Trend, Variability, Change-Point Analysis and SARIMA-Based Forecasting of Rainfall and Temperature in Northeastern Bangladesh

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ABSTRACT

This study investigates the long-term variability, trend, and change-point characteristics of rainfall and temperature in the Sylhet and Sreemangal regions of northeastern Bangladesh using observed data from 1990 to 2024. The analysis incorporates descriptive statistics, the Pettitt test for change-point detection, autocorrelation analysis, and the Mann–Kendall (MK) and Modified Mann–Kendall (MMK) tests for trend assessment, along with Sen's slope estimator to quantify trend magnitude. Results show strong seasonal variability, with peak rainfall occurring during the monsoon season, while temperature exhibits a clear annual cycle with relatively stable variability. Pettitt test results indicate multiple structural shifts in both rainfall and temperature, with more significant and consistent breakpoints in temperature around 2015–2016, suggesting the onset of a persistent warming phase. Autocorrelation analysis reveals weak and insignificant serial dependence in rainfall but strong positive autocorrelation in temperature, justifying the use of MMK for temperature trend detection. Trend analysis demonstrates that rainfall patterns are largely non-significant and irregular, whereas temperature shows statistically significant increasing trends across multiple months and seasons, indicating consistent warming in the region. Furthermore, SARIMA-based forecasting suggests the continuation of seasonal patterns in both rainfall and temperature for the period 2025–2034, with increasing uncertainty over time. Overall, the findings highlight an asymmetric climatic response characterized by stable rainfall but significant warming, which has important implications for water resources, agriculture, and climate adaptation strategies in northeastern Bangladesh.

Key Words: Rainfall variability; Temperature trends; Change-point detection; Pettitt & Mann–Kendall test; SARIMA forecasting.

1. INTRODUCTION

Bangladesh is recognized as one of the most climate-sensitive countries in the world due to its geographical location, monsoon-dominated climate, dense population, and dependence on climate-sensitive sectors such as agriculture and water resources **[1].** Variations in rainfall and temperature significantly influence the hydrological cycle, crop production, ecosystem stability, and socio-economic activities throughout the country. In recent decades, increasing climate variability and global warming have altered regional climatic characteristics, resulting in irregular rainfall distribution, rising temperatures, prolonged dry periods, and extreme weather events. These climatic changes are particularly important in northeastern Bangladesh, where both natural ecosystems and human livelihoods are highly dependent on seasonal rainfall and temperature patterns.

The Sylhet region, located in northeastern Bangladesh, possesses unique physiographic and climatic characteristics that distinguish it from other parts of the country. The region consists of numerous hills and hillocks locally known as tilas, extensive wetlands or haors, and high floodplains. Parts of the foothills of the Meghalaya Plateau extend into this region, contributing to its complex topography and high rainfall variability. Several important rivers, including the Surma and Kushiyara, flow through Sylhet after originating from the Barak River system in India. These rivers later merge with the Meghna River before draining into the Bay of Bengal. Due to its topographic setting and exposure to moisture-laden monsoon winds, Sylhet receives some of the highest annual rainfall totals in Bangladesh and frequently experiences flooding and waterlogging during the monsoon season. Sreemangal, another important area within the region, is well known for its tea gardens, forest ecosystems, and comparatively lower temperatures during winter. The climatic conditions of these areas strongly influence agriculture, fisheries, wetlands, biodiversity, and local livelihoods.

Bangladesh experiences four major meteorological seasons: pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February). The pre-monsoon season is characterized by high temperatures and convective rainfall, while the monsoon season contributes more than 70% of the country's annual rainfall. Post-monsoon acts as a transitional period between the wet monsoon and dry winter seasons. Winter is generally cool and dry, with very limited rainfall. Seasonal rainfall and temperature variability across Bangladesh are controlled by large-scale atmospheric circulation, monsoon dynamics, local topography, and land–atmosphere interactions (bmd met-report). However, recent climate studies indicate increasing irregularities in seasonal rainfall patterns and continuous warming trends across South Asia, including Bangladesh. Changes in rainfall intensity, shifting monsoon onset, and rising temperatures have become major concerns for climate researchers and policymakers **[2]**.

Rainfall and temperature are among the most important climatic variables used to assess climate variability and climate change. Previous studies reported that global warming has intensified the hydrological cycle, leading to fluctuations in rainfall frequency, intensity, and distribution. Increasing temperature trends have also been observed in many tropical and subtropical regions. In Bangladesh, several studies have identified increasing temperature trends and irregular rainfall variability, which directly affect agricultural productivity, water availability, flood occurrence, and ecosystem sustainability. Although national-scale climate assessments are common, regional analyses remain limited, particularly for northeastern Bangladesh, where topographic complexity and monsoon influences create localized climatic behavior. Therefore, understanding long-term climatic trends and variability in Sylhet and Sreemangal is essential for climate adaptation planning and sustainable resource management.

To investigate long-term climatic changes, several statistical and time-series techniques are commonly used in climatological research. The Pettitt test is a widely applied non-parametric method for detecting abrupt change points or structural breaks within a time series. It identifies the probable timing of sudden shifts in climatic variables without requiring normally distributed data, making it suitable for rainfall and temperature analysis. Autocorrelation analysis is another important approach used to examine the persistence and serial dependence of climatic observations over time. Detecting autocorrelation is necessary because serially correlated data may influence the reliability of statistical trend tests. Among trend detection techniques, the Mann–Kendall (MK) test is one of the most widely used non-parametric methods for identifying monotonic increasing or decreasing trends in hydro-climatic time series. However, climatic datasets often exhibit serial correlation, which can affect the significance of the MK test. To overcome this limitation, the Modified Mann–Kendall (MMK) test adjusts the original MK approach by accounting for autocorrelation effects, thereby providing more robust trend estimates. Sen's slope estimator is frequently used alongside MK and MMK tests to quantify the magnitude and direction of climatic trends. In addition to historical trend analysis, time-series forecasting models such as Seasonal Autoregressive Integrated Moving Average (SARIMA) are increasingly applied to predict future climatic behavior**[3],[4].** SARIMA models are particularly effective for climatic data because they can capture both temporal trends and seasonal variations simultaneously **[5–8].**

Many researchers used the SARIMA model for forecasting and predicting climatic parameters. Despite the growing number of climate-related studies in Bangladesh, comprehensive investigations combining trend analysis, change-point detection, autocorrelation assessment, and future forecasting for northeastern Bangladesh remain limited. Most previous studies focused either on rainfall or temperature individually, while integrated assessments covering both variables at regional scales are comparatively scarce. Furthermore, limited attention has been given to the detection of structural climatic shifts and future seasonal forecasting using advanced statistical approaches such as SARIMA. Therefore, this study aims to fill these research gaps by conducting a detailed analysis of long-term rainfall and temperature variability in Sylhet and Sreemangal using robust statistical and forecasting techniques. Therefore, the specific objectives of this study are:

1. To analyze the long-term trends and seasonal variability of rainfall and temperature in Sylhet and Sreemangal during the period 1990–2024 using the Mann–Kendall (MK), Modified Mann–Kendall (MMK), and Sen's slope methods.
2. To detect abrupt climatic shifts and serial dependence in rainfall and temperature data using the Pettitt change-point test and autocorrelation analysis.
3. To forecast future rainfall and temperature patterns for the period 2025–2034 using Seasonal Autoregressive Integrated Moving Average (SARIMA) models and evaluate their potential implications for climate adaptation in northeastern Bangladesh.

2. METHODOLOGY

2.1 Study Area

The study area is located in the northeastern part of Bangladesh, covering the Sylhet region and including the meteorological stations at Sylhet and Sreemangal. Geographically, the area extends approximately between 24°30′N to 25°15′N latitude and 91°30′E to 92°30′E longitude. Sylhet city is located at about 24.89°N latitude and 91.87°E longitude, while Sreemangal lies around 24.31°N latitude and 91.73°E longitude. Topographically, the region consists of low-lying floodplains interspersed with elevated hill ranges, with elevations ranging from about −21 m to 335 m above sea level. The southern and eastern parts, particularly around Sreemangal, are characterized by hilly terrain and tea garden landscapes, while the central and northern parts are dominated by alluvial plains. The region is strongly influenced by the nearby Meghalaya Plateau, which enhances orographic rainfall, making it one of the wettest regions in the country. This combination of geographic location, elevation variability, and monsoonal climate makes the area highly significant for rainfall and temperature trend analysis.

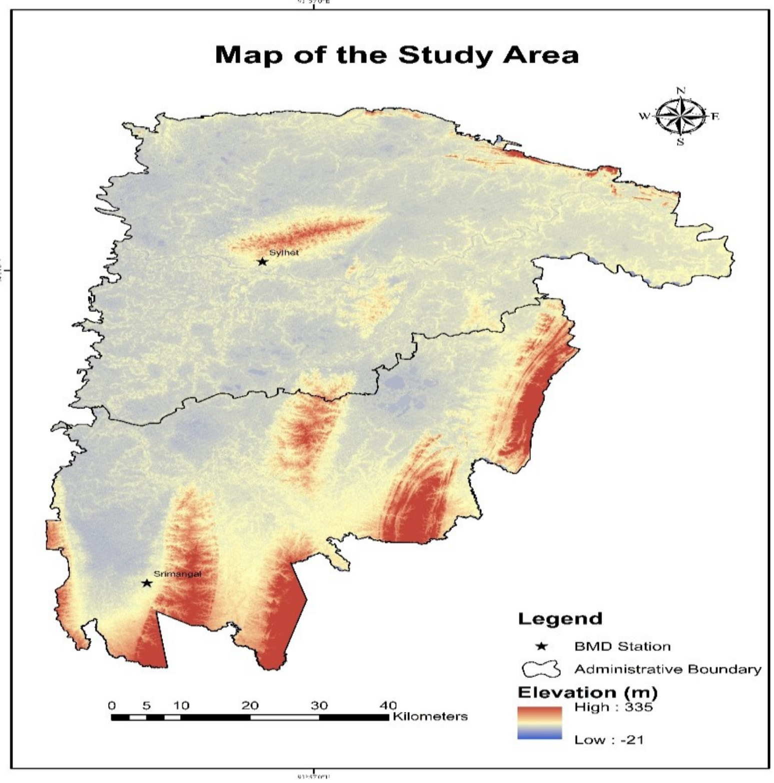


Fig. 1 Map of the study area

2.2 MK/MMK test

The MK test is a non-parametric statistical method commonly used to detect increasing or decreasing trends in climatic time-series data such as rainfall and temperature**[6].** Since the method does not require normally distributed data, it is widely applied in hydro-climatological studies. In this study, the MK test was used to analyze monthly, seasonal, and annual trends of rainfall and temperature. Before conducting the MK test, lag–1 autocorrelation was examined because serial correlation can affect the significance of trend results **[9].** Where significant autocorrelation was detected, the Trend-Free Pre-Whitening (TFPW) method proposed by Yue and Wang**[10]** was applied to reduce autocorrelation effects. The standardized test statistics (Z) was calculated to determine the significance of the detected trends:

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

The MMK test is an improved version of the MK test that accounts for autocorrelation in climatic time-series data, making trend results more reliable **[8]**. It was used in this study for rainfall and temperature trend analysis where serial dependence was detected in the dataset. In this study, both 5% and 10% significance levels were used to assess rainfall and temperature trends. A positive Z value represents an increasing trend, whereas a negative Z value indicates a decreasing trend over time. Similar methodologies have been widely adopted in climatological and hydrological studies for long-term trend analysis and climate variability assessment **[11]**.

2.3 Sen's slope

Sen's Slope estimator is a non-parametric method used to quantify the magnitude of monotonic trends in time-series data such as rainfall and temperature **[12].** It provides a robust estimate of the rate of change per unit time and is widely used alongside the MK/MMK test. In this study, the method was adopted based on the study established by Nadim et al**.[13].**

2.4 SARIMA Model

The Seasonal Autoregressive Integrated Moving Average (SARIMA) model was used in this study to forecast future rainfall and temperature patterns. This model is capable of capturing both seasonal and non-seasonal components of time-series data, making it suitable for climatic variables with strong seasonal fluctuations. The SARIMA approach was applied to generate projections for the period 2025–2034, providing an indication of possible future variability and long-term trends in rainfall and temperature in the study area.

3. RESULTS AND DISCUSSION

3.1 Climatology

The integrated analysis of rainfall and temperature patterns demonstrates in Sylhet and Sreemangal is illustrated in Fig. 2. Rainfall shows strong seasonal variation, with very low values during winter (DJF) and a rapid increase from March, indicating the onset of the pre-monsoon period. Peak rainfall occurs in June during the monsoon season, reaching about 850 mm in Sylhet and around 450 mm in Sreemangal. After June, rainfall gradually decreases and becomes minimal. Rainfall variability is highest during the monsoon months, especially in June when Sylhet records SD values of about 340 mm. CV values remain very high during winter and late autumn (often exceeding 150–200%), indicating irregular and unreliable rainfall, whereas during June–August CV falls below 40%, reflecting stable precipitation. Sylhet receives higher rainfall and shows greater variability than Sreemangal, suggesting stronger monsoonal influence and higher exposure to extreme rainfall and flood risk.

Mean temperature patterns also exhibit clear seasonal contrasts (Fig.1b, d, and f). Mean temperature is lowest in January and February (about 16–19°C) and increases steadily to reach maximum values of around 28–29°C during June to August (Fig. 1b). After the monsoon (JJAS), temperature gradually declines toward December. Sylhet remains slightly warmer than Sreemangal throughout most of the year. Mean temperature variability is highest during winter and early spring, with SD and CV values peaking in January (CV up to about 8% in Sylhet), indicating unstable atmospheric conditions. During the monsoon season, temperature variability decreases significantly, with CV values falling to around 1.5–2%, reflecting stable thermal conditions due to cloud cover and high humidity. Compared to rainfall, temperature remains relatively stable throughout the year.

The results indicate the seasonal rainfall and mean temperature distributions for Sylhet and Sreemangal (Fig. 3). The results show a strong dominance of the monsoon season, followed by clear contrasts among the other seasons. During the pre-monsoon period, Sylhet receives about 380 mm of rainfall, while Sreemangal records around 240 mm, indicating early moisture buildup before the onset of the main monsoon. The highest rainfall occurs in the monsoon season, with Sylhet recording approximately 680 mm and Sreemangal about 350 mm, confirming the strong influence of monsoonal circulation in the region. In the post-monsoon season, rainfall decreases sharply to around 90 mm in Sylhet and 75 mm in Sreemangal, reflecting the retreat of monsoon systems. Winter rainfall remains minimal in both areas, with values below 25 mm, indicating a pronounced dry season. Seasonal mean temperature variations show clear thermal contrasts among different seasons in both study areas. During the pre-monsoon season, the mean temperature reaches about 26°C in both Sylhet and Sreemangal, reflecting increasing solar radiation and surface heating. The highest temperatures are observed in the monsoon season, with values around 28–28.5°C, indicating warm and humid conditions associated with persistent cloud cover and high atmospheric moisture. In the post-monsoon period, temperature declines to about 23°C in Sylhet and 22°C in Sreemangal, marking the transition toward cooler conditions. The lowest temperatures occur in winter, with mean values of approximately 19.5°C in Sylhet and 18°C in Sreemangal.

The results indicate that Sylhet exhibits stronger monsoon intensity, higher rainfall totals, and greater variability, making it more vulnerable to hydrological hazards, while Sreemangal shows relatively moderate climatic conditions with lower extremes. In addition, monsoon months provide reliable rainfall and stable mean temperatures suitable for agriculture and water resource recharge, while high rainfall variability in Sylhet increases flood vulnerability, and high winter CV values indicate uncertainty in dry-season water availability. These results are reported with the previous study by **[14–16].** patterns highlight the strong control of monsoonal circulation and local geographic conditions on the climate of northeastern Bangladesh.

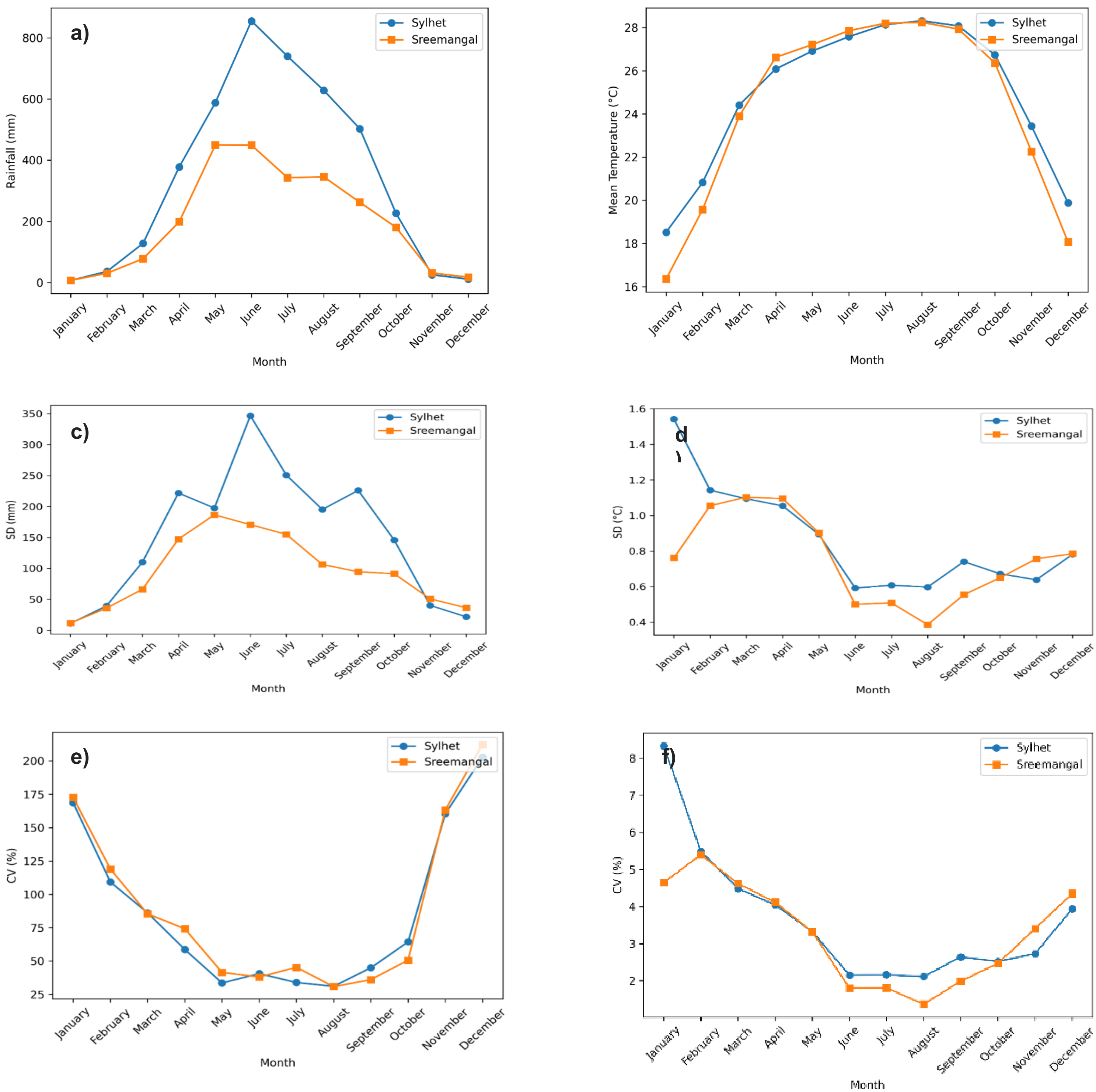


Fig. 2 Mean, SD (%), and CV of rainfall (a,c,e) and mean temperature (b,d,f) in Sylhet and Srimangal

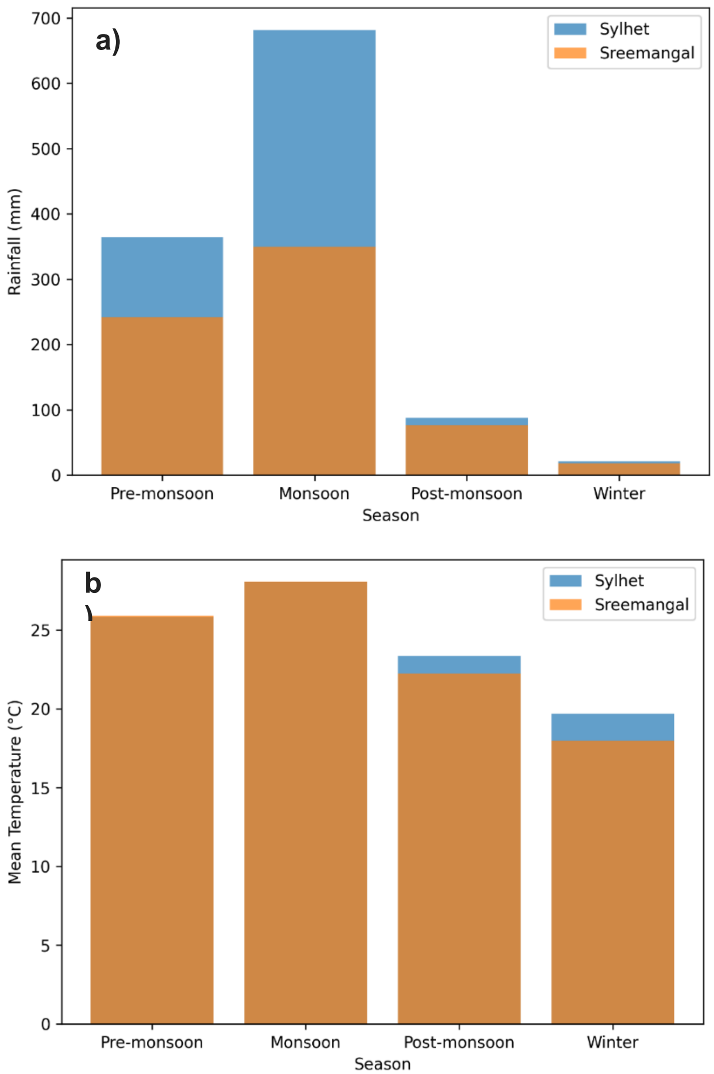


Fig. 3 Seasonal rainfall (a) and the mean temperature (b) plots in the study stations

3.2 Pettit test

Table 1 represents the results of the Pettitt test applied to monthly, seasonal, and annual rainfall and mean temperature series for Sylhet and Sreemangal to identify possible changes in long-term climatic patterns. The analysis reveals several structural shifts in both rainfall and mean temperature, particularly after the early 2000s, indicating increasing climate variability in northeastern Bangladesh. For rainfall, Sylhet shows noticeable breakpoints mainly after 2000. Significant shifts were detected in July (2017, $p = 0.002$) and September (2015, $p = 0.011$), suggesting major changes in peak monsoon rainfall behavior. At the seasonal scale, the most prominent change was observed during the monsoon season in 2020 ($p = 0.486$) and the pre-monsoon season in 2015 ($p = 1.443$), although these were not statistically significant at the 5% level. However, the annual rainfall series of Sylhet indicates a breakpoint in 2015 ($p = 0.486$), reflecting a recent transition toward more variable rainfall conditions. In Sreemangal, rainfall breakpoints were detected earlier, particularly in March (2004), June (2000), and July (1993), reflecting early monsoon instability. Although most rainfall breakpoints in Sreemangal were statistically insignificant, the monsoon season (2022) and annual rainfall (2000) suggest a shift toward altered precipitation regimes since the early 2000s. On the other hand, mean temperature records exhibit more statistically significant changes than rainfall, especially after 2010. In Sylhet, significant breakpoints were detected in July (2019, $p = 0.002$), September (2015, $p = 0.011$), October (2015, $p = 0.033$), pre-monsoon (2016, $p = 0.033$), monsoon (2015, $p = 0.001$), post-monsoon (2024, $p = 0.045$), and annual series (2015, $p = 0.004$). These results indicate a major shift in temperature patterns around 2015–2016, marking the beginning of a persistent warming phase. Similarly, Sreemangal also shows significant temperature breakpoints in July (2019, p = 0.002), September (2018, p = 0.010), pre-monsoon (2016, p = 0.033), monsoon (2015, p = 0.002), and post-monsoon (2024, p = 0.040). The consistency of these breakpoints across both stations suggests a region-wide climatic transition rather than localized variability. In annual scale, the mean temperature showed a statistically significant change point in 2015 (p = 0.004).

The analysis further confirms that the Pettitt test results demonstrate that temperature series exhibit greater and more statistically significant structural changes than rainfall. Most significant temperature breakpoints cluster around 2015–2016, which corresponds to the period of intensified warming observed in the anomaly analysis. This indicates that recent decades have experienced a fundamental change in regional thermal conditions. Rainfall series, although showing multiple breakpoints, display weaker statistical significance, suggesting that rainfall variability is more irregular and influenced by short-term climatic fluctuations rather than abrupt long-term shifts.

Table 1 Results of the Pettit test

Month / Season	Sylhet				Sreemangal			
	Rainfall		Mean temperature		Rainfall		Mean temperature	
	Breakpoint year	P-value	Breakpoint year	P-value	Breakpoint year	P-value	Breakpoint year	P-value
Jan	2001	0.2387	2024	0.301	2003	1.365	2024	0.527
Feb	1997	0.1676	2012	0.139	1997	0.341	2024	0.518
Mar	1999	0.3413	2014	0.059	2004	0.341	2014	1.246
Apr	1998	1.1057	2018	0.409	2021	0.601	2021	0.571
May	2005	0.6974	2013	0.601	1999	0.499	2013	0.311
Jun	2022	0.6011	2021	0.129	2000	0.632	2023	0.134
Jul	2017	0.6323	**2019**	**0.002**	1993	1.086	**2019**	**0.002**
Aug	2008	0.7312	2011	0.168	2007	0.421	2024	0.119
Sep	1994	0.8741	**2015**	**0.011**	2006	0.571	**2018**	**0.010**
Oct	2017	0.1191	**2015**	**0.033**	2016	1.046	2014	0.291
Nov	2008	1.4618	2024	0.180	1996	1.126	2013	0.714
Dec	2015	0.4722	2024	0.231	2015	0.556	2016	0.352
Pre-monsoon	2015	1.4426	**2016**	**0.033**	2000	0.397	**2016**	**0.033**
Monsoon	2020	0.4856	**2015**	**0.001**	2022	1.226	**2015**	**0.002**
Post-monsoon	2012	0.1287	**2024**	**0.045**	2016	1.027	**2024**	**0.040**
Winter	1997	0.2307	2006	0.239	2015	0.352	2006	0.238
Annual	2015	0.4856	**2015**	**0.004**	2000	0.541	2024	0.098

Bold color indicates 5% significance level

3.3 Autocorrelation test

The serial dependence (Table 2) analysis indicates that most rainfall series in Sylhet (particularly July, r = 0.124) and Sreemangal (particularly October, r = 0.003) exhibit weak and statistically insignificant autocorrelation, with correlation values ranging from −0.305 to 0.201. This suggests that rainfall variability is largely irregular and random in nature. Therefore, the independence assumption of the MK test is generally satisfied for rainfall data, allowing reliable application of the MK test for rainfall trend detection. In contrast, mean temperature series show relatively strong and significant positive autocorrelation, particularly in Sylhet during post-monsoon (r = 0.499), winter (r = 0.351), and at the annual scale (r = 0.512), and in Sreemangal during July (r = 0.453), monsoon (r = 0.499), and post-monsoon (r = 0.350), with correlation coefficients ranging from 0.350 to 0.512 and significant at the 5% level. This indicates strong temporal persistence and long-term memory in temperature records. Under such conditions, the classical

MK test may overestimate trend significance. Hence, the MMK test, which accounts for serial correlation, is more suitable for temperature trend analysis. Accordingly, this study applies the MK test primarily for rainfall and the MMK test for temperature to ensure robust and reliable trend detection.
Monthly, seasonally, and annually significant autocorrelation in study stations is consistent with the findings of the previous study reported by **[17]** and **[18].** These results highlight the importance of accounting for serial correlation when analyzing climatic time series, ensuring that trend detection is both accurate and reliable across different variables and temporal scales.

Table 2 Results of serial dependence

Month / Season	Rainfall		Mean temperature	
	Sylhet	Sreemangal	Sylhet	Sreemangal
	r	r	r	r
Jan	-0.070	-0.304	-0.189	-0.122
Feb	0.092	-0.022	-0.052	-0.006
Mar	-0.227	-0.171	-0.031	-0.247
Apr	0.065	0.035	-0.057	-0.026
May	-0.275	-0.034	-0.027	0.035
Jun	-0.002	-0.145	-0.003	-0.078
Jul	**0.124**	-0.028	0.301	**0.453**
Aug	-0.135	0.255	0.028	0.205
Sep	-0.126	-0.234	0.319	0.311
Oct	0.236	**0.003**	0.326	0.110
Nov	-0.170	-0.131	0.173	0.093
Dec	-0.008	-0.067	0.242	0.235
Pre-monsoon	-0.091	0.124	0.190	0.255
Monsoon	-0.053	-0.305	0.255	**0.499**
Post-monsoon	0.201	0.164	**0.499**	**0.350**
Winter	0.127	0.030	**0.351**	0.190
Annual	-0.048	0.026	**0.512**	0.298

Bold colour indicates 5% significance level

3.4 Trend analysis

The MK/MMK trend analysis of rainfall in Sylhet and Sreemangal (Table 3) shows that most monthly, seasonal, and annual rainfall series exhibit no statistically significant trends at the 5% level. In Sylhet, none of the months show a significant trend, with October having the highest Z-value ($Z = 0.225$, $p = 0.059$) but still insignificant. In Sreemangal, all months are non-significant, with the highest Z-value in August ($Z = 0.207$, $p = 0.083$). Seasonal analysis indicates that only the post-monsoon season in Sylhet shows a significant increasing trend ($Z = 0.269$, $p = 0.024$, Sen's slope = 5.097 mm/year), while pre-monsoon, monsoon, and winter remain stable. In Sreemangal, no seasons show significant changes, including the monsoon and post-monsoon periods (post-monsoon Sen's slope = 2.533). Annual rainfall also shows no significant trend in both locations (Sylhet $Z = 0.099$, $p = 0.410$, Sen's slope = 12.091 mm/year; Sreemangal

Z = 0.072, p = 0.551, Sen's slope = 5.821 mm/year). Sen's slope values generally reflect minimal changes in rainfall intensity, except for the weak post-monsoon increase in Sylhet.

In contrast, mean temperature trends (Table 4) show strong and statistically significant warming across both Sylhet and Sreemangal. In Sylhet, significant monthly increases are observed in March (Z = 2.406, p = 0.016, Sen's slope = 0.043), July (Z = 3.873, p = 0.001, slope = 0.039 °C/year), September (Z = 3.876, p < 0.001, slope = 0.044 °C/year), and October (Z = 3.291, p = 0.001, slope = 0.035 °C/year), while other months remain non-significant. Sreemangal shows significant increases in July (Z = 3.832, p < 0.001, slope = 0.031 °C/year), September (Z = 3.752, p < 0.001, slope = 0.031 °C/year), and October (Z = 2.079, p = 0.038, slope = 0.025 °C/year). Seasonal trends are significant in both locations during pre-monsoon, monsoon, post-monsoon, and winter, with Sen's slopes ranging from 0.023–0.035 °C/year in Sylhet and 0.023–0.034 °C/year in Sreemangal. Annual mean temperatures also increased significantly (Sylhet Z = 4.675, p < 0.001, slope = 0.029 °C/year; Sreemangal Z = 2.685, p = 0.007, slope = 0.016 °C/year). These results indicate persistent warming with strong temporal persistence and long-term memory, as supported by serial dependence analysis.

Overall, rainfall variability in both regions is largely irregular and random, consistent with serial dependence analysis, suggesting that long-term changes in rainfall are minor and dominated by short-term variability, consistent with **[19].** The results also highlight an asymmetric climatic response: while rainfall remains largely non-significant, mean temperatures are steadily increasing, which is also contradicted by some studies on climate change and variability **[20,21].** These results indicate signaling a clear warming trend with potential implications for agriculture, water resources, and climate adaptation strategies in Sylhet and Sreemangal.

Table 3 Rainfall trend analysis

Month / Season	Rainfall							
	Sylhet				Sreemangal			
	Z	**p**	**Trend**	**Sen's slope (mm/year)**	**Z**	**p**	**Trend**	**Sen's slope (mm/year)**
Jan	-0.198	0.073	no trend	0	0	1	no trend	0
Feb	-0.182	0.128	no trend	-0.647	-0.155	0.194	no trend	-0.375
Mar	-0.163	0.173	no trend	-1.440	-0.131	0.274	no trend	-0.800
Apr	0.055	0.650	no trend	2.143	-0.064	0.599	no trend	-0.722
May	0.126	0.293	no trend	3.667	0.074	0.541	no trend	1.765
Jun	0.143	0.233	no trend	6.125	0.139	0.244	no trend	3.500
Jul	0.045	0.712	no trend	1.269	0.007	0.966	no trend	0.040
Aug	0.153	0.201	no trend	5.818	0.207	0.083	no trend	3.273
Sep	-0.062	0.609	no trend	-2.130	-0.143	0.233	no trend	-1.739
Oct	0.225	0.059	no trend	5	0.008	0.955	no trend	0.087
Nov	-0.017	0.896	no trend	0	-0.015	0.909	no trend	0
Dec	0.118	0.276	no trend	0	0.084	0.446	no trend	0
Pre-monsoon	0.037	0.766	no trend	2.421	0.034	0.787	no trend	0.148
Monsoon	0.124	0.300	no trend	6.545	0.064	0.599	no trend	1.364
Post-monsoon	0.269*	0.024	increasing	5.097	-0.005	0.977	no trend	2.533
Winter	-0.131	0.274	no trend	-0.458	0.035	0.776	no trend	-0.120
Annual	0.099	0.410	no trend	12.091	0.072	0.551	no trend	5.821

* Indicates 5% significance level

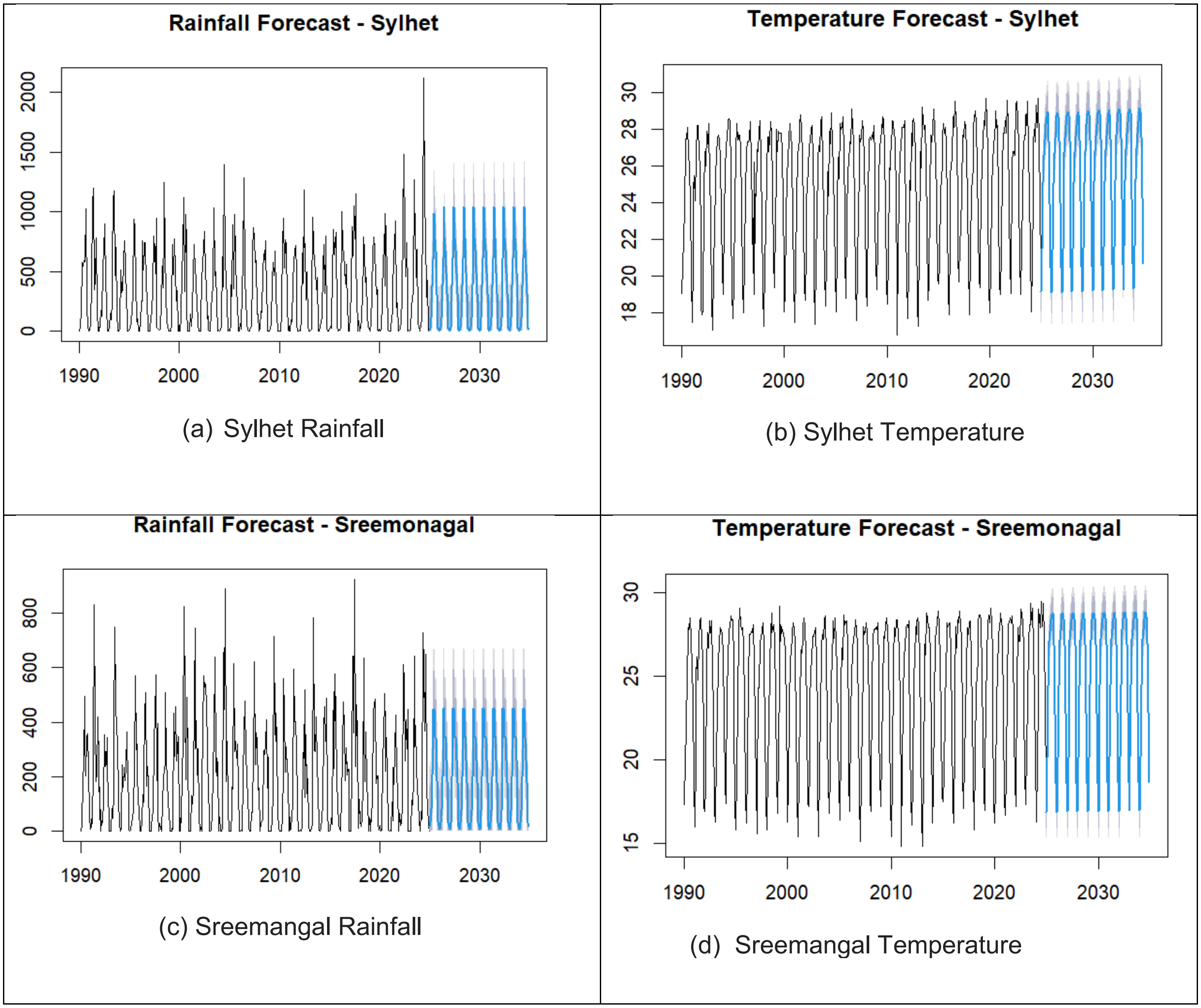
Table 4 Trend analysis of mean temperature

Month / Season	Mean temperature							
	Sylhet				Sreemangal			
	Z	p	Trend	Sen's slope (°C/year)	Z	p	Trend	Sen's slope (°C/year)
Jan	1.409	0.159	no trend	0.025	0.455	0.648514	no trend	0.005
Feb	1.751	0.080	no trend	0.029	0.028	0.977312	no trend	0
Mar	2.406*	0.016	increasing	0.043	-0.042	0.965945	no trend	0
Apr	1.778	0.075	no trend	0.036	1.251	0.210816	no trend	0.027
May	1.580	0.114	no trend	0.025	1.895	0.058027	no trend	0.029
Jun	1.909	0.056	no trend	0.019	1.628	0.103509	no trend	0.013
Jul	3.873*	0.001	increasing	0.039	3.832*	0.000127	increasing	0.031
Aug	1.781	0.075	no trend	0.019	1.700	0.089044	no trend	0.013
Sep	3.876*	0.000	increasing	0.044	3.752*	0.000175	increasing	0.031
Oct	3.291*	0.001	increasing	0.035	2.079*	0.037604	increasing	0.025
Nov	1.863	0.062	no trend	0.022	-0.071	0.943295	no trend	0
Dec	1.665	0.096	no trend	0.024	1.452	0.146265	no trend	0.019
Pre-monsoon	2.018*	0.044	increasing	0.023	2.957*	0.003104	increasing	0.035
Monsoon	2.957*	0.003	increasing	0.035	12.937*	0	increasing	0.034
Post-monsoon	12.937*	0.000	increasing	0.034	3.259*	0.001118	increasing	0.032
Winter	3.259*	0.001	increasing	0.032	2.017*	0.043595	increasing	0.023
Annual	4.675*	0.000	increasing	0.029	2.685*	0.00724	increasing	0.016

* Indicates 5% significance level

3.5 Time series forecasting

Fig 4 presents the monthly rainfall and temperature forecasts for Sylhet and Sreemongal for the period 2025–2034 based on the selected SARIMA models. The historical series (1990–2024) exhibit pronounced seasonal patterns in both rainfall and temperature at the two locations. Sylhet rainfall shows high interannual variability with strong monsoonal peaks, while Sreemongal rainfall follows a similar seasonal structure but with comparatively lower magnitudes. Temperature series for both stations display clear annual cyclical behavior with relatively stable long-term trends. The forecast results indicate the continuation of these seasonal dynamics over the projection horizon, with rainfall maintaining periodic peaks and troughs and temperature preserving its regular annual oscillation. The prediction intervals widen gradually over time, reflecting increasing uncertainty in longer-term forecasts, yet remain consistent with the historical variability structure of the series. Overall, the models capture the dominant seasonal characteristics and provide stable short- to medium-term projections for both climatic variables.



(a) Sylhet Rainfall

(b) Sylhet Temperature

(c) Sreemangal Rainfall

(d) Sreemangal Temperature

Fig 4: Forecasting (2025-2034) of Sylhet's (a) rainfall, (b) temperature, and Sreemangal's (c) rainfall, (d) temperature

4. CONCLUSION

This study examined the long-term variability, trends, structural changes, and future behavior of rainfall and temperature in Sylhet and Sreemangal, northeastern Bangladesh, using multiple non-parametric statistical approaches and time-series forecasting techniques. The integrated climatological analysis shows that both regions are strongly influenced by seasonal monsoon dynamics, with rainfall highly concentrated during the monsoon period and very low during winter. Sylhet consistently receives higher rainfall than Sreemangal, indicating stronger monsoonal influence and greater exposure to flood-related hazards. Temperature patterns show a clear seasonal cycle with higher values during pre-monsoon and monsoon periods and lower values in winter, while overall temperature variability remains comparatively stable throughout the year. The change-point analysis using the Pettitt test indicates noticeable structural shifts in both rainfall and temperature series, particularly after the early 2000s. However, temperature records exhibit more consistent and statistically significant breakpoints, especially around 2015–2016, suggesting the onset of a sustained warming phase across the region. Autocorrelation analysis further confirms weak and irregular dependence in rainfall data, whereas temperature shows strong positive serial correlation, indicating long-term persistence in thermal conditions. This justifies the use of MMK for temperature trend assessment and

MK for rainfall. Trend analysis reveals that rainfall exhibits mostly non-significant and irregular trends at monthly, seasonal, and annual scales, indicating high natural variability without a clear long-term directional change. In contrast, temperature shows a consistent and statistically significant increasing trend across several months, seasons, and both study stations, confirming persistent regional warming. Sen’s slope results further quantify this warming signal, highlighting steady increases in mean temperature over time. SARIMA-based forecasting suggests that the observed seasonal patterns in both rainfall and temperature are likely to continue into the future (2025–2034). While rainfall variability remains highly seasonal with strong monsoon dominance, temperature is expected to maintain its gradual upward trajectory. However, forecast uncertainty increases with time, indicating the inherent unpredictability of long-term climatic projections. The findings demonstrate an asymmetric climatic response in northeastern Bangladesh, where rainfall remains highly variable but largely trend-free, while temperature shows a clear and persistent warming signal. These changes have important implications for agriculture, water resource management, flood risk, and climate adaptation planning in Sylhet and Sreemangal.

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