have changed over time on both a temporal and spatial level will be easier. Given its varied heights and low coverage of meteorological stations, the state is more vulnerable and so this is very crucial for it. This study aimed to address existing research gaps and provide an in-depth understanding of likely consequences of climate change on rainfall patterns in the future. The present work focuses on examining rainfall trends in order to evaluate the distribution of rainfall among sites that have undergone increases or declines over time. The aim of the present work is to understand the temporal and spatial fluctuations in rainfall over the research area over the past 121 years. Pai *et al.,* (2014) created high-resolution gridded dataset based on IMD daily data, to examine the patterns of seasonal and annual rainfall, along with change points, for the entire Sikkim region between 1901 and 2021. The following website provides the rainfall data, which is accessible free of charge and can be downloaded (http://www.imdpune.gov.in/).

The following objectives were thoroughly analyzed in order to conduct the current study:

- To assess rainfall trends in different districts of Sikkim during 1901-2021 using non-parametric methods.
- To create a spatial rainfall trend map for the years 1901–2021.

Study area and data

Approximately seventy percent (70%) of Sikkim's residents rely on agricultural products and forests for their livelihood. Its entire area is about 7096 square kilometers in size. Mostly found between longitude 88.6065° E and latitude 27.3389° N. With heights extending from 300 to 6000 m above sea level, the area gets 2000 to 4000 mm of average precipitation (Shukla *et al.,* 2018). Monsoon rainfall for the state is rather high, which is required for agricultural output. The state's unique topography and temperature cause a variety in rainfall. But erratic rainfall patterns and climate change threaten Sikkim's agricultural viability (Sharma *et al.,* 2016). The state is comprised of four districts and were examined for rainfall variation as shown in Fig. 1. Subsequently the daily rainfall data was compiled into seasonal and annual series, which then categorized into the pre-monsoon, monsoon, post-monsoon, and winter seasons.

Methodology

Autocorrelation

Serial correlation in long-term datasets can substantially affect the outcomes of trend analyses (Yue and Wang, 2004) (Fig. 2). A non-parametric correlation test was performed to detect significant correlations within the data. The serial correlation coefficient at lag(k), as described by Pandey *et al.* (2019), was utilized to assess serial correlation. The following formula is used to verify serial correlation:

$$\tilde{n}=\frac{\frac{1}{n-1}\sum_{i=1}^{n-1}\left(x_i-e(x)\right)\left(x_{i+1}-e(x)\right)}{\frac{1}{n}\sum_{i=1}^{n}\left(X_i-e(x)\right)^2} \tag{1}$$

where $e(x)=\frac{1}{n}\sum_{i=1}^{n}X_i$ denotes the mean, and n represent size of the sample. A significance test is performed autocorrelation coefficient (ρ) at lag(1). The following lists the one-tailed test's probability limitations for an independent series on the correlogram.

$$\rho=\left\{\begin{matrix}\frac{-1+1.645\sqrt{n-2}}{n-1}\\ \frac{-1\pm1.645\sqrt{n-2}}{n-1}\end{matrix}\right\} \tag{2}$$

n is the size of the dataset

When the value of ρ falls inside the confidence interval, the data is considered to be free from of serial correlation. Alternatively, the dataset is assumed to exhibit serial correlation if ρ lies outside the specified range. A 95% confidence level (CL) was applied in this study to check for serial correlation at lag(1)

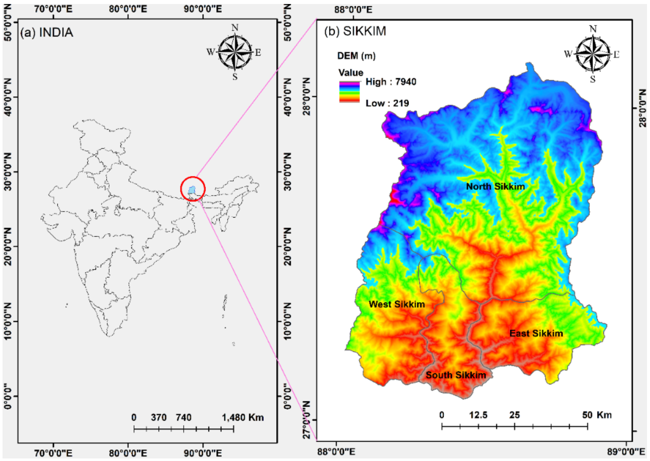

Fig. 1: Study area location map

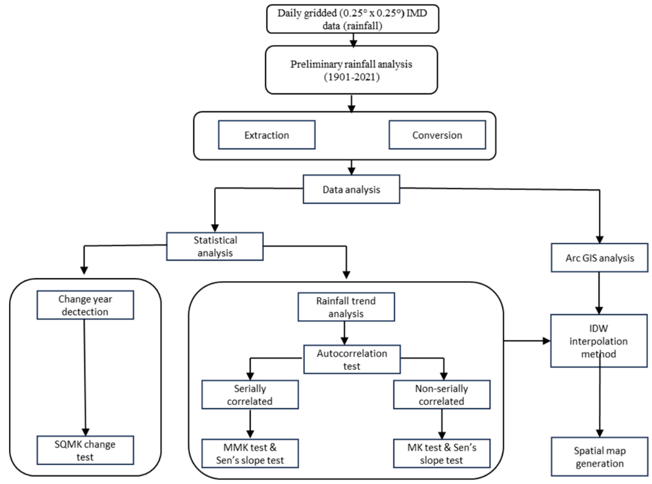

Fig 2: Methodology sequence for rainfall trend analysis

Detection of trends

Mann and Kendall (1945 and 1975) developed the Mann-Kendall (MK) method to detect trends in long-term time series data. Several research have found monotonic trends in a variety of climatic variables (Luwangleima and Shrivastava 2019; Das *et al.,* 2021). Since the time series data is free from outliers, it is considered as the most reliable and simple technique for trend analysis (Hess *et al.,* 2001; Chen *et al.,* 2007; Hejam, 2008; Shahid 2010; Suhaila *et al.,* 2011). The null hypothesis suggests the absence of a trend, whereas the alternative hypothesis indicates the existence of a monotonic trend (upward or downward). The modified Mann-Kendall test, on the other hand, was suggested by Yue and Wang (2004) and Hamed and Rao (1998) minimized the influence of serial correlation on trend outcomes.

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{3}$$

Where, n is the number of data points, xi and xj are sequential data,

Var (S) variance can be computed using the formula below:

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \tag{4}$$

t represents tied group and t_k is the number of data points. The $_{Zmk}$ statistic is computed as given below:

$$z_{mk} = \begin{cases} \dfrac{s-1}{\sqrt{Va(s)}} & s > 0 \\ 0 & s = 0 \\ \dfrac{s+1}{\sqrt{Var(s)}} & s < 0 \end{cases} \tag{5}$$

Positive(rising) and negative(falling) $_{Zmk}$ values denotes an increasing/decreasing trend.

Sen's slope

Widely used Sen's slope (Theil 1950 and Sen 1968) was used to calculate the rate of change in magnitude. Numerous studies (Hejam 2008; Lu *et al.*, 2016; Gurara *et al.,* 2022) have used this approach. Sen's slope is calculated using the equation (6):

$$q_i = \frac{x_j - x_k}{j-k} \quad for \quad i = 1, 2, \ldots\ldots\ldots\ldots n, j > k \tag{6}$$

q_i is Sen's slope estimator and *n* is the values of data

SQMK trend change

The Sequential Mann-Kendall (SQMK) test was employed to the time series to identify significant change points. The SQMK test calculates the $U_{(t_i)}$ statistic as the forward series while, for the backward series, starting from the end of the data series $U'_{(t_i)}$. The formula shown below is used to calculate $U_{(t_i)}$ and $U'_{(t_i)}$ statics:

$$U_{(t_i)} = \frac{[t_i - E(t_i)]}{\sqrt{V_{t_i}}} \tag{7}$$

$$U'_{(t_i)} = -\frac{\sum t'_i - E'(t_i)}{\sqrt{V'(t_i)}} \tag{8}$$

A graphic representation of the two consecutive numbers U and U′ above will be created to show the various data changes. The point where the retrograde and prograde series meet indicates the potential change point in the time series. If the prograde curve crosses the significant range, trend (positive/negative) is considered significant. On the other hand, if the prograde and retrograde curves overlap at many locations or cross inside the significant range it shows no significant trend (Alijani *et al.,* 2011; Das *et al.,* 2021).

Results And Discussion

Using the autocorrelation test at lag(1), the p-value (±0.1727) was investigated. To further assess serial correlation, lag(10) and lag(15) Ljung-Box tests were conducted on the time series data (Table 1). A 95% confidence level was used, corresponding to a significance threshold of 0.05. The study found that serial correlation was present in the p-values for the pre-monsoon, monsoon, and annual seasons across all four districts, except for East Sikkim during the winter season. With p-values < 0.05, serial correlation was observed in all districts, except East Sikkim in winter in the lag(1) Ljung-Box test. These findings agreed with the autocorrelation results. In contrast, the lag(10) and lag(15) Ljung-Box tests showed outcomes that contradicted the autocorrelation findings (Fig. 3). To detect significant trends in the time series, the MK and m-MK tests were used. Additionally, the temporal change point for the 121-year period across the four districts of Sikkim was determined using the SQMK method. All tests were conducted at a significant level at 5%.

East Sikkim

Table 2 provide the summary of the findings, the pre-monsoon and annual seasons in Sikkim demonstrated the strongest statistically significant rising trends in 1901–2021 when compared to the other three districts. The findings coincide with those of Sathyanathan *et al.,* (2020), it is obvious that pre-monsoon season developing trend. Based on Sen's slope value, East Sikkim recorded the highest annual rainfall slope value of 3.63 mm per year. Additionally, Figs. 4(a-e) present the graphical representation of the SQMK test results for rainfall patterns in East Sikkim district. Figs. 4(a), 4(c), and 4(d) demonstrate that the rainfall data showed no trend during the winter, monsoon, and post-monsoon seasons, as the prograde and retrograde curves consistently overlapped within the significance threshold (±1.96). Beginning in 2001, the two curves crossed each other in the pre-monsoon season (Fig. 4(b)). Having exceeded the relevant range (±1.96), the U curve displayed a statistically significant growing trend. Likewise, Fig. 4(e) displays a rising trend during the years 1983, 1986, 1987, 1992, and 1993 when the two curves in the annual series crossed inside the significant range. Since the U curve exceeded the critical threshold (±1.96), there has been a noticeable acceleration in the rainfall pattern. Overall, the results generally indicate a clear increasing trend in East Sikkim district rainfall over the period from 1901-2021.

North Sikkim

Table 2 presents the results of the Sen's slope, MK and m-MK tests at a 5% significance level. The table reveals a significant downward trend in the monsoon season, while the winter, pre-monsoon, and post-monsoon seasons exhibited significant upward significant trends. At 5% significance level, the monsoon season recorded a significant decreasing slope of -4.68 mm per year whereas, the pre-monsoon season experienced a significant rising slope of 2.62 mm per year. Two curves, U and U′ crossed each other in the short years 1981, 1982, and 1983 as Fig. 5(a) indicates, hence it can be said that the trend started from these points in time series. Showing a statistically significant upward (increasing) trend, the U curve has beyond the significant range (±1.96). Fig. 5(b) clearly shows that a notable shift took place about 2004. The two curves have crossed outside the significant level (±1.96), suggesting the presence of significant upward trend. The SQMK test results indicate that the monsoon and post-monsoon seasons exhibited comparable shift points in the years 1985, 1987, 1989, 2007, and 2008. It implies that the tendency of the present started in these years. With changes occurring in a little period of time (1907, 1909, 1920 & 2020), the SQMK test results for annual series point to no clear trend. since the significance range has overlapped the prograde and retrograde curves Fig. 5(e).

South Sikkim

For the South Sikkim, the trend study reveals an increasing trend at 5% significant level in the winter, pre-monsoon and post-monsoon seasons, while the monsoon season exhibits a clear downward trend over the study period (1901–2021). Similar findings were also obtained by Sathyanathan R *et al.,* (2020). Measuring 2.01 mm per year, the pre-monsoon season revealed the steepest Sen slope, while the monsoon season recorded a slope of -3.54 mm per year. In Figs. 6(a-e) display the SQMK test graphs for the rainfall time series, both annually and seasonally. The results indicate a single change point in 2003 for the pre-monsoon series, implying a strong rising trend. The U curve's deviation from the significance range (±1.96) results in several change points observed across the winter, monsoon, post-monsoon, and annual seasons.

West Sikkim

The monotonic trend results of the West Sikkim district revealed statistically significant rising trends in winter and

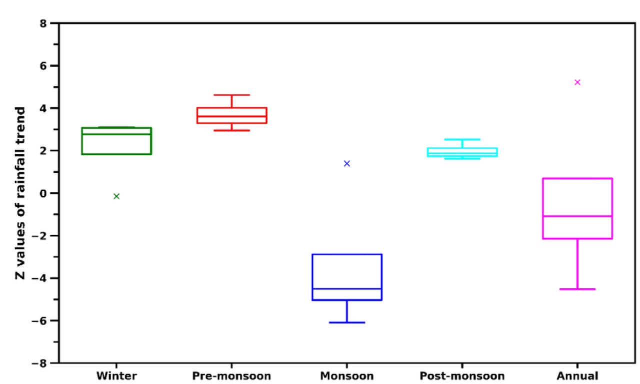

Fig. 3: Box plots illustrating the Z values for seasonal and annual trends in Sikkim

Table 1: Tests for serial correlation

District	Serial correlation lag(1)					Ljung-Box Tests lag(10)					Ljung-Box Tests lag(15)				
	Winter	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Annual*	*Winter*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Annual*	*Winter*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Annual*
East Sikkim	0.07	0.26	0.18	-0.04	0.21	0.99	< 2.20e-16	0.69	0.45	1.87e-03	0.97	< 2.20e-16	0.78	0.38	0.01
West Sikkim	0.26	0.47	0.59	-0.03	0.43	1.20E-06	< 2.20e-16	< 2.20e-16	0.36	1.22e-11	1.16e-06	< 2.20e-16	< 2.20e-16	0.12	3.08e-10
North Sikkim	0.33	0.53	0.55	-0.02	0.33	1.75E-14	< 2.20e-16	< 2.20e-16	0.52	8.76e-06	2.24e-14	< 2.20e-16	< 2.20e-16	0.31	1.94e-05
South Sikkim	0.22	0.48	0.40	-0.04	0.23	0.01	< 2.20e-16	2.37e-09	0.46	0.04	0.01	< 2.20e-16	1.62e-08	0.26	0.08

Note: Numbers in bold are serially correlated

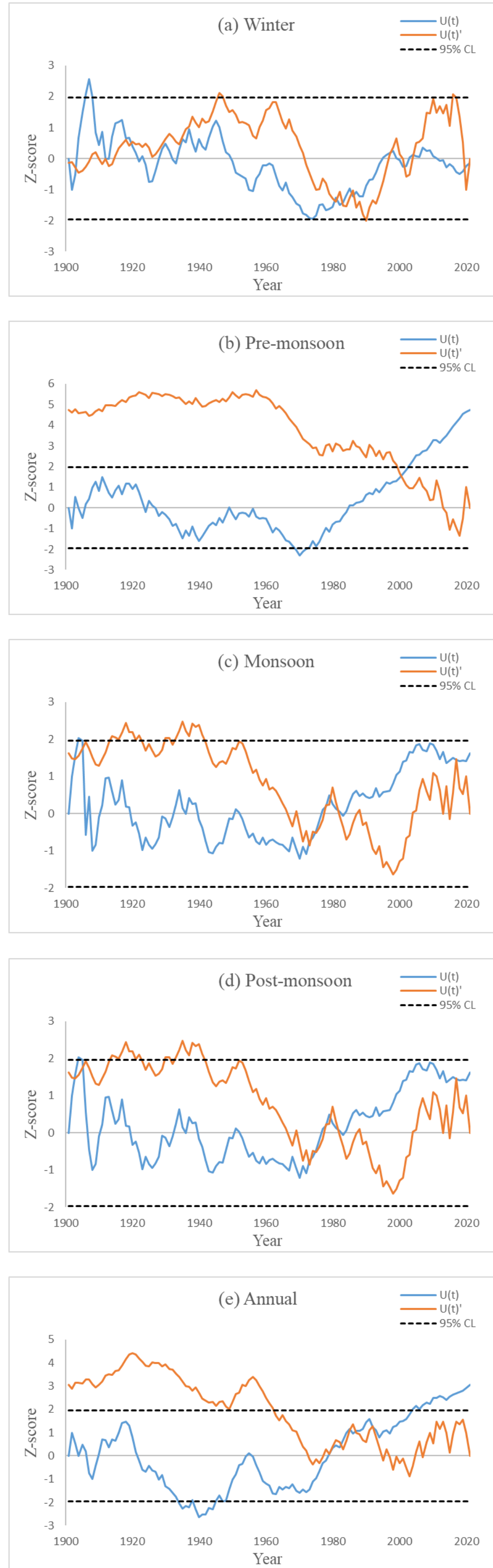

Fig. 4: Change point analysis for rainfall in East Sikkim district using SQMK (a-e).

Table 2: Outcomes of the Sen's slope (Q) and MK/m-MK (Z) tests for different districts in Sikkim districts.

Districts	*Tests*	*Winter*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Annual*
East Sikkim	MK/m-MK (Z)	-0.14	4.61$^{\uparrow}$	1.39	1.62	5.22$^{\uparrow}$
	Sen's slope (Q, mm per year)	-0.01	1.73	1.26	0.38	3.63
North Sikkim	MK/m-MK (Z)	3.07$^{\uparrow}$	3.80$^{\uparrow}$	-4.68$^{\downarrow}$	2.53$^{\uparrow}$	-1.35
	Sen's slope (Q, mm per year)	0.31	2.63	-4.68	0.57	-0.84
South Sikkim	MK/m-MK (Z)	2.48$^{\uparrow}$	3.42$^{\uparrow}$	-4.32$^{\downarrow}$	1.97$^{\uparrow}$	-0.83
	Sen's slope (Q, mm per year)	0.14	2.01	-3.54	0.45	-0.45
West Sikkim	MK/m-MK (Z)	3.09$^{\uparrow}$	2.95$^{\uparrow}$	-6.09$^{\downarrow}$	1.77	-4.52$^{\downarrow}$
	Sen's slope (Q, mm per year)	0.21	1.81	-6.26	0.38	-3.75

Note: statistically significant trends are indicated in bold at 5% significance level
Legends: ↑: denotes an upward trend, ↓: denotes a downward trend

Fig. 5: Change point analysis for rainfall in North Sikkim district using SQMK (a-e)

pre-monsoon seasons. A similar trend was also observed by Chakma and Biswas (2022). West Sikkim showed the most marked drop in both the monsoon and annual seasons among the other Sikkim districts. This reveals regional variations in rainfall trend and indicates that the West Sikkim area has benefited much from changing climatic patterns.

The maximum Sen slope of 1.81 mm per year occurred during the pre-monsoon season, then followed by -3.74 mm per year; the annual series showed the sharpest dropping Sen slope. Figs. 7(a–e) show seasonal and annual rainfall time series SQMK testing. Clearly, there was just one shift point for the winter season in 1987 and for the pre-monsoon

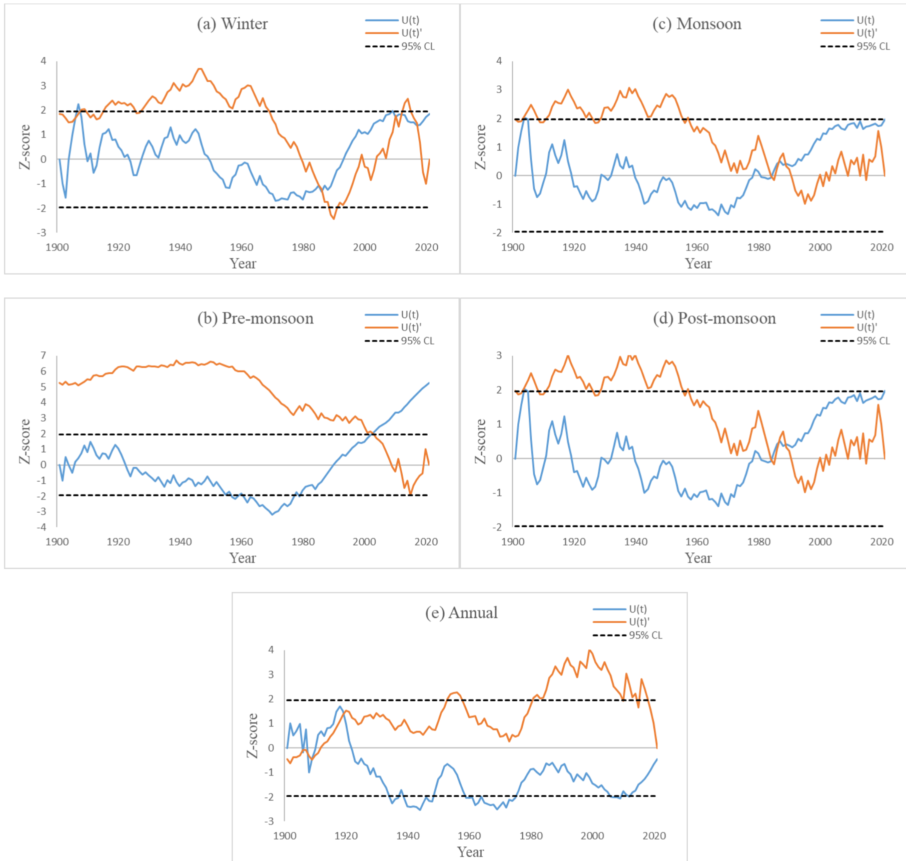

Fig. 6: Change point analysis for rainfall in South Sikkim district using SQMK (a-e)

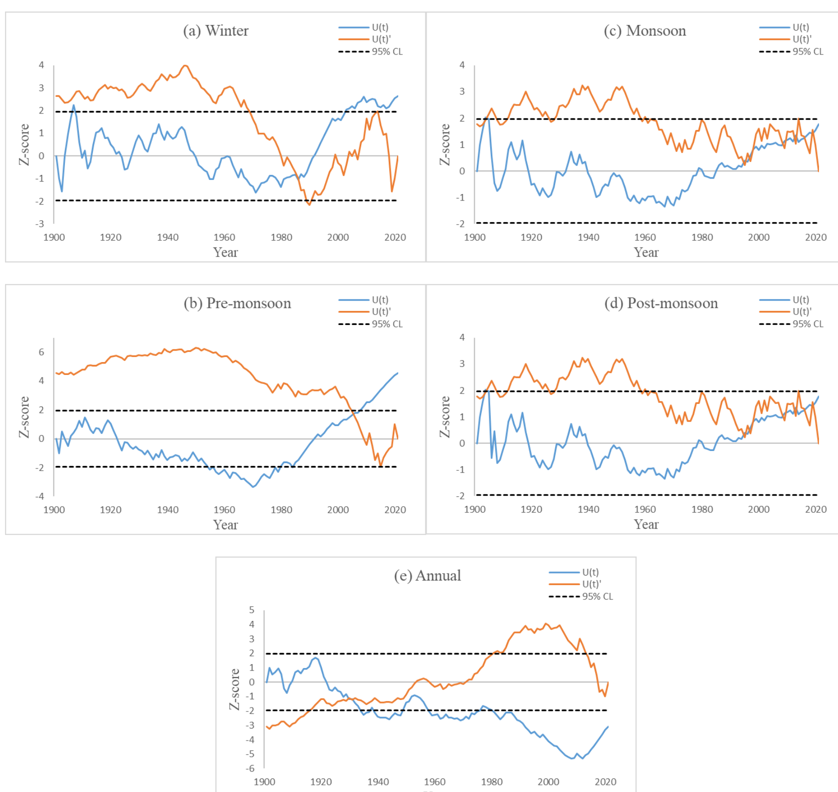

Fig. 7: Change point analysis for rainfall in West Sikkim district using SQMK (a-e).

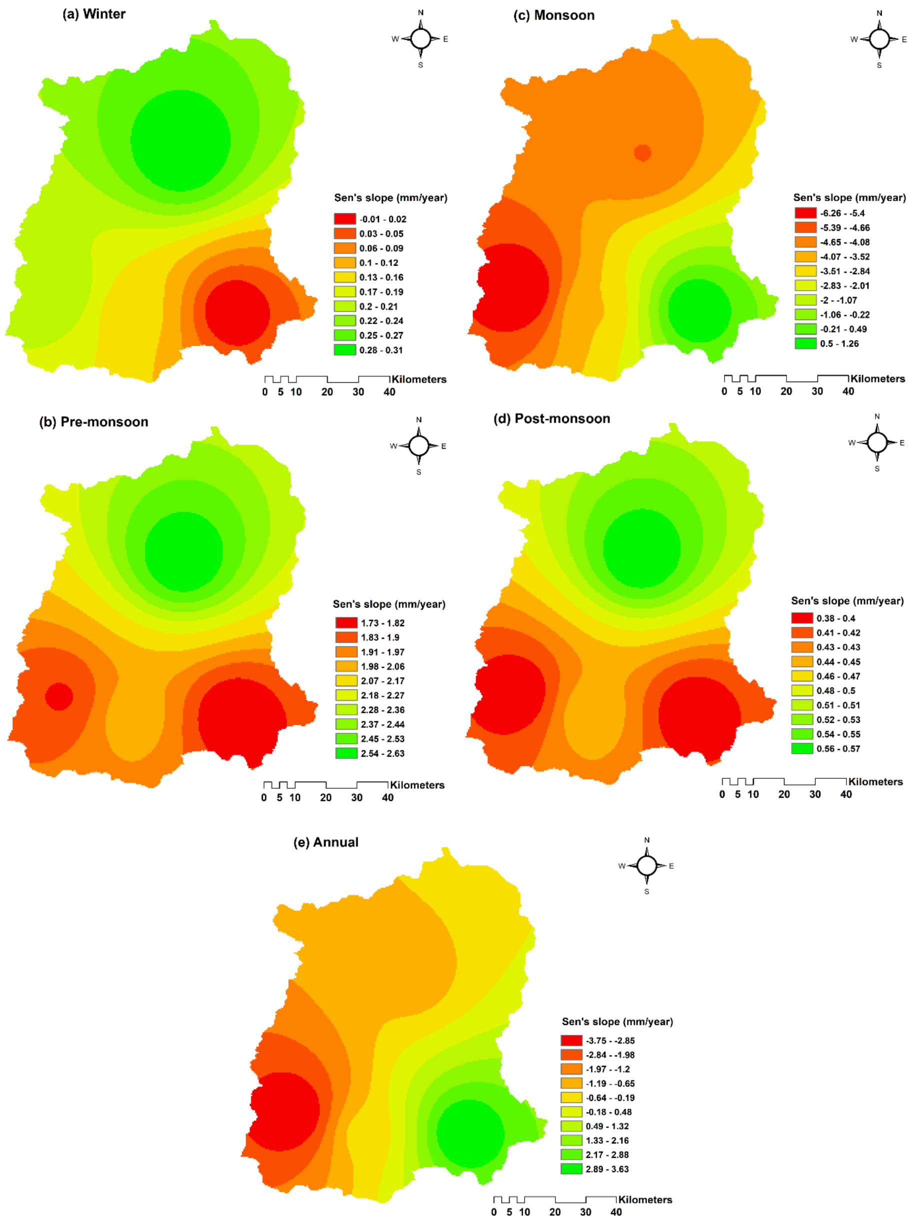

Fig. 8: Sen's slope spatially distributed

season in 2006, pointing to a clear rising trend. Because of the deviation of the U curve from the significant range (±1.96). Several transition spots in the monsoon and post-monsoon seasons (Fig. 7c&d). The two curves in the annual rainfall series crossed in 1930, 1931, and 1932; the U curve indicates the occurrence of an increasing negative trend and exceeds the significant threshold (±1.96). Usually, the trend started during these years.

Spatial variability of rainfall analysis

The spatial fluctuations in the rainfall patterns across the study area were investigated using an inverse distance weighted (IDW) interpolation technique (Kumar and kumar 2020; Rana *et al.,* 2022; Paradkar and Mittal 2024). Figs. 8(a-e) illustrate the slope maps for annual and seasonal rainfall. These maps provide crucial information that offers valuable insights for enhancing water resources and future water forecast.

Conclusion

In a state like Sikkim, where about 80% of the population depends largely on spring water for activities including drinking, industry, and agriculture, climate change may lead to changes in precipitation patterns. Comprehensive knowledge of climate change impacts will help to resolve the water-related challenges in the state by means of crucial information on the amount of rainfall received and the distribution of water resources in the study area. The temporal fluctuations in annual and seasonal rainfall over Sikkim for 121 years were investigated using Sen's slope estimator and the MK/m-MK approaches. Apart from East Sikkim district, the trend analysis showed on a seasonal basis that pre-monsoon rainfall was increasing in all districts at the 5% significance level, but monsoon rainfall was sharply dropping in most of the districts. Therefore, it is evident that the state has lately experienced less rainfall, which would suggest that catastrophic natural events like droughts are occurring more often. According to the SQMK study, most of the districts displayed trend changes in the late 1980s, early 1900s, and 2000s, respectively. These findings provide planners and farmers with vital knowledge on the changing rainfall patterns of the state, which enables them to develop workable strategies for better water management in view of climate change.

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