Effect of rainfall variability on cropping windows of Patuakhali and Rangpur Regions

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The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

Contents

Abbreviations and acronyms

ABC	Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT)
BARC	Bangladesh Agricultural Research Council
CIMMYT	International Maize and Wheat Improvement Center
ICARDA	International Center for Agricultural Research in the Dry Areas
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
SDG	Sustainable Development Goals
SI-MFS	Sustainable Intensification of Mixed Farming Systems Initiative
WP	Work Package
CC	Climate Change
MC	Markov Chain
BMD	Bangladesh Meteorological Department
SMW	Standard Meteorological Week
IQR	Interquartile Range
PD	Probability of a Dry Week
PW	Probability of a Wet Week
FD	Frequency of Dry Week
FW	Frequency of Wet Week
PDD	Probability of a Dry Week following a Dry Week
PWW	Probability of a Wet Week following a Wet Week
FDD	Frequency of Dry week following another Dry week
FWW	Frequency of Wet week following another Wet week
PWD	Probability of a Wet week following a Dry week
PDW	Probability of a Dry week following a Wet week
P2D	Probability of two consecutive Dry weeks
P3D	Probability of three consecutive Dry weeks
P2W	Probability of two consecutive Wet weeks
P3W	Probability of three consecutive Wet weeks

1. Introduction

Rainfall is a crucial climate variable upon which agriculture relies. Uncertainty in rainfall typically impacts food production. Fluctuations in rainfall quantity and distribution impact agricultural output in rainfed areas, hence directly affecting the nation's economy. Understanding the precipitation pattern is crucial for effective crop management. Farmers face significant challenges due to their weak socioeconomic status, restricted availability of modern farming techniques, and the lack of opportunities to diversify their crop production. These factors hinder the effective use of the nation's water resources (Mandal et al., 2015). Consequently, the conventional rainfed agricultural farming method remains focused on subsistence farming, and smallholder farmers experience food shortages due to variations in precipitation and extreme climatic conditions like droughts and floods.

Climate change (CC), precipitation patterns, and soil quality play a critical role in determining the food security of any region. In the context of precipitation variance, agricultural productivity is dependent upon critical parameters like soil water content, the quantity of rainfall, its commencement, withdrawal, and the duration of the growing season. Access to accurate annual and seasonal rainfall data is crucial for addressing the socioeconomic challenges faced by farmers who rely solely on precipitation. Agriculturalists typically depend on historical weather data when organizing farming operations. Nonetheless, CC has rendered the accurate prediction of rainfall variability and the corresponding planning of agricultural activities increasingly challenging. A research-backed investigation into CC and rainfall variability can aid conventional farmers in strategizing crop management alternatives and formulating adaptation and mitigation measures. The role of soil and appropriate ecosystem services establishes the ideal interaction among soil, water, organisms, organic matter, and minerals. Extreme rainfall elevates soil water content, resulting in increased waterlogging, runoff, and erosion, whereas diminished rainfall in arid conditions reduces organic matter and the availability of nutrients. Alterations in rainfall also influence plants, thereby affecting the soil's organic matter cycle and modifying soil characteristics.

Bangladesh has a very different agricultural setting where northern Bangladesh is known for its highly intensified farming practices that incorporate advanced technology and southern coastal Bangladesh is known for its relatively low productivity and low levels of intensification (Assefa et al., 2021). The southern coastal zone exhibits markedly elevated levels of food insecurity and hunger and is also particularly susceptible to CC. Waterlogging and salinity in coastal regions are significant concerns, impacting agricultural output, socio-economic status, and the livelihoods of millions (Mainuddin & Kirby, 2021). In the rainy season, over 2.85 million hectares—approximately 30% of the nation's arable land—become flooded, while nearly one million hectares encounter varied degrees of salinity during the dry season because of drought conditions (Maniruzzaman et al., 2024). Intense precipitation during the sowing period postpones the seeding of Aman rice, as waterlogging and flooding can damage crop roots, potentially leading to seedling failure. Therefore, it is critical to study and observe data to comprehend the changes in precipitation. In addition to helping with crop calendar updates, farmers can benefit from an in-depth knowledge of weather data by increasing crop yields, decreasing crop failures, and preparing for the abrupt weather changes triggered by CC.

To stabilize crop yields at a specific level, it is important to plan farming scientifically, optimizing the rainfall patterns of the region. This requires analyzing the patterns of dry and wet periods in a region to implement appropriate measures for developing a crop plan in rainfed areas

(Srinivasareddy et al. 2008). Forecasting rainy and dry spell patterns for effective crop planning and agricultural practices may benefit farmers by enhancing productivity and cropping intensity. The Markov chain (MC) probability model has been previously employed to determine the probabilities of dry and rainy spells over brief intervals, such as weeks, and has illustrated its practical application in agricultural planning (Hirapara et al., 2020; Mandal et al., 2015; Pandarinath, 1991). The accumulation of rainfall, both forward and backward, is crucial for identifying the commencement and cessation of the monsoon. Pre-monsoon precipitation facilitates field preparation and the seeding of crops for the rainy season. The delayed commencement of the monsoon hinders crop sowing, leading to suboptimal yields. Likewise, premature withdrawal impacts the yield significantly due to acute moisture stress, particularly during critical growth phases of grain formation and development in rainy-season crops (Dixit et al., 2005). Forecasting the onset date of the effective monsoon is crucial, as even a minor delay in the sowing of rainfed crops can result in a significant decrease in grain yield and could impact subsequent crops.

2. Objectives of the Study

The objectives of the study are as follows-

- To explore the rainfall variability pattern in the Patuakhali and Rangpur regions
- To reveal the onset and withdrawal of rainfall season, and
- To analyze initial, conditional, and consecutive dry and wet spells using the MC model.

3. Data and Methods

3.1 Study Area

This study considers mixed farming working areas, Rangpur and Patuakhali of Bangladesh, which are situated in the northern and Southern parts of the country, respectively **(Figure 1).** Rangpur district covers an area of 2,641.84 km², with 681,405 acres allocated for rice cultivation. The climate in Rangpur is characterized as humid subtropical, featuring typically humid and hot summers alongside comparatively cool winters (Rokonuzzaman et al., 2018). The average annual rainfall in Rangpur from 1980 to 2020 is approximately 2,268 mm. During the early and last months of each year, rainfall is either nonexistent or very little. In May and June, Rangpur had over 350 mm of precipitation. The mean temperature in Rangpur is 24.9°C. Rice, maize, potatoes Tobacco, and mustard are the main crops grown in this region.

Patuakhali is situated in the southcentral region of Bangladesh. The average annual rainfall of Patuakhali is 2614 mm. It is particularly vulnerable to the detrimental effects of CC due to its proximity to the Bay of Bengal. Natural hazards, including cyclones, floods, and storm surges, predominantly impact the study region; however, additional hazards such as river erosion, drought, erratic precipitation, tidal flooding, and waterlogging also adversely affect the inhabitants of this region. It has been forecasted that, owing to climate change, these hazards are expected to intensify and occur with greater frequency in the future (Kamal et al., 2022), jeopardizing the impoverished people of the region. Consequently, it is imperative to implement mitigation and adaptive measures proactively to diminish the area's risk. Aman rice is the main crop in this area with few areas of *rabi* crops such as sunflower and mungbean.

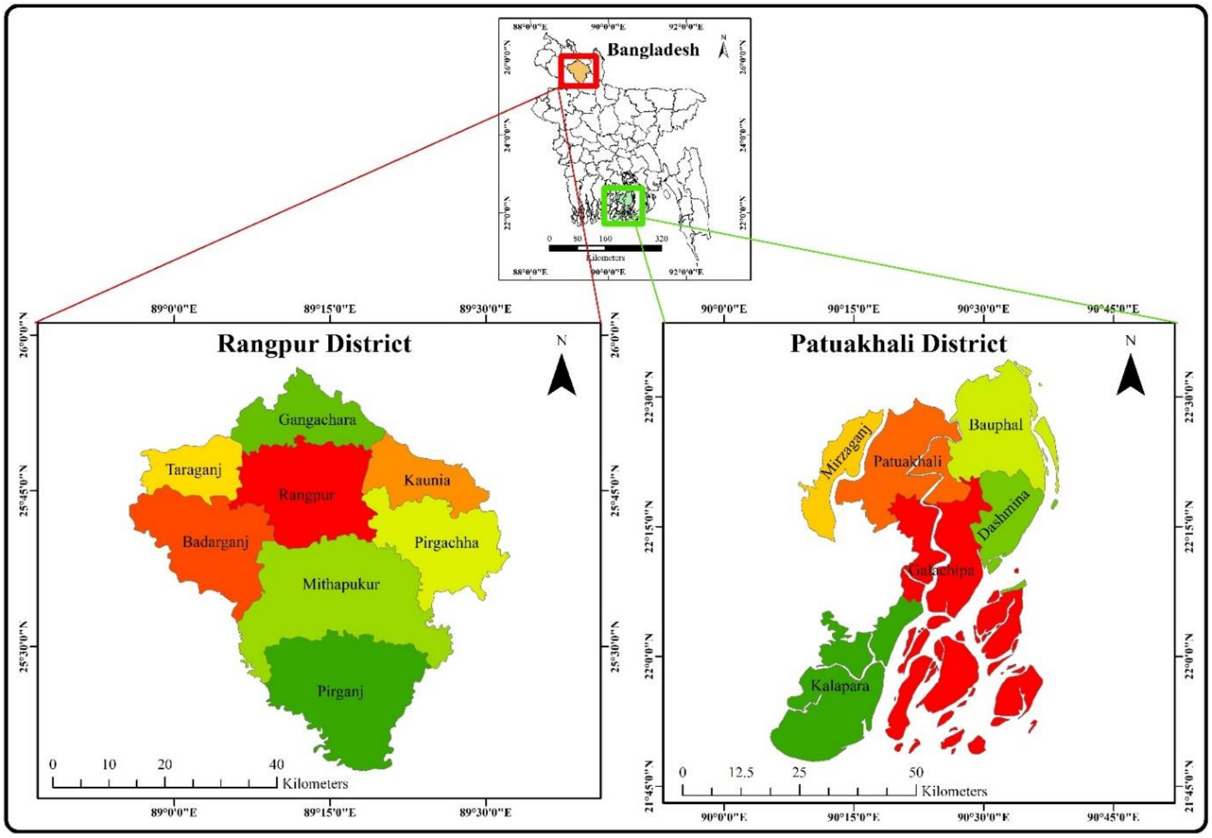

Figure 1: Geographical map of the study area.

3.2 Data

Daily rainfall data spanning 41 years, from 1980 to 2020, were collected from the Bangladesh Meteorological Department (BMD) for the Rangpur and Patuakhali stations. In this study, meteorological data were organized by standard meteorological weeks (SMWs) which have 52 weeks.

3.3 Quantification of the onset and withdrawal of Rainfall

For rainfed crops, the success or failure is mostly dependent on when the rainfall arrives and goes. With this information in hand, farmers may better plan their crop rotations, select more water-efficient crop types, and increase yields per acre by making better use of the rainwater that falls on their fields. For that reason, we used forward and backward accumulation approaches to determine when the rainy season began and ended based on weekly precipitation data. The accumulation of 75 mm and 20 mm of precipitation has been regarded as the onset and withdrawal of precipitation (Hirapara et al., 2022). The probability percentage (P) for each rank was determined by ordering them in ascending order and selecting the highest rank assigned to each specific week. The calculation used Weibull's formula as follows:

$$P = \left(\frac{m}{N+1}\right) \times 100$$

where m denotes the rank position, and N signifies the total number of years of data utilized.

3.4 Calculation of dry and rainy spells utilizing Markov Chain (MC) probability models

The MC probability model introduced by Pandarinath (1991) is utilized to analyze initial, conditional, and successive dry and wet spells using weekly rainfall estimated from daily data. The research classified wet weeks as those with 20 mm or more of rainfall, and dry weeks as those with less. To examine 52 SMWs, including initial, conditional, and subsequent dry and wet spells can be calculated as:

3.4.1 Initial Probabilities

The probability of a dry week (PD) and a wet week (PW) are computed as follows:

$$PD = \left(\frac{FD}{n}\right)$$

$$PW = \left(\frac{FW}{n}\right)$$

Where FD and FW denotes the frequency of dry and wet weeks, respectively.

3.4.2 Conditional Probabilities

The probability of a dry week following a dry week (PDD) and a wet week following a wet week (PWW) are calculated as:

$$PDD = \left(\frac{FDD}{FD}\right)$$

$$PWW = \left(\frac{FWW}{FW}\right)$$

Where FDD and FWW denotes the frequency of dry weeks following another dry week and wet weeks following another wet week, respectively.

The probability of a wet week following a dry week (PWD) and a dry week following a wet week (PDW) can be found as:

$$PWD = 1 - PDD$$
$$PDW = 1 - PWW$$

3.4.3 Consecutive Dry and Wet Week Probabilities

The probability of two consecutive dry weeks (P2D) and three consecutive dry weeks (P3D) are calculated as:

P2D =$PDW_1 \times PDDW_2$

$P3D = PDW_1 \times PDDW_2 \times PDDW_3$

Similarly, the probabilities for two and three consecutive wet weeks (P2W) and P(3W) are:

$P2W = PWW_1 \times PWWW_2$

$P3W = PWW_1 \times PWWW_2 \times PWWW_3$

Where PDW_1 and PWW_1 represent the likelihood of the first week being dry and wet respectively. $PDDW_2$ and $PDDW_3$ represent the likelihood of the second and third week being dry, respectively, following the previous week's dry. Similarly, $PWWW_2$ and $PWWW_3$ represent the likelihood of the second and third week being wet, respectively, following the previous week's wet.

4. Results

4.1 Rainfall statistics

Figure 2 displays the average annual and five-year moving average of rainfall over the period of 1980–2020. The annual rainfall in Patuakhali, represented by the red line, has a considerable interannual variability, with peaks of up to 4000 mm in the early 1980s. This is followed by fluctuating but generally lower yearly totals over the next few decades, which settle at an average of 2800 mm. A five-year moving average (blue line) shows these oscillations while smoothing out year-to-year variability, revealing a slight downward trend over the research period. The linear trend line (green) with a slope of -9.87 mm/year and a R^2 value of 0.06 supports the pattern of decreasing rainfall over time **(Figure 2a)**.

Rangpur exhibits comparable interannual rainfall variability, with early peaks exceeding 3500 mm in the 1980s. There is a pronounced decline in yearly rainfall over time, particularly obvious in the post-2000 period, during which annual totals often fall below 2500 mm.
The five-year moving average reveals more subdued swings, exhibiting a more pronounced falling trend compared to Patuakhali. The linear trend line (green) indicates a slope of -10.30 mm/year, marginally steeper than that of Patuakhali, implying a more rapid decrease in annual rainfall for Rangpur. Similarly, the R^2 score for Patuakhali is low (0.06), indicating minimal statistical significance **(Figure 2b)**.

Table 1 represents Monthly and Annual rainfall (mm) statistics of Patuakhali and Rangpur stations from 1980–2020. The average annual precipitation in Patuakhali is roughly 2614 mm, with a standard deviation of 473.5 mm and a coefficient of variation of 18.1%. The precipitation varies from a minimum of 1830 mm to a maximum of 4320 mm, signifying a considerable annual fluctuation. Conversely, Rangpur has a mean annual rainfall of 2267.8 mm and a higher coefficient of variation of 22.5%, indicating marginally greater interannual variability compared to Patuakhali.

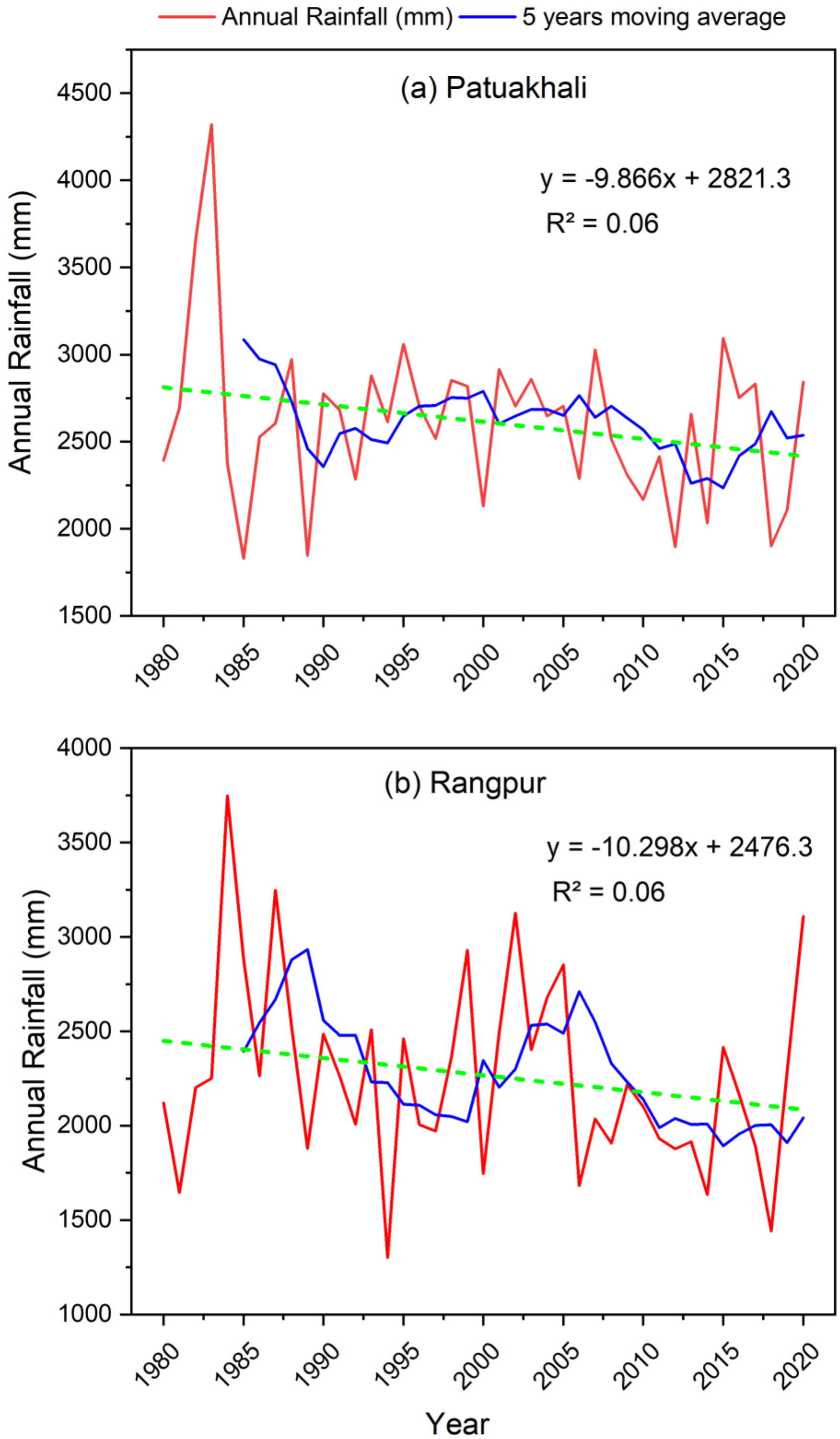

Figure 2: The annual rainfall trends for (a) Patuakhali and (b) Rangpur over the years of 1980–2020, along with a 5-year moving average and a linear trend line.

Table 1: Monthly and Annual rainfall (mm) statistics of Patuakhali and Rangpur stations from 1980–2020.

Months	Patuakhali						Rangpur					
	Mean	STD	CV (%)	Min	Max	Range	Mean	STD	CV (%)	Min	Max	Range
Jan	8.61	13.90	161.42	0	63	63	8.37	11.96	142.96	0	49	49
Feb	21.80	31.62	145.01	0	113	113	11.80	13.98	118.39	0	57	57
Mar	42.05	56.17	133.59	0	199	199	28.07	33.58	119.62	0	123	123
Apr	106.10	93.59	88.21	7	342	335	116.46	79.84	68.56	0	376	376
May	242.24	162.12	66.92	38	912	874	286.63	86.28	30.10	99	545	446
Jun	519.22	250.91	48.32	197	1084	887	434.63	169.14	38.91	97	989	892
Jul	584.41	174.35	29.83	354	1042	688	465.07	235.27	50.59	110	1314	1204
Aug	458.56	167.00	36.42	131	892	761	350.51	189.65	54.11	96	832	736
Sep	358.44	180.45	50.34	106	877	771	391.71	195.54	49.92	77	1035	958
Oct	215.05	134.67	62.62	18	533	515	161.73	141.19	87.30	0	581	581
Nov	52.27	75.94	145.29	0	293	293	6.41	18.23	284.14	0	109	109
Dec	5.39	10.78	199.98	0	52	52	6.41	11.80	183.99	0	47	47
Annual	2614.15	473.49	18.11	1830	4320	2490	2267.83	510.29	22.50	1301	3748	2447

4.2 Rainfall distribution

Figure 3 illustrates the seasonal rainfall patterns and their contribution to annual rainfall in Patuakhali and Rangpur. Patuakhali receives greater overall rainfall than Rangpur, particularly during the monsoon season, with Patuakhali accumulating about 1920 mm compared to around 1642 mm in Rangpur. In the pre-monsoon period, both sites experience precipitation, with Patuakhali receiving little less than Rangpur. During the post-monsoon and winter seasons, precipitation levels markedly decrease in both regions, with minimal rainfall occurring in winter (Figure 3a). The monsoon season constitutes the predominant source of yearly precipitation in both Patuakhali and Rangpur, representing over 70% in each site (Figure 3b). In summary, both localities experience the majority of their precipitation during the monsoon season; but, Patuakhali receives a much greater volume, resulting in heightened hazards of waterlogging. Rangpur exhibits a little greater contribution during the pre-monsoon period, indicating diversity in seasonal rainfall distribution throughout the regions. Both locations receive minimal precipitation during winter, resulting in insignificant contributions to the annual totals.

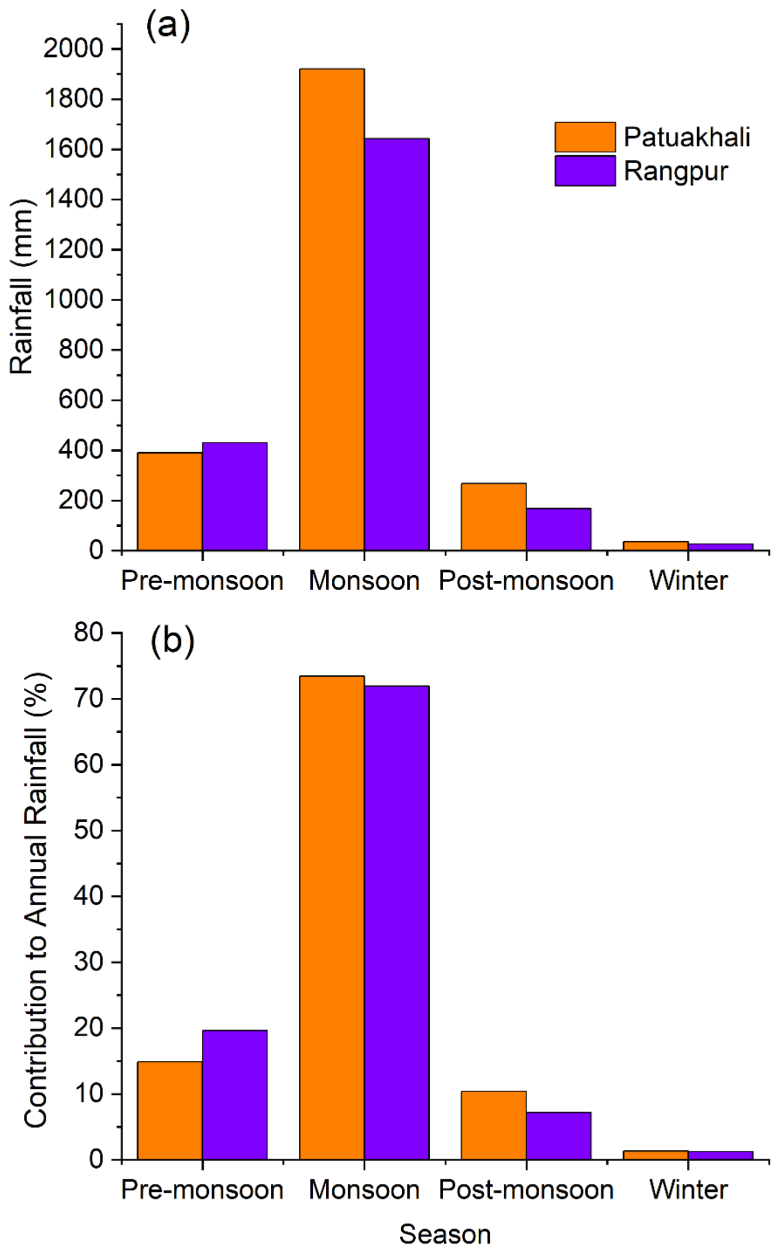

Figure 3: (a) Seasonal rainfall patterns and (b) contribution to Annual Rainfall in Patuakhali and Rangpur.

Figures 4 and 5 illustrate the rainfall variations in Patuakhali and Rangpur according to standard meteorological weeks (SMWs). In Patuakhali, the apex of precipitation transpires between SMWs 22 and 36, with maximum rainfall approaching approximately 600 mm during certain weeks. During peak periods, rainfall demonstrates a significant interquartile range (IQR) and numerous outliers, reflecting considerable variability. The 25-75% range for these periods is elevated, indicating a significant variation in average rainfall quantities. Precipitation begins to rise approximately around SMW 10, reaches its zenith between SMWs 22-36 (the normal monsoon period), and thereafter diminishes, exhibiting negligible rainfall beyond this interval (Figure 4). Rangpur exhibits a comparable pattern, with maximum precipitation occurring between SMWs 22 and 36. Nevertheless, the maximum rainfall amounts in this region reach approximately 700 mm during certain weeks (Figure 5).

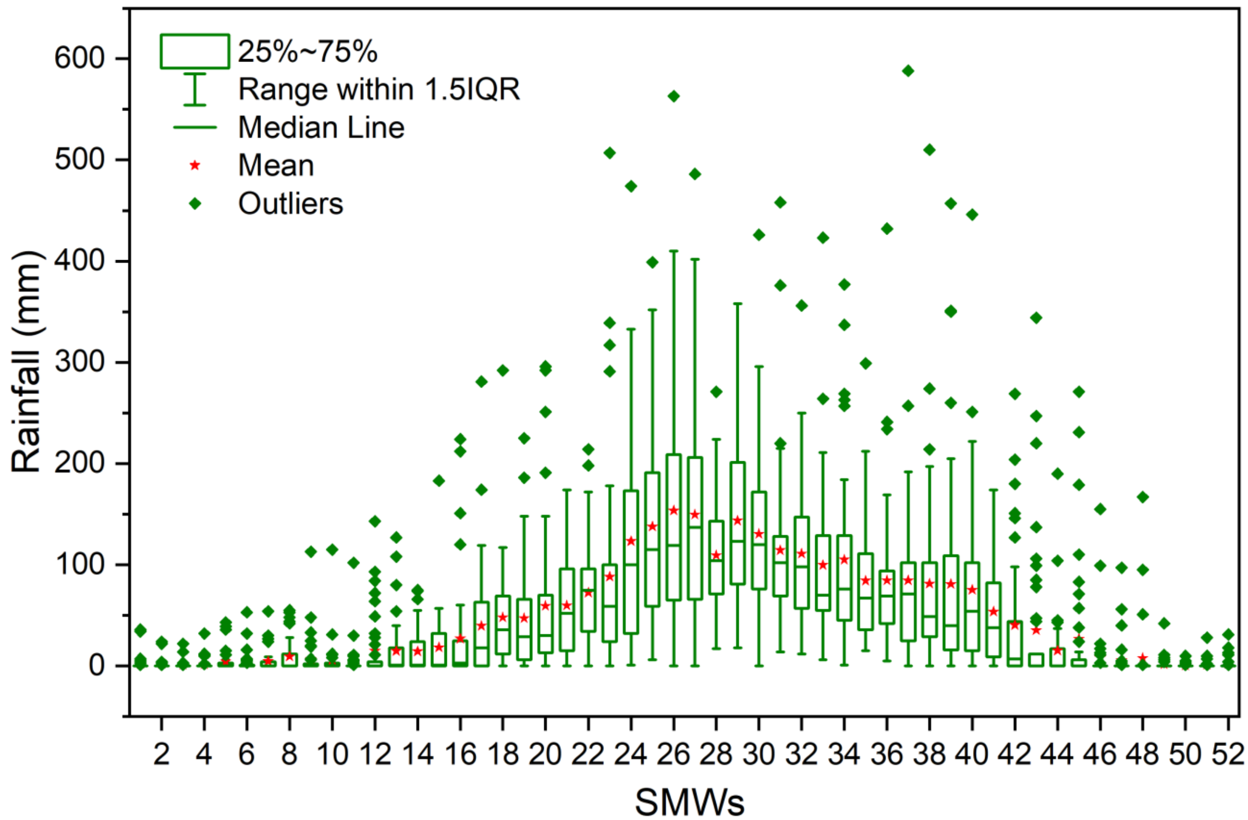

Figure 4: Box plot of weekly rainfall at Patuakhali.

Patuakhali experiences around 2000 mm of precipitation during the monsoon season, much exceeding that of Rangpur. The coastal district's closeness to the Bay of Bengal and its low altitude lead to inadequate drainage, intensifying waterlogging during the monsoon season. Intense and concentrated precipitation over a short duration result in soil saturation, and when coupled with elevated tidal inflows, waterlogged situations endure long in the monsoonal period. Prolonged waterlogging frequently causes delays in planting and harvesting for farmers in Patuakhali, particularly affecting Aman rice, the primary monsoon crop.

Despite Rangpur receiving significant monsoon precipitation (1620 mm), its inland position and elevated terrain facilitate expedited drainage. This leads to reduced waterlogging, allowing rainfall to drain more rapidly. Pre-monsoon precipitation at Rangpur marginally exceeds that of Patuakhali, offering initial moisture for crop development while avoiding excessive saturation of the soil due to enhanced natural drainage.

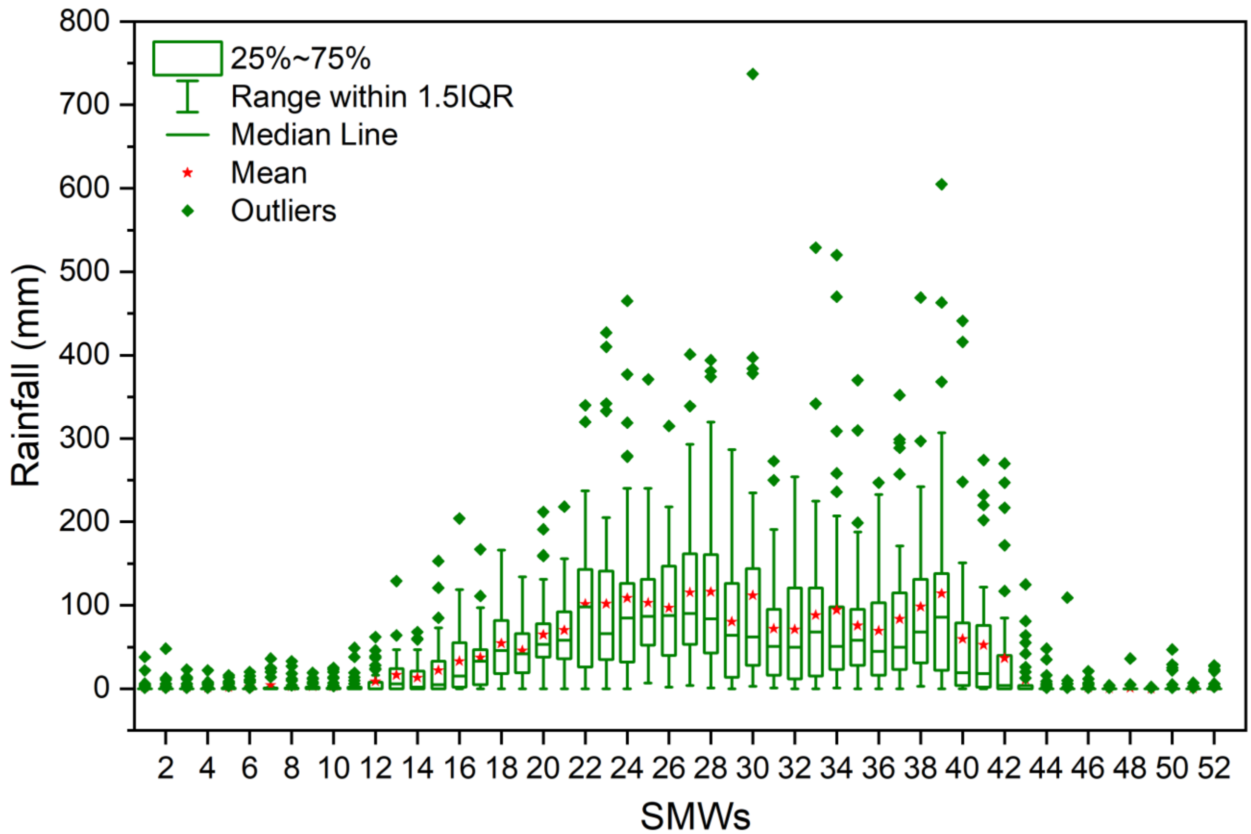

Figure 5: Box plot of weekly rainfall at Rangpur.

4.3 Onset and withdrawal of rainfall

Table 2 describes the data about the start, withdrawal, and duration of the rainy season for the Patuakhali and Rangpur stations. Weekly precipitation data revealed that the average commencement of the rainy season for both regions unfolded during the 21st Standard Meteorological Week (SMW), precisely from May 21st to May 27th. The earliest onset was documented in the 20th SMW (14th to 20th May), whereas the delayed onset was noted in the 25th SMW (18th to 24th June) for Patuakhali and in the 23rd SMW (4th to 10th June) for Rangpur.

The mean withdrawal of the rainy season in Patuakhali occurred during the 44th SMW (29th October to 4th November), although Rangpur experienced it earlier in the 42nd SMW (15th to 21st October). The initial withdrawal for both regions was recorded in the 39th SMW (24th to 30th September), whereas the final pullout transpired in the 48th SMW (26th November to 2nd December) for both regions.

Table 2: Characterization of the rainy season at the Patuakhali and Rangpur.

Particulars	Patuakhali		Rangpur	
	SMWs	Date	SMWs	Date
Mean onset	21.5	21 May–27 May	21	21 May–27 May
Earliest onset	20	14 May–20 May	20	14 May–20 May
Delayed onset	25	18 Jun–24 Jun	23	4 Jun–10 Jun
Mean withdrawal	44	29 Oct–4 Nov	42	15 Oct–21 Oct
Earliest withdrawal	39	24 Sep–30 Sep	39	24 Sep–30 Sep
Delayed withdrawal	48	26 Nov–2 Dec	48	26 Nov–2 Dec

The probability for the commencement and cessation of the rainy season were determined using Weibull's method, with results displayed in Table 3. The findings indicate a 97.62% and 85.71% probability that the onset and cessation of the rainy season will take place within the 24th and 48th SMWs, respectively for Patuakhali station. On the other hand, for Rangpur station, 97.67% and 83.72% onset and cessation of the rainy season will take place within the 22th and 48th SMWs.

Table 3: Probability of onset and cessation of the rainy season for Patuakhali and Rangpur stations.

SMW	Patuakhali		Rangpur		
	Onset (%)	Withdrawal (%)	SMW	Onset (%)	Withdrawal (%)
20	2.38		20	2.33	
21	69.05		21	86.05	
22	83.33		22	97.67	
23	90.22		39		2.33
24	97.62		40		9.30
39		2.38	41		13.95
40		4.76	42		32.56
41		7.55	43		58.14
42		11.90	44		69.77
43		28.57	45		81.40
44		42.86	48		83.72
45		59.52			
46		73.81			
47		80.95			
48		85.71			

From the onset and withdrawal data of Patuakhali and Rangpur, we observe that Patuakhali has delayed withdrawal with a mean of 44th SMW, 2 weeks later than Rangpur (42th SMW). Furthermore, the probability analysis revealed that Patuakhali has higher withdrawal probabilities starting from the 45th SMW (59.52%), which is at least 2 weeks later than Rangpur's 43rd SMW (58.14%). The delayed monsoon withdrawing in Patuakhali and its closeness to the Bay of Bengal and distinct hydro-geographical circumstances, presents difficulties for the prompt sowing of Rabi crops. The prolonged rainy season might impede soil preparation and early planting, affecting agricultural planning and productivity in the area.

4.4 MC Probability for the dry and wet spells

4.4.1 Initial and Conditional Probability

The results of initial and conditional probability for dry and wet weeks at the Patuakhali station are displayed in Table 4 for the 52 SMWs. The findings indicate that the likelihood of a dry week was elevated until the conclusion of the 17th SMW. The likelihood range for the occurrence of a dry week from the 1st to the 17th Standard Meteorological Week was between 51.22% and 97.56%. The probabilities of a dry week following another dry week (PDD) and a dry week following a wet week (PDW) ranged from 47.62% to 97.5% and 55% to 100%, respectively, for the 1st to 17th SMW periods. However, from the 18th to the 41st SMW, the likelihood of both PD and PDD was minimal. The likelihood of these weeks (18th – 41st SMW) remaining wet (PW) ranged from 63.41% to 100%. The conditional probability of a wet week following another wet week (PWW) ranged from 65.38% to 97.56%. The likelihood of dry spells was elevated once more from the 42nd SMW to the year's conclusion.

Table 4: Initial and conditional probabilities of dry and wet spells of rainfall at Patuakhali.

SMWs	Initial probabilities (%)		Conditional probabilities (%)			
	PD	PW	PDD	PWD	PWW	PDW
1	97.56	2.44	97.5	2.5	0	100
2	92.68	7.32	89.47	10.53	0	100
3	97.56	2.44	95	5	0	100
4	95.12	4.88	92.31	7.69	0	100
5	95.12	4.88	92.31	7.69	0	100
6	92.68	7.32	89.47	10.53	0	100
7	87.8	12.2	83.33	16.67	0	100
8	85.37	14.63	82.86	17.14	16.67	83.33
9	90.24	9.76	86.49	13.51	0	100
10	90.24	9.76	86.49	13.51	0	100
11	92.68	7.32	89.47	10.53	0	100
12	82.93	17.07	79.41	20.59	14.29	85.71
13	78.05	21.95	78.12	21.88	22.22	77.78
14	73.17	26.83	70	30	27.27	72.73
15	56.1	43.9	43.48	56.52	33.33	66.67
16	78.05	21.95	81.25	18.75	44.44	55.56
17	51.22	48.78	47.62	52.38	45	55
18	31.71	68.29	30.77	69.23	67.86	32.14
19	34.15	65.85	21.43	78.57	59.26	40.74
20	36.59	63.41	26.67	73.33	57.69	42.31
21	29.27	70.73	8.33	91.67	62.07	37.93
22	26.83	73.17	18.18	81.82	66.67	33.33
23	14.63	85.37	16.67	83.33	82.86	17.14

SMWs	Initial probabilities (%)		Conditional probabilities (%)			
	PD	PW	PDD	PWD	PWW	PDW
24	17.07	82.93	14.29	85.71	79.41	20.59
25	4.88	95.12	0	100	94.87	5.13
26	4.88	95.12	0	100	92.31	7.69
27	0	100	0	100	97.56	2.44
28	2.44	97.56	0	100	95	5
29	2.44	97.56	0	100	95	5
30	4.88	95.12	0	100	92.31	7.69
31	2.44	97.56	0	100	95	5
32	2.44	97.56	0	100	95	5
33	2.44	97.56	0	100	95	5
34	9.76	90.24	0	100	86.49	13.51
35	4.88	95.12	0	100	92.31	7.69
36	12.2	87.8	20	80	88.89	11.11
37	17.07	82.93	0	100	79.41	20.59
38	24.39	75.61	30	70	74.19	25.81
39	14.63	85.37	33.33	66.67	85.71	14.29
40	24.39	75.61	30	70	74.19	25.81
41	36.59	63.41	40	60	65.38	34.62
42	58.54	41.46	41.67	58.33	23.53	76.47
43	73.17	26.83	70	30	18.18	81.82
44	80.49	19.51	75.76	24.24	12.5	87.5
45	80.49	19.51	75.76	24.24	12.5	87.5
46	92.68	7.32	89.47	10.53	0	100
47	92.68	7.32	92.11	7.89	0	100
48	92.68	7.32	92.11	7.89	0	100
49	97.56	2.44	95	5	0	100
50	100	0	97.56	2.44	0	100
51	96.15	3.85	92	8	0	100
52	100	2.44	96.36	3.64	0	100

Table 5 shows for the 52 SMWs the outcomes of initial and conditional likelihood for dry and rainy weeks at the Rangpur station. The results show that the possibility of a dry week was raised right until the end of the 17th SMW. From the first to the sixteen Standard Meteorological Week, the likely range for a dry week was 61.9% to 100%. For the first to 17th SMW periods, the odds of a dry week following another dry week (PDD) ranged from 53.85% to 97.62% while the odds of a dry week following a wet week (PDW) ranged from 68.75% to 100%. But from the 17th to the 40th SMW, PD and PDD had very little probability. These weeks (17th–40th SMW) had a 61.9% to 92.86% probability of remaining wet (PW). A wet week following another wet week (PWW) has a conditional probability ranging from 52% to 89.74%. From the 41st SMW until the year's end, the probability of dry periods climbed once more.

Table 5: Initial and conditional probabilities of dry and wet spells of rainfall at Rangpur.

SMWs	Initial probabilities (%)		Conditional probabilities (%)			
	PD	PW	PDD	PWD	PWW	PDW
1	90.48	9.52	86.84	13.16	0	100
2	100	0	97.62	2.38	0	100
3	100	0	97.62	2.38	0	100
4	97.62	2.38	95.12	4.88	0	100
5	100	0	97.62	2.38	0	100
6	97.62	2.38	95.12	4.88	0	100
7	88.1	11.9	83.78	16.22	0	100
8	95.24	4.76	92.5	7.5	0	100
9	100	0	97.62	2.38	0	100
10	92.86	7.14	89.74	10.26	0	100
11	90.48	9.52	86.84	13.16	0	100
12	85.71	14.29	86.11	13.89	33.33	66.67
13	76.19	23.81	81.25	18.75	50	50
14	71.43	28.57	60	40	8.33	91.67
15	64.29	35.71	66.67	33.33	46.67	53.33
16	61.9	38.1	53.85	46.15	31.25	68.75
17	40.48	59.52	23.53	76.47	52	48
18	21.43	78.57	22.22	77.78	75.76	24.24
19	30.95	69.05	46.15	53.85	72.41	27.59
20	23.81	76.19	30	70	75	25
21	7.14	92.86	0	100	89.74	10.26
22	16.67	83.33	28.57	71.43	82.86	17.14
23	28.57	71.43	16.67	83.33	66.67	33.33
24	14.29	85.71	0	100	80.56	19.44
25	14.29	85.71	0	100	83.33	16.67
26	11.9	88.1	0	100	86.49	13.51
27	19.05	80.95	12.5	87.5	79.41	20.59
28	11.9	88.1	0	100	83.78	16.22
29	28.57	71.43	16.67	83.33	66.67	33.33
30	23.81	76.19	20	80	75	25
31	26.19	73.81	45.45	54.55	77.42	22.58
32	35.71	64.29	20	80	51.85	48.15
33	30.95	69.05	30.77	69.23	65.52	34.48
34	16.67	83.33	0	100	77.14	22.86
35	21.43	78.57	33.33	66.67	78.79	21.21
36	26.19	73.81	45.45	54.55	77.42	22.58
37	23.81	76.19	20	80	71.88	28.12
38	23.81	76.19	10	90	71.88	28.12
39	28.57	71.43	33.33	66.67	70	30
40	38.1	61.9	31.25	68.75	57.69	42.31
41	50	50	57.14	42.86	57.14	42.86
42	61.9	38.1	61.54	38.46	37.5	62.5
43	85.71	14.29	86.11	13.89	16.67	83.33
44	90.48	9.52	86.84	13.16	0	100
45	97.62	2.38	95.12	4.88	0	100
46	97.62	2.38	95.12	4.88	0	100
47	100	0	97.62	2.38	0	100

SMWs	Initial probabilities (%)		Conditional probabilities (%)			
	PD	PW	PDD	PWD	PWW	PDW
48	97.62	2.38	95.12	4.88	0	100
49	100	0	97.62	2.38	0	100
50	92.86	7.14	89.74	10.26	0	100
51	96.15	3.85	92	8	0	100
52	100	6.98	92.73	7.27	0	100

4.4.2 Consecutive dry and wet week probabilities

The analysis of consecutive dry and wet spells (Table 6) for the Patuakhali station indicated a 24.39 to 95.12% probability of two consecutive dry weeks (P2D) occurring within the first 17 weeks of the year. The likelihoods of occurrence of three consecutive dry weeks (P3D) were notably high, ranging from 11.61% to 92.74% during the first 17 weeks of the year. The values for two and three consecutive wet weeks (P2W and P3W) from the 1st to the 17th SMW were notably low, ranging from 0 to 21.95% and 0 to 9.88%, respectively. Between the 18th and 42nd SMW, the probabilities of experiencing two and three consecutive dry weeks ranged from 0 to 24.39% and 0 to 10.16%, respectively. The probability of receiving sufficient rainfall during the weeks from the 18th to the 41st SMW ranges from 41.46% to 97.56% for two consecutive wet weeks and from 27.11% to 95.18% for three consecutive wet weeks. This study indicates that the final eight weeks of the year, specifically from the 43rd to the 52nd SMW, may experience average stress levels, with probabilities ranging from 51.22% to 97.56% for the occurrence of two consecutive dry weeks. The value for three consecutive dry weeks during the period ranged from 35.85% to 95.18%.

Table 6: Analyses of the probabilities of consecutive dry and wet weeks of precipitation at Patuakhali station.

SMWs	Consecutive dry week (%)		Consecutive wet week (%)	
	P(2D)	P(3D)	P(2W)	P(3W)
1	95.12	92.74	0	0
2	82.93	74.2	0	0
3	92.68	88.05	0	0
4	87.8	81.05	0	0
5	87.8	81.05	0	0
6	82.93	74.2	0	0
7	73.17	60.98	0	0
8	70.73	58.61	2.44	0.41
9	78.05	67.5	0	0
10	78.05	67.5	0	0
11	82.93	74.2	0	0
12	65.85	52.3	2.44	0.35
13	60.98	47.64	4.88	1.08
14	51.22	35.85	7.32	2
15	30.39	14.6	14.63	4.88
16	63.41	51.52	9.76	4.34
17	24.39	11.61	21.95	9.88

SMWs	Consecutive dry week (%)		Consecutive wet week (%)	
	P(2D)	P(3D)	P(2W)	P(3W)
18	9.76	3	46.34	31.45
19	7.32	1.57	39.02	23.13
20	9.76	2.6	36.59	21.11
21	2.44	0.2	43.9	27.25
22	4.88	0.89	48.78	32.52
23	2.44	0.41	70.73	58.61
24	2.44	0.35	65.85	52.3
25	0	0	90.24	85.62
26	0	0	87.8	81.05
27	0	0	97.56	95.18
28	0	0	92.68	88.05
29	0	0	92.68	88.05
30	0	0	87.8	81.05
31	0	0	92.68	88.05
32	0	0	92.68	88.05
33	0	0	92.68	88.05
34	0	0	78.05	67.5
35	0	0	87.8	81.05
36	2.44	0.49	78.05	69.38
37	0	0	65.85	52.3
38	7.32	2.2	56.1	41.62
39	4.88	1.63	73.17	62.72
40	7.32	2.2	56.1	41.62
41	14.63	5.85	41.46	27.11
42	24.39	10.16	9.76	2.3
43	51.22	35.85	4.88	0.89
44	60.98	46.19	2.44	0.3
45	60.98	46.19	2.44	0.3
46	82.93	74.2	0	0
47	85.37	78.63	0	0
48	85.37	78.63	0	0
49	92.68	88.05	0	0
50	97.56	95.18	0	0
51	92.68	88.05	0	0
52	92.68	88.05	0	0

The study of successive dry and wet periods (Table 7) for the Rangpur station revealed a probability of 33.33% to 97.62% for the occurrence of two consecutive dry weeks (P2D) within the initial 16 weeks of the year. The probabilities of three consecutive dry weeks (P3D) were significantly elevated, varying from 17.95% to 95.29% in the initial 16 weeks of the year. The values for two and three consecutive wet weeks (P2W and P3W) from the 1st to the 16th SMW were very low, varying from 0 to 11.9% and 0 to 3.72%, respectively. From the 18th to the 42nd SMW, the likelihood of encountering two consecutive dry weeks varied between 0% and 38.1%, while the probability for three consecutive dry weeks ranged from 0% to 23.44%. The likelihood of obtaining adequate rainfall between the 18th and 41st SMW varies from 28.57% to 83.33% for two successive wet weeks and from 16.33% to 74.79% for three successive wet weeks. This study suggests that the concluding eight weeks of the year, particularly from the 43rd to the 52nd SMW, may exhibit average stress levels, with probabilities reaching 97.62% for the occurrence of two consecutive dry weeks. The value for three consecutive dry weeks during the period reaches 95.29%.

Table 7: Analyses of the probabilities of consecutive dry and wet weeks of precipitation at Rangpur station.

SMW	Consecutive dry week		Consecutive wet week	
	P(2D)	P(3D)	P(2W)	P(3W)
1	78.57	68.23	0	0
2	97.62	95.29	0	0
3	97.62	95.29	0	0
4	92.86	88.33	0	0
5	97.62	95.29	0	0
6	92.86	88.33	0	0
7	73.81	61.84	0	0
8	88.1	81.49	0	0
9	97.62	95.29	0	0
10	83.33	74.79	0	0
11	78.57	68.23	0	0
12	73.81	63.56	4.76	1.59
13	61.9	50.3	11.9	5.95
14	42.86	25.71	2.38	0.2
15	42.86	28.57	16.67	7.78
16	33.33	17.95	11.9	3.72
17	9.52	2.24	30.95	16.1
18	4.76	1.06	59.52	45.09
19	14.29	6.59	50	36.21
20	7.14	2.14	57.14	42.86
21	0	0	83.33	74.79
22	4.76	1.36	69.05	57.21
23	4.76	0.79	47.62	31.75
24	0	0	69.05	55.62
25	0	0	71.43	59.52
26	0	0	76.19	65.89
27	2.38	0.3	64.29	51.05
28	0	0	73.81	61.84
29	4.76	0.79	47.62	31.75
30	4.76	0.95	57.14	42.86

SMW	Consecutive dry week		Consecutive wet week	
	P(2D)	P(3D)	P(2W)	P(3W)
31	11.9	5.41	57.14	44.24
32	7.14	1.43	33.33	17.28
33	9.52	2.93	45.24	29.64
34	0	0	64.29	49.59
35	7.14	2.38	61.9	48.77
36	11.9	5.41	57.14	44.24
37	4.76	0.95	54.76	39.36
38	2.38	0.24	54.76	39.36
39	9.52	3.17	50	35
40	11.9	3.72	35.71	20.6
41	28.57	16.33	28.57	16.33
42	38.1	23.44	14.29	5.36
43	73.81	63.56	2.38	0.4
44	78.57	68.23	0	0
45	92.86	88.33	0	0
46	92.86	88.33	0	0
47	97.62	95.29	0	0
48	92.86	88.33	0	0
49	97.62	95.29	0	0
50	83.33	74.79	0	0
51	92.86	88.33	0	0
52	83.33	74.79	0	0

The initial, conditional, and consecutive dry and wet SMWs results derived from the MC probability model indicate that from the 16th to 18th SMWs, the rainfall or wet weeks probability got higher in both the Patuakhali and Rangpur stations, which is attributed to the heavier pre-monsoon rainfall. This increases the higher waterlogging situation in Patuakhali than Rangpur station because of the weak drainage system, lower elevation and topography, and higher soil saturation conditions. As a result, the land preparation for the Aman rice is hindered due to the waterlogged condition. This results in late transplantation of the Aman rice, often after the peak of the monsoon rainfall.

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