Assessing spatiotemporal pattern of Temperature and Rainfall and Its Implications for Flash Flood Risks in Northeastern Bangladesh

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Abstract

The northeastern region is one of the most flash flood-prone areas in Bangladesh, where regular flash floods have tremendous impact on the lives, property and livelihoods of the people living in the region. Long-term rainfall trends were analyzed using linear regression and the Student's *t* test to assess statistical significance over a 71-years period (1948-2019) based on data obtained from the Bangladesh Meteorological Department. This study also examined monthly temperature and rainfall pattern in during the pre-monsoon and monsoon seasons over the last decade (2014-2025) using satellite-derived Land Surface Temperature (LST) dataset from MODIS, and the CHIRPS daily rainfall dataset. The findings indicate a gradual increase in rainfall across the northeastern region, particularly in Sylhet due to strong orographic influence. Although most rainfall trends were not statistically significant, pre-monsoon rainfall in Sylhet showed a significant increasing trend at a rate of approximately 6 mm per year. This trend is alarming because intense pre-monsoon rainfall during April and May contribute to earlier and more frequent flash flood in *Haor* (wetland) region (located Northeastern Bangladesh), threatening farmers during the *Boro* rice harvesting season. The *Haor* region contributes nearly one-fifth of the national rice production, making it highly vulnerable to climate-induced flooding. At the same time, most station in the region showed declining post-monsoon rainfall trends, which may assist faster recession of floodwaters and facilitates for land preparation and seedbed establishment during November. Future climate projections by IPCC suggest increasing monsoon rainfall and greater climate variability in South Asia, which may further intensify flood risk in the future. Since the *Haor* region is one of the major producer of *Boro* rice in Bangladesh, increasing floods and heavy pre-monsoon rainfall pose significant threats to agricultural production, rural livelihoods, and regional food security.

Keywords: Pre-monsoon, Flash flood, Northeast region, and Rainfall trend.

1. INTRODUCTION

Bangladesh, a relatively small country with an area of 145,452 km², extends from 20°45′N to 26°40′N latitude and from 88°05′E to 92°40′E longitude (Ahmed and Kim, 2003; Salahuddin *et al.*, 2006; Sarker, 2021). Located in South Asia, Bangladesh lies between the Himalayas to the north and the Bay of Bengal to the south (Messerli and Ives, 1984).The country is predominantly composed of flat alluvial plains, except for the hilly regions in the southeast (Brammer, 2000) , and the majority of the country lies at elevations below 10 m above mean sea level (Sarker and Bigg, 2010; Sarker, Bigg and Zimmerer, 2010; Sarker, 2015, 2021, 2022). One of the major impacts of climate change and variability in Bangladesh is the effect on water resources. The Ganges–Brahmaputra–Meghna River System (GBM) has a discharge greater than all river systems globally except the Amazon and Congo (Rasheed, 2008). Heavy rainfall and flooding in northern Bangladesh often occur during the break monsoon period, when the monsoon trough shifts toward the foothills of the Himalayas (Ahmed and Kim, 2003). Monsoon rainfall affect hydrological processes, leading to drying trends in the northwest due to declining rainfall (Sarker, 2005, 2009, 2021), as well as increased flooding in central regions and flash floods in the northeast due to topography and orographic rainfall (Ahmed and Kim, 2003; Quadir *et al.*, 2003; Sarker, 2005, 2021). Bangladesh experiences flooding almost every year. Most floods are regular seasonal inundations that submerge land without causing significant damage to crops or property and are commonly referred to as "normal floods (Brammer, 1997). In contrast, "disastrous floods" cause extensive damage to crops, infrastructure, and property (Brammer, 1997). Among these hazards, flash floods are one of the most destructive and rapidly occurring natural disasters in northeastern Bangladesh, particularly in Sylhet Division (Hossain and Haq, 2026). Although flash floods occur in several regions of Bangladesh, they are especially frequent in the northeastern region, including

Sylhet Division (Haque, 2026). For example, in 2024, a severe flash flood affected Feni and Noakhali districts, impacting approximately seven million people. But *Haor* region it is common, the *Haor* wetlands of northeastern Bangladesh remain inundated for four to seven months (June-Nov) each year (Hossain *et al.*, 2023; Bokhtiar *et al.*, 2024; Haque, 2026), increasing the vulnerability of local communities. Despite the significance of the Sylhet region, relatively few studies have focused on this area. Bhuiyan and Paul (2024), investigated the 2022 flash flood in the *Haor* region, particularly in Sunamganj, using a descriptive qualitative approach. The study identified major causes of the flood and highlighted its impacts, including loss of life and property, infrastructure damage, and disruptions to education and social life (Bhuiyan and Paul, 2024). More recently, Khan and Islam, (2025) generated flood extent maps for Sylhet Division using Sentinel-1 SAR imagery from 25 May, 5 June, and 19 June 2024, capturing both major flood waves. However, the present study extends beyond flood mapping by incorporating rainfall and temperature analysis using meteorological datasets.

The study focuses on the pre-monsoon, monsoon and post monsoon seasons. In Bangladesh, the pre-monsoon hot season from March to May, followed by the summer monsoon from June through September and a short and mild autumn (Post-monsoon) season from October to November (Asian Development Bank, 1994; Ahmed, 2003, 2004; Rasheed, 2008; as noted by Sarker, 2009). The analysis encompasses the broader northeastern region of Bangladesh, covering the *Haor* basin, which is larger than administrative boundary of Sylhet Division. In addition, this research investigates seasonal rainfall trends and temperature dynamics to understand the meteorological impact on the region and to assess whether the climate of northeastern Bangladesh is changing over time.

2. EXPERIMENTAL SET-UP & METHODOLOGY

2.1 STUDY AREA: **NORTHEASTERN REGION OF BANGLADESH**

The northeastern region of Bangladesh was selected as the study area because of its unique hydrological, geological and topographical characteristics, which contribute to its environmental and socio-economic importance. It shares border with Indian states of Meghalaya to the north, Assam to the east and Tripura to the south. The region is situated at the foothills of the Meghalaya Plateau in northeastern India (Khan and Islam, 2025). The upstream catchments are relatively steep, and intense rainfall over the Meghalaya, Barak, and Tripura basins rapidly drains downstream, frequently triggering flash floods in the low-lying Sylhet region (Khan and Islam, 2025). The region contains extensive permanent water bodies and wetlands, locally known as *Haor*, which occupy the central basins (Brammer, 1997). The Sylhet Basin is a vast depressed area, much of which remains inundated even during the dry season (Brammer, 1997; Rasheed, 2008). The lowest parts of the basin lie below five meters above sea level (Rasheed, 2008). See figure 1 for the study area and figure 2(a) for river network 2(b) elevation map of study area. Three meteorological stations—Sylhet, Sreemangal, and Mymensingh—were selected to examine climatic variability, particularly pre monsoon and monsoon rainfall patterns, across the region.

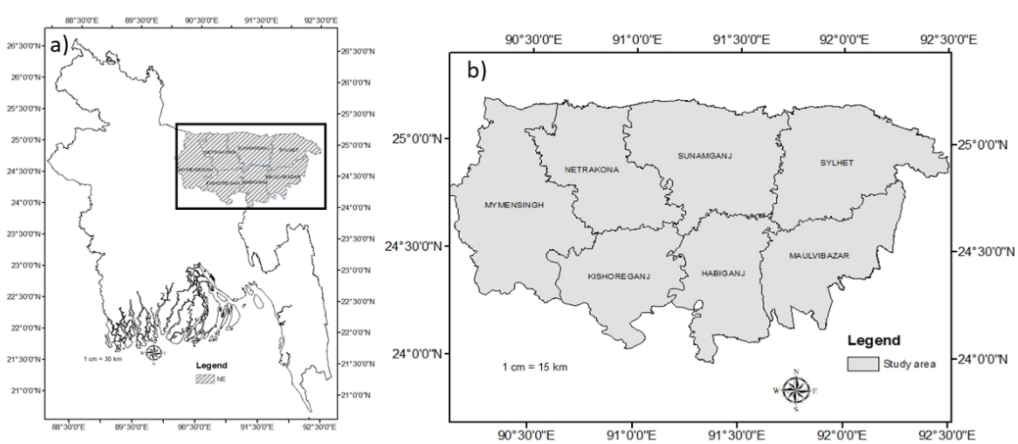

Figure 1: Study area a) Bangladesh b) Northeast region.

2.2 DATA AND METHOD

Monthly rainfall data were obtained from the meteorological stations from Bangladesh Meteorological Department (BMD). A continuous time series of 71 years (1948–2019) was used for analysis. The selected stations include Sylhet, Mymensingh, and Srimangal. Linear regression analysis was employed to trend analysis using the following formula, y=max+c, Here, x represent time (year) as the independent variable and y represent the dependent variable (temperature, rainfall), slope of the regression line (m), denote magnitude of the trend (see also (Sarker, 2021). To determine whether the observed trends were statistically significant, the Student's *t*-test was applied using the null hypothesis (H_0: m = 0), indicating no trend, and the alternative hypothesis (H_1: $m \neq 0$), indicating a significant trend. This methodology has been described in detail by (Sarker, 2021).

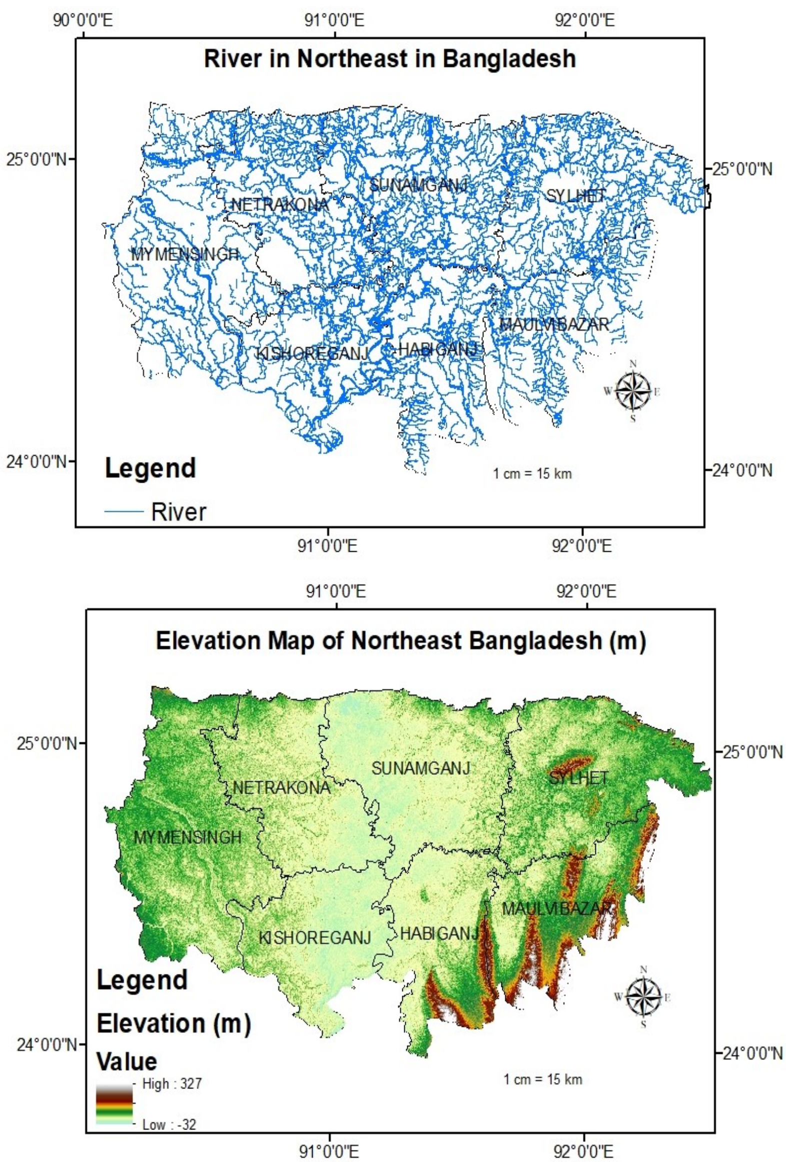

Figure 2 (a): River network b) Elevation map of Northeast region.

As the study area is larger than the Sylhet division and includes additional districts such as Mymensingh, the Northeast region of Bangladesh was selected for this study, and a new Shapefile for the region was created using ARC GIS software. For satellite-based temperature analysis, data were obtained from the MODIS Land Surface Temperature and Emissivity Daily Global 1 km product (MOD11A1 Version 6.1) [ee.ImageCollection("MODIS/061/MOD11A1")]. The MOD11A1 V6.1 product provides daily land surface temperature (LST) and emissivity measurements derived from the MOD11_L2 swath product and gridded into a 1200 × 1200 km tile system. The dataset offers consistent observations suitable for long-term temperature monitoring and spatial analysis. For satellite-based analysis of average temperature, MODIS data were collected from the MOD11A1 V6.1 dataset [ee.ImageCollection ("MODIS/061/MOD11A1")]. The MOD11A1 V6.1 product provides daily land surface temperature (LST) and emissivity data derived from the MOD11_L2 swath product within a 1200 × 1200 km grid. Rainfall analysis was conducted using the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) Daily dataset. This dataset has an approximate spatial resolution of 5 km, with precipitation values expressed in millimeters (mm). Daily rainfall data from 2014 to 2025 were analyzed to assess recent rainfall variability across the study area. Daily mean rainfall maps for April, May, and June were generated for the study period, with particular emphasis on the years 2020, 2022, and 2024. Special attention was given to the April–June periods of 2022 and 2024 because severe flood events occurred in the Northeast region during these years. Similarly, temperature data for the period 2014–2025 were analyzed, with a particular focus on 2024. This emphasis was justified by the findings of the World Meteorological Organization, which reported that 2024 was the warmest year on record globally. Monthly mean rainfall and average temperature values were calculated for each month, while seasonal mean values were generated for the monsoon period (June–September). All spatial analyses and map visualizations were produced using Google Earth Engine (GEE) code.

3. RESULT AND DISCUSSION

3.1. TEMPERATURE PATTERNS

Figures 3 and 4(a-c) clearly show that temperatures during April and May were higher than in June, while rainfall gradually increased from April to June. From the beginning of June 2024, rainfall gradually increased across the northeastern region, particularly in Sylhet. The findings suggest that prolonged heavy rainfall and flash flooding contributed to lower-than-expected temperatures across northeastern Bangladesh. Consequently, temperatures during June were lower than those recorded in April and May. On 8 June 2024, Sylhet recorded 257 mm of rainfall according to BMD observations (Figure 5b). Similar date temperature fall. Correspondingly, satellite-derived LST maps for the same period showed a noticeable decline in surface temperature. BMD data further indicated that the mean maximum temperature was approximately 32°C in Sylhet and 31.04°C in Sreemangal, whereas Ishwardi in the northwestern region recorded a substantially higher maximum temperature of 37.5°C. This is because the atmospheric moisture content and cloud cover absorb the outgoing long wave radiation very efficiently, and thereby they trap the heat decrease the temperature is slightly lower than expected (Ahmed, 2005; Sarker, 2005, 2021). As Temperature continue to rise in this reason (Sarker, 2005, 2009, 2015, 2021), the intensity and frequency of tornado are projected to increase (Bokhtiar *et al.*, 2024). An analysis of daily rainfall distribution (mm) and temperature patterns during in the northeastern region of Bangladesh, using data from satellite-derived rainfall and land surface temperature (LST) datasets, indicates a strong inverse relationship between rainfall intensity and temperature variation in this region.

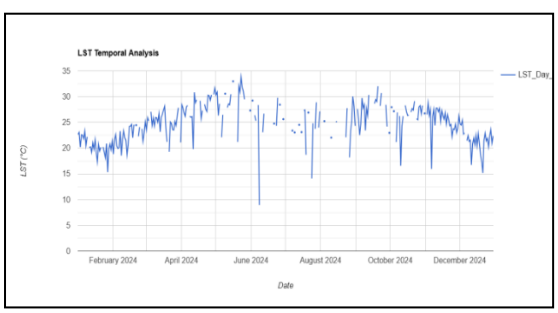

Figure 3. Daily mean temperature for the year 2024.

Figures 4(a-c) clearly show that temperatures during April and May were higher than in June, while rainfall gradually increased from April to June and temperature decreased. Figure 4(d) shows the mean monsoon land surface temperature (LST) during 2014-2025, repressing spatial temperature behavior across the study area during the summer monsoon season.

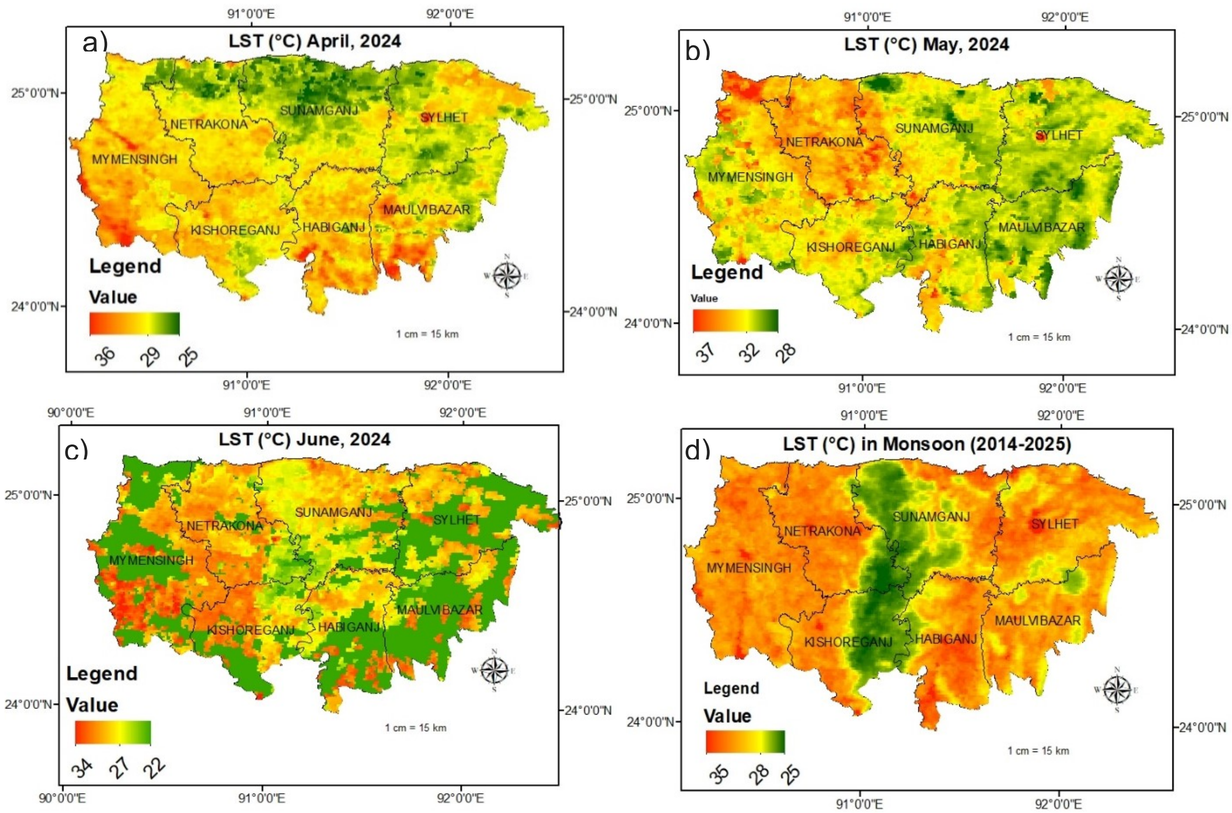

Figure 4: Mean land surface temperature for a) April, b) May, c) June, 2024 and d) Monsoon (2014-2025).

3.2 SEASONAL RAINFALL TREND

Linear regression and the Student's *t*-test were employed to explore the long-term rainfall dataset. The analysis found that most of the stations rainfall is increasing but statistically non-significant, except for the pre-monsoon rainfall increasing in Sylhet with increasing at the rate at a rate of approximately 6 mm per year (Table 1 and Figure 5(a) , which may lead to earlier flash floods in the region and adversely affect *Boro* farmers and agricultural production. Nevertheless, most stations in the northeast region showed increasing rainfall trends, except during the post-monsoon season. Sylhet demonstrated strong average rainfall in all seasons and annually due to the orographic effect, and the rate of increase was also comparatively higher, with an annual increase of about 9 mm per year. Similarly, rainfall in Sreemangal also showed an increasing trend, particularly for annual rainfall. However, none of these trends were statistically significant enough to conclusively confirm that rainfall is increasing. Overall, the comparative analysis suggests that rainfall in the northeast region of Bangladesh is gradually increasing 4.9 mm per year (but not significant), with the highest rate of increase observed in Sylhet due to its strong orographic influence (see section 3.4).

3.3 SATELLITE-BASED ANALYSIS OF RAINFALL (2014-2025)

Figure 5(b) illustrates the comparison of mean monthly rainfall among the three selected stations during June, indicating that Sylhet consistently recorded higher rainfall than the other stations. Figure 6, derived from the CHIRPS Daily rainfall dataset, further demonstrate that rainfall during June was substantially higher than in April or May during the major flood years of 2022 and 2024.

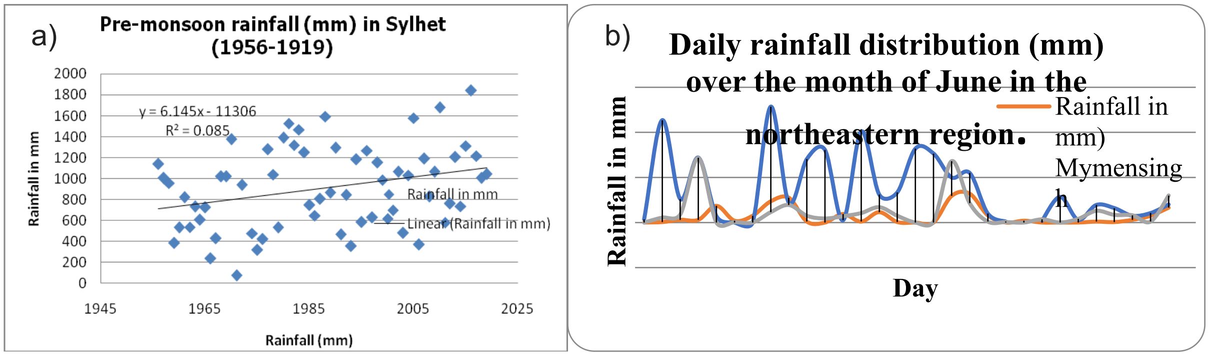

Figure 5: a) Pre-monsoon rainfall trend in Sylhet (left), b) Daily rainfall distribution at three stations in June 2024 (right)

Consequently, the flash floods of 2022 and 2024 occurred during the early monsoon period and caused widespread destruction across the region. In contrast, an unusually early rainfall event for April 2026 severely affected for farmers and regional food security, as a significant portion of the country's rice production originates from the *Haor* region. Regarding the 2022 flood event, Atiqul Haque stated that "the flooding is the worst in 122 years in the Sylhet region" (as noted by Gupta and Mogul, 2022). The data further indicate that in years such as 2014, 2016, and 2018, the region experienced relatively early and intense rainfall during May, which negatively affected agricultural activities in the following production cycle. Many farmers suffered economic losses because they were unable to harvest their *boro* rice fields before flooding occurred. Although July and August are generally considered the peak flood months in Bangladesh, the timing of monsoon onset is particularly critical in the Sylhet division. Early or delayed monsoon rainfall strongly influences agricultural activities, especially the harvesting period of *boro* rice, which usually occurs between April and early May. Most farmers begin harvesting in mid-April to minimize the risk of damage from pre-monsoon flash floods. If heavy rainfall begins during April or May, standing *boro* crops can be severely damaged, as observed in several recent years. In contrast, when the monsoon begins in June, farmers generally have more time to complete harvesting; however, extreme flooding events can still result in substantial losses of life, property, agriculture, and livelihoods. For example, the major flash floods of 2022 and 2024 occurred in mid-June and caused extensive damage throughout the region.

Table 1: Mean rainfall variation and slope from the linear regression analysis of rainfall measured seasonally, annually over the period of 1948-2019.

Northeast region	**Seasonal rainfall (mm) pattern**									
Stations	Winter (Dec-Feb)		Pre-monsoon Mar-May		Monsoon June-Sept		Post-monsoon Oct-Nov		Annual Jan-Dec	
	Slope	Mean	Slope	Mean	Slope	Mean	Slope	Mean	Slope	Mean
Mymensing	-0.04	32	+2.5	439	+0.3	1434	-0.4	196	2.4	2284
Sylhet	+0.15	51	+6.2*	910	+3.3	2034	-0.18	244	9	3238
Srimongal	+0.14	52	+3.5	692	+3	1339	-0.5	200	7.07	2100
Northeast (study area)	-0.18	68	+4.2	680	+1.02	1600	-0.16	215	+4.9	2550

*Refer to statistically significant at 95% confidence level; **Refer to statistically significant at 95% confidence level

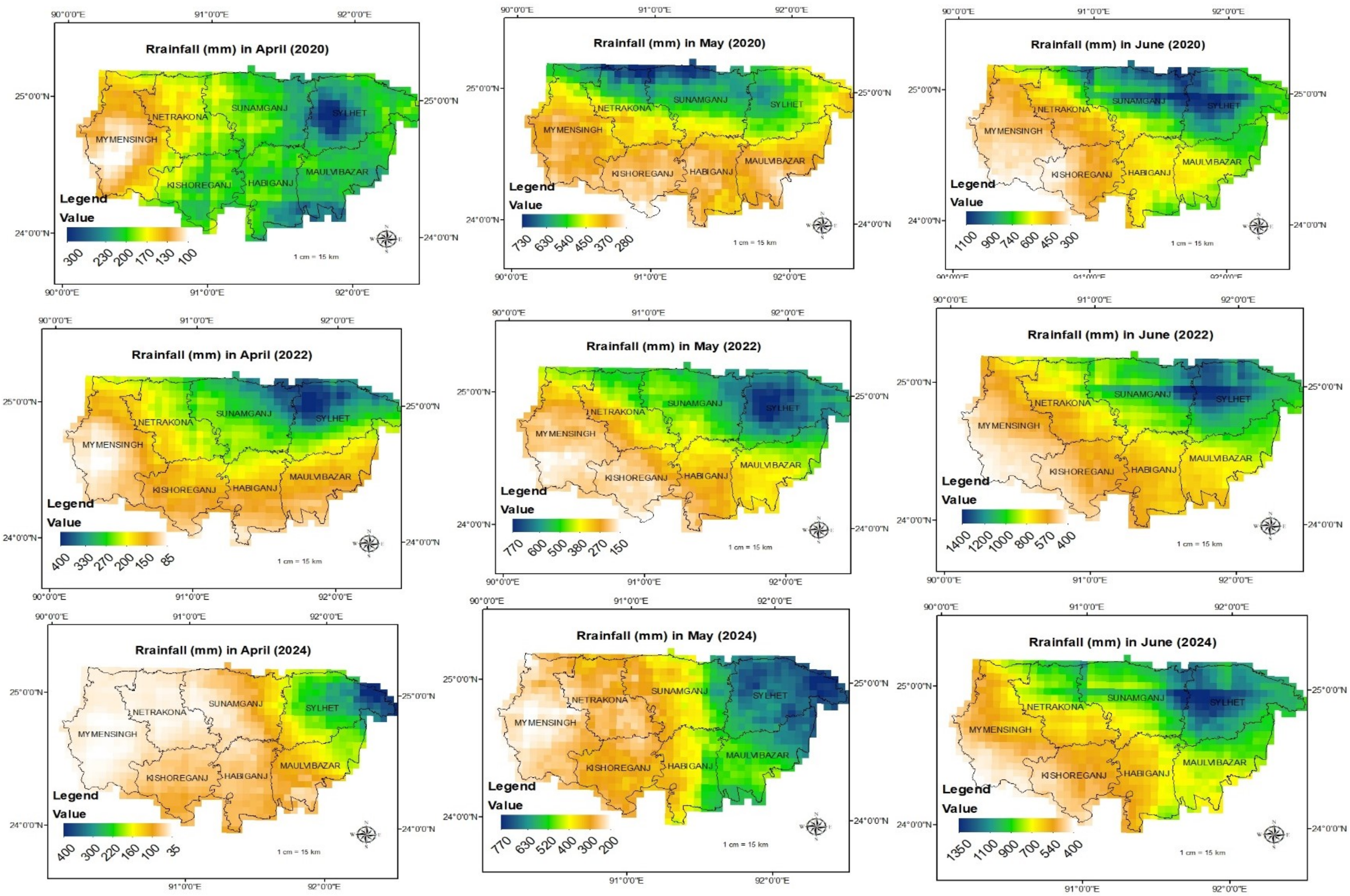

Figure 6. Rainfall during April, May, and June in different years (2020, 2022, and 2024).

3.4 LOCATION-SPECIFIC HYDRO-METEOROLOGICAL CHARACTERISTICS AND FLASH FLOODS

The northeastern region of Bangladesh lies at the foothills of the Meghalaya Plateau, and Sylhet is located very close to Indian state of Meghalaya (Ahmed & Kim,2003; Ahmed,2004; Sarker,2005,2009,2021). Notably, Cherrapunji, situated in the mountainous region adjacent to northeastern Bangladesh, receives some of the highest annual rainfall in the world, averaging around 11,000 mm due to strong orographic precipitation (Quadir *et al.*, 2003). Owing to its unique topographic and climatic conditions, the northeastern region of Bangladesh, particularly Sylhet, receives the highest annual rainfall in the country, averaging approximately 4,200 mm (Sarker, 2005, 2009, 2021). Several previous studies have also reported exceptionally high rainfall in the northeastern region of Bangladesh (Ahmed and Kim, 2003; Ahmed, 2004; Sarker, 2005, 2009, 2021; Sarker and Bigg, 2010; Sarker, Bigg and Zimmerer, 2010). Consequently, the region is highly vulnerable to flash floods (Islam, 2024). The present study also demonstrates that monsoon rainfall is considerably higher in Sylhet compared to other stations in the northeastern region as well as the rest of Bangladesh (Table 1; Figure 7 a-c). Although monsoon rainfall is generally associated with widespread flooding in Bangladesh, heavy pre-monsoon rainfall has a particularly strong relationship with flash flood occurrence in the northeastern region. Short-duration intense rainfall events, combined with rapid runoff from the surrounding hilly catchments, frequently trigger flash floods in the region. Analysis of rainfall data from 1995–2022 indicates that extreme rainfall events in Meghalaya and Sylhet are closely associated with severe flash floods, which are increasingly linked to climate change (Islam, 2024). Moisture influx from the Bay of Bengal is a major driver of rainfall variability in Bangladesh, particularly in the Northeast region. Sarker (2021) reported that pre-monsoon sea surface temperature (SST) in the northern Bay of Bengal has been increasing at a rate of approximately 0.6°C per year, with a 99% confidence level. Rising SSTs can enhance evaporation and atmospheric moisture content, thereby increasing the moisture supply available for precipitation over the Northeast region. This warming trend may enhance moisture availability and atmospheric water vapor transport toward the Northeast region, potentially leading to increased rainfall. Consequently, the frequency and intensity of flash flood events may increase in the future. In recent years, the Northeast region has already experienced several severe flash floods, highlighting its growing vulnerability to climate-induced hydro meteorological hazards. For instance, during the pre-monsoon of 2017, intense rainfall triggered an early flood in the northeast region, causing extensive damage to boro rice. According the government of Bangladesh 8000000 MT of Boro rice damaged (Goverment of Bangladesh, 2017). Analysis of satellite-derived rainfall data indicates that pre-monsoon rainfall exceeded 2,200 mm in parts of the region, highlighting the exceptional magnitude of the event. The northeastern region experienced another severe flooding in June 2024. This intense rainfall, combined with runoff from upstream catchments, triggered widespread flash flooding across the region. On 18 June 2024, the Surma River was flowing 131 cm above the danger level (IFRC, 2024). According to the Bangladesh Water Development Board (BWDB), rainfall recorded during the previous 24 hours (18 June 2024) included 333 mm in Lalakhal, Sylhet; 327 mm in Jaflong; 191 mm in Kanaighat and Zakiganj; 159 mm in Laurer Garh, Sunamganj; and 95 mm in Sunamganj city and Chhatak upazila (IFRC, 2024). The northeastern region experiences two major types of flooding: flash floods and regular seasonal floods. In most parts of Bangladesh, major flooding generally occurs during July and August. In contrast, flash floods in the northeastern region usually occur during the pre-monsoon and early monsoon seasons, particularly between April and June, due to intense short-term rainfall. Unlike normal river floods, flash floods occur suddenly with little or no warning (Montz and Gruntfest, 2002) and often cause severe damage to human lives, property, agriculture, and the environment (Hossain and Haq, 2026).

3.5 RECENT IMPACTS OF FLASH FLOODS (2022–2026)

The 2022 flash floods inundated approximately 94% of Sunamganj District and more than 84% of Sylhet District, causing extensive damage to agricultural land and severely affecting housing infrastructure, particularly in Comanyjanj *upazila* where homes were destroyed beyond repair (Haque, 2026). As a coping strategy, a large number of affected residents temporarily migrated to city in search of wage labor opportunities (Haque, 2026; Jabin and Atiqul Haq, 2026). Since the flooding occurred during the early monsoon season rather than the pre-monsoon period, crop damage was comparatively lower (Khan and Islam, 2025). However, severe inundation affected major urban centers, including Sylhet and Sunamganj, resulting in substantial impacts on densely populated areas (Khan and Islam, 2025). In contrast, the early flash flood event of 2026 had a greater impact on *boro* rice cultivation because it occurred during the harvesting season. Northeast region experienced severe flooding in June 2024. Sylhet and Sunamganj districts were among the worst affected areas, where more than 3 million people experienced displacement and livelihood disruption due to severe flooding (United Nation, 2024). The excessive rainfall caused widespread inundation, significantly damaging agriculture, infrastructure, and local economic activities (United Nation, 2024).

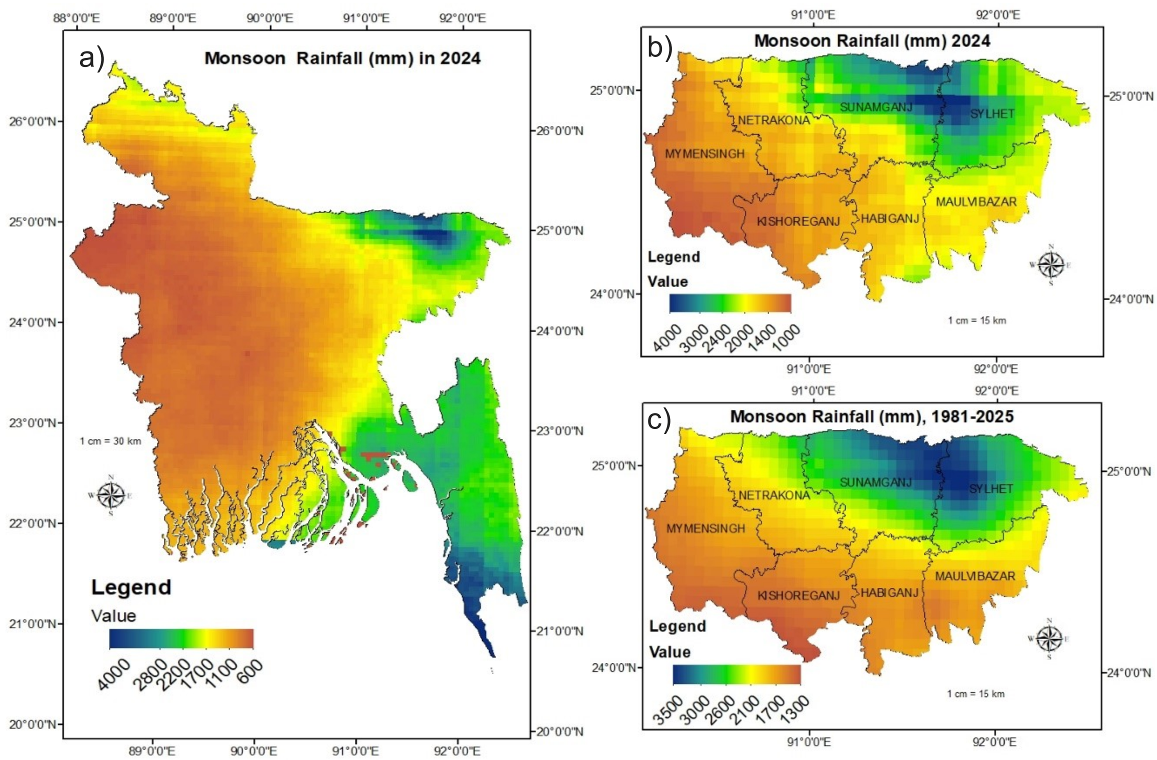

Figure 7: a)Total Monsoon Rainfall (mm) distribution in 2024 entire Bangladesh b) Northeast region c) Monsoon Rainfall over the period of 1981-2025.

4. CONCLUSION

The Northeastern *Haor* region of Bangladesh is highly vulnerable to flash floods, which frequently cause server damage to local communities, livelihoods and property. Historical analysis indicate that rainfall has generally increased across most seasons and meteorological stations in the region. In particular, both pre-monsoon and monsoon rainfall exhibit increasing trends over time, with rainfall in Sylhet remaining considerably higher than in other parts of the region. This trend is likely to intensify flash flood risks in northeastern Bangladesh. The situation is particularly alarming because the region is highly sensitives to early rainfall events during April and May, which coincide with the harvesting period of *Boro rice.* In recent year, such as 2026, excessive early rainfall and flash floods severely disrupted *Boro* paddy harvesting, resulting in substantial economic losses for farmers. *Boro* rice is the principal rice crop in Bangladesh, contributing approximately half of the country's total rice production (Shahrier and Hasan, 2025; Alim, 2026). The seven *Haor* districts alone account for nearly 18–20% of national *boro* rice production; however, these areas are increasingly vulnerable to climate-induced hazards, particularly heavy pre-monsoon rainfall and flash floods (Alim, 2026). At the same time, most stations in the region showed declining post-monsoon rainfall trends, which may facilitate faster recession of floodwaters and create more favorable conditions for land preparation and seedbed establishment during November. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2022), both annual and summer monsoon precipitation in South Asia are projected to increase throughout the 21st century, accompanied by greater inter-annual variability. This suggests that flash flood frequency and intensity may further increase in the future. Moreover, the *Haor* Basin is a tectonic depression formed by the collision between the Indian and Eurasian plates, resulting in continuous subsidence at a rate of approximately 2–4 mm per year (Kamruzzaman and Shaw, 2018). This ongoing subsidence is expected to increase both the extent and frequency of annual flooding in the region (Kamruzzaman and Shaw, 2018). Since the *Haor* region is one of the major producers of *boro* rice in Bangladesh, increasing flash floods and heavy pre-monsoon rainfall pose significant threats to agricultural production, rural livelihoods, and regional food security.

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We declare that this manuscript represents our original research and writing. AI tools were used exclusively for proofreading and language enhancement, including corrections to grammar and spelling and did not contribute to the study's content or findings.

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