Journal of Agrometeorology

(A publication of Association of Agrometeorologists)

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 28 (3) : 356-365 (September - 2026)
https://doi.org/10.54386/jam.v28i3.3389
https://journal.agrimetassociation.org/index.php/jam

Research paper

An Assessment of Climatic Risk and Temporal Trend of Rainfed Crop Potential in the Sub-Himalayan Plains of West Bengal

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ABSTRACT

This study assessed water availability, climatic risk and temporal trends for *Kharif* transplanted rice and rainfed *Rabi* crops in six blocks of Alipurduar district of Sub-Himalayan West Bengal, viz, Alipurduar I & II combined, Falakata, Madarihat, Kalchini and Kumargram, using IMD gridded rainfall (1921–2020) and temperature (1951–2020) data. Trends in water availability parameters were analyzed using the non-parametric Mann–Kendall test and Sen's slope estimator, while crop water balance components and length of growing period (LGP) were estimated following the Thornthwaite & Mather, (1955) approach. *Kharif* rainfall exhibited a significant declining trend (47-87 mm/Decade) at three of the five locations. Only 20–24% (20–26 Standard Meteorological Week [SMW]) and 29–33% (28–30 SMW) of seasonal rainfall was stable and effective for transplanted rice, with lower values at Madarihat. Assured LGP exceeded 200 days in three out of four years, indicating low risk for rainfed double cropping, although LGP variability was relatively higher at Kumargram and Madarihat. For rainfed yellow sarson sown at 42 SMW, stored soil moisture met about 50% of crop water requirement, declining by 20–22 mm per fortnight with delayed sowing up to 48 SMW. Overall, water availability conditions for rainfed crops, in terms of LGP, showed improvement (1.7-2.4 days /Decade) across the study locations.

Keywords: Climatic risk, LGP, Water balance, Profile moisture at sowing

Assessment of climatic risk with respect to water availability at different crop growth stages is essential for identifying optimum sowing/transplanting time, suitable crop duration and cultivars, potential length of growing period (LGP), selection of rainfed winter crops based on profile moisture, and sustainable cropping systems. In tropical agroecosystems such as Sub-Himalayan West Bengal, rainfall assessment must consider not only total amount but also its seasonal and intra-seasonal distribution, which is often non-normal and requires probabilistic analysis. Such analyses help demarcate rainfall zones, identify onset and cessation of effective rains, mid-season dry spells and agronomically homogeneous areas (Moron and Robertson, 2014). Although rainfall provides a broad indication of crop water availability, a realistic assessment requires integration with atmospheric water demand and soil water holding capacity using climatological water balance techniques. In the context of climate change, shifts in the frequency and distribution of wet and dry periods and extreme events have been reported across agroecosystems, making it necessary to examine temporal trends in crop water availability. Similar climatological water balance–based assessments have been reported earlier. Panigrahi & Pasupalak (2018) observed that in Khorda district of Odisha, the growing season generally commenced around 24th SMW and terminated between 48th and 50th SMW depending on available water holding capacity, supporting a 120-day cereal followed by a 60-day pulse crop. Palit, (2022) recommended transplanting rainfed rice in the Red and Laterite Zone of West Bengal within mid-July to minimize water stress during reproductive and maturity stages. Oraon, (2020) reported a decline in stable rainfall availability with delayed transplanting of *Kharif* rice from 27 to 35 SMW, along with a positive temporal trend in LGP (4.7 days per decade) in Bankura district. Ghosal, (2025) classified crop growing periods based on critical moisture adequacy index (MAI) thresholds (0.5 and 0.33) while assessing rainfed cropping potential at Red and laterite zone of West Bengal. Deepika *et al.* (2024) undertook a

Article info - DOI: *https://doi.org/10.54386/jam.v28i3.3389*
Received:20 February 2026; Accepted: 28 July 2026; Published online : 7 September 2026

comprehensive study for the sixty-three mandals of Ananthapur district, Andhra Pradesh, India, to quantify MAI for each mandal to assess crop growing period along with underlined moisture stress for groundnut, maize and sorghum crop. Despite these studies, information on climatological water balance, crop water availability, and their temporal variability for the sub-Himalayan region of West Bengal, particularly Alipurduar district, remains limited. The region is characterized by high seasonal rainfall but low to moderate soil water holding capacity, where rice is the dominant *Kharif* crop followed by rainfed rape/mustard during the *Rabi* season. However, a comprehensive assessment integrating rainfall probability, water balance analysis, moisture adequacy, and temporal trends for this humid subtropical agroecosystem is somehow lacking in the existing studies Hence, investigation on these issues are essential for identifying optimum crop establishment windows, evaluating the feasibility of rainfed *Rabi* cropping, and improving climate-resilient cropping strategies under changing climatic conditions. Hence, this investigation was undertaken to (i) assess crop water availability in Alipurduar district using climatological water balance analysis, (ii) ascertain the temporal dynamics of moisture availability vis-a-vis LGP under rainfed agroecosystem, (iii) evaluate the suitability of various practicable sowing/transplanting windows for *Kharif* rice and the potential of rainfed *Rabi* cropping based primarily on profile moisture at the end of rainy season, and (iv) visualize temporal trends in crop water availability to help develop sustainable and climate-resilient cropping system planning in the Sub-Himalayan region of West Bengal.

MATERIALS AND METHODS

Data Collection

Daily Gridded Rainfall data at 0.25^{o} X 0.25^{o} resolution (Pai *et al.,* 2014) pertaining to five blocks of Alipurduar district (Alipurduar I & II combined, Falakata, Madarihat, Kalchini and Kumargram) for the period 1921-2020 and daily gridded maximum and minimum temperature data at 1^{o} X 1^{o} resolution (Srivastava *et al.,* 2009) pertaining to Alipurduar district for the period 1951-2020 were obtained from India Meteorological department portal. Daily weather data were then processed on Standard Meteorological Week (SMW) basis. Soil water holding capacity (AWHC) data, required for climatological water balance analysis were collected from Harmonized World Soil database 1.2 (FAO, 2012). As per this database, majority soils of all the blocks of this district having AWHC of 150mm/m depth.

Data Analysis

Weekly rainfall was aggregated for pre-*Kharif* (10–22 SMW), *Kharif* (23–41 SMW) and Rabi (42–9 SMW) seasons. For rice fields in eastern India, daily evapotranspiration and percolation losses were assumed to be 3–4 mm each (Singh & Singh, 2000); hence, weekly rainfall of 50 mm was considered sufficient to meet crop water requirement, with excess likely lost through runoff or deep percolation. Daily maximum and minimum temperature data (1951–2020) were used to estimate PET (ETr) using the Hargreaves & Samani (1985) method.

Table 1: Annual and seasonal rainfall along with their variabilities in different blocks of Alipurduar

Season	Statistics	Alipurduar	Falakata	Kalchini	Kumargram	Madarihat
	Mean	707.2	704.9	816.8	828.6	823.2
Pre-Kharif	SD	279.2	256.3	288.3	312.5	332.4
	CV%	39.5	36.4	35.3	37.7	40.4
	Mean	3031.9	2978.1	3373.2	2880.8	3774.6
Kharif	SD	649.4	570.0	711.6	688.7	1130.3
	CV%	21.4	19.1	21.1	23.9	29.9
	Mean	102.3	99.1	121.4	103.1	156.1
Rabi	SD	74.3	82.6	80.1	74.4	132.9
	CV%	72.6	83.4	66.0	72.2	85.1
	Mean	3841.4	3782.1	4311.4	3812.5	4753.9
Annual	SD	778.5	717.1	870.6	848.1	1403.4
	CV%	20.3	19.0	20.2	22.2	29.5

Table 2: Sen's slope (Q) (mm/year) and Z statistics (with corresponding significance level) of Mann-Kendall trend test for annual and seasonal rainfall in Alipurduar

Blocks	Pre-Kharif		Kharif		Rabi		Annual	
	Z-Value	Trend (MM/Y)	Z-Value	Trend (MM/Y)	Z-Value	Trend (MM/Y)	Z-Value	Trend (MM/Y)
Alipurduar	-0.88	-0.73	-2.11*	-4.82	-1.77	-0.35	-1.91	-5.15
Falakata	-0.70	-0.54	-0.22	-0.53	-1.06	-0.20	-0.59	-1.72
Kalchini	-0.85	-0.62	-1.87	-4.71	-2.16*	-0.52	-1.69	-5.00
Kumargram	-0.97	-0.84	-2.11*	-4.90	-0.68	-0.15	-1.93	-5.82
Madarihat	-2.09*	-2.03	-2.58**	-8.73	-2.85**	-0.97	-2.49*	-10.58

Significant at 5% (*) and 1% (**) level

Climatological water balance was computed on a weekly basis using the Thornthwaite & Mather, (1955) method, incorporating rainfall, PET and AWHC, with calculations performed using WeatherCock v1.0 software (AICRPAM-CRIDA, 2011). Moisture Adequacy Index (MAI ≈ AET/PET) derived from the water balance was used to estimate the start, end and length of growing period (LGP). The growing season was assumed to begin when MAI ≥ 0.5 (Krishnan *et al.,* 1980) and to cease when MAI declined to 0.33 (Virmani *et al*., 1982); LGP was computed as the duration between these thresholds. Soil moisture during the *Rabi* season was obtained from weekly profile soil moisture outputs.

Temporal trends in hydrological parameters were analyzed using non-parametric Mann–Kendall (Mann, 1945; Kendall, 1975) and Sen's slope (Sen, 1968) methods at the 5% significance level. Time series were smoothed using the LOWESS technique (Cleveland, 1981) implemented through the *ggplot2* package in R to better visualize trend behaviour.

RESULTS AND DISCUSSION

Annual and seasonal rainfall along with their trends and variabilities

Average annual and seasonal rainfall in Alipurduar district showed substantial spatial and temporal variability (Table 1). Annual and Kharif rainfall showed less variability (19-30%), whereas, rainfall in other seasons showed variability to the extent of 35-133%. Among blocks, Madarihat consistently recorded the

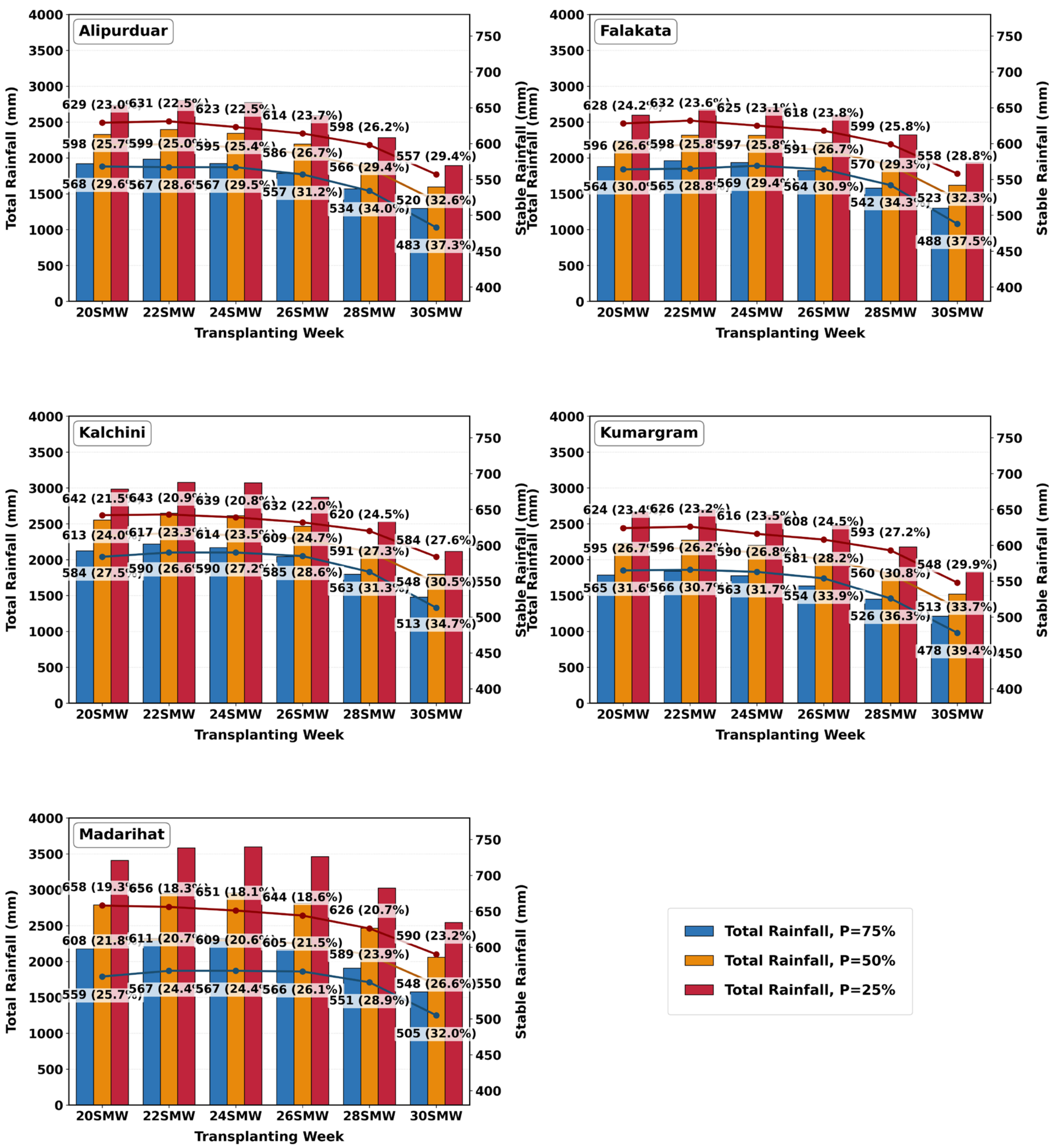

Fig. 1: Minimum expected total and stable rainfall (mm) amount at different probability level during rice growing season in different blocks of Alipurduar district

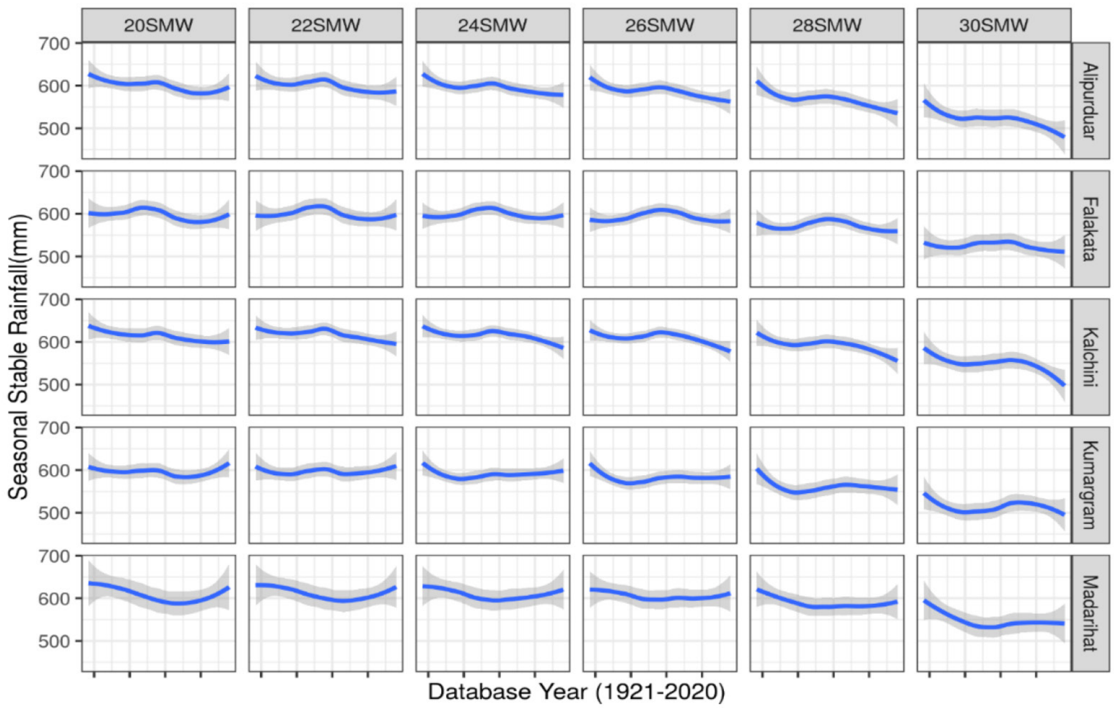

Fig. 2: Temporal trend of seasonal stable rainfall for rainfed *Kharif* rice at different transplanting date in different blocks of Alipurduar district.

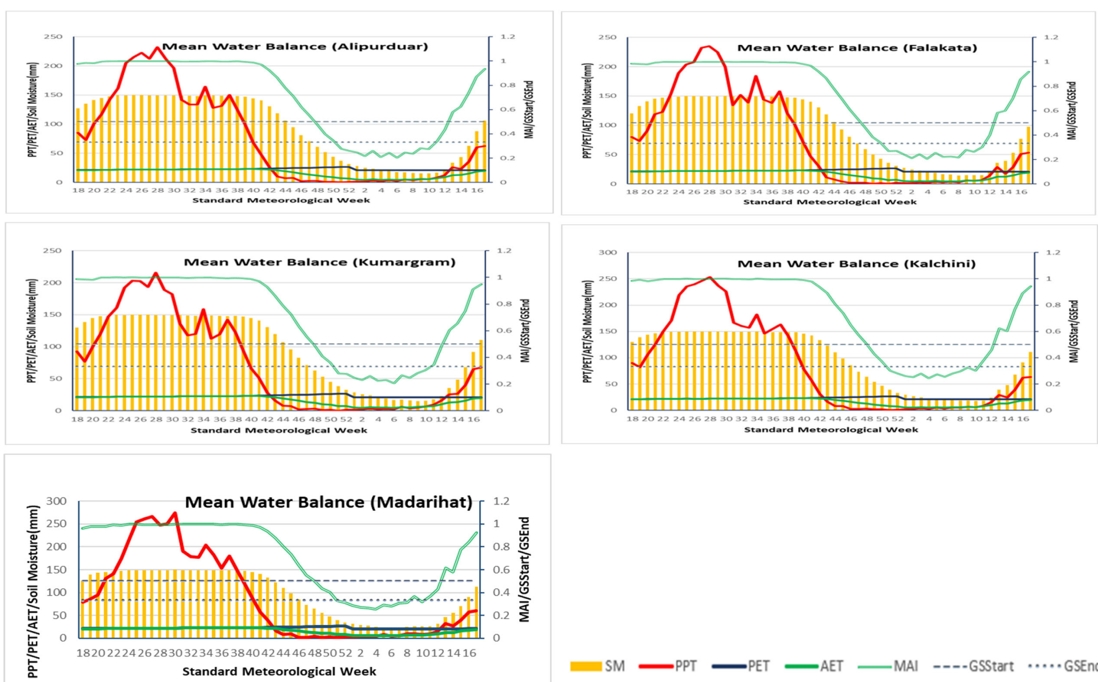

Fig. 3: Dynamics of weekly mean climatological water balance components over the year

highest seasonal and annual rainfall, except during pre-*Kharif*. Two distinct rainfall regimes were identified: Alipurduar, Falakata, and Kumargram with relatively lower rainfall, and Kalchini and Madarihat with higher rainfall. Analysis of trends showed a significant decline in annual rainfall (~106 mm/10 years) over 1921–2020, with *Kharif* rainfall decreasing significantly at Alipurduar (48 mm/10 years), Kumargram (49 mm/10 years), and Madarihat (87 mm/10 years) (Table 2). Similar negative trend of long term annual and seasonal is consistent with findings from northeastern India (Kamal & Pachouri, 2019) which is very near to the study location.

Minimum expected Total and Stable Rainfall (mm) amount at different probability

Total and stable rainfall (mm) during the *Kharif* rice

Table 3: Sen's slope (Q) (mm/year), and Z statistics (with corresponding significance level) of M-K test for total rainfall for rice transplanted at different weeks (SMW)

Transplanting week	Alipurduar		Falakata		Kalchini		Kumargram		Madarihat	
	Z-Value	Q-Trend	Z-Value	Q-Trend	Z-Value	Q-Trend	Z-Value	Q-Trend	Z-Value	Q-Trend
20 SMW	-1.96*	-4.21	-0.92	-1.51	-1.52	-3.02	-2.21*	-4.69	-2.40*	-5.79
22 SMW	-1.45	-2.77	0.13	0.30	-1.22	-2.53	-1.52	-3.49	-2.42*	-5.70
24 SMW	-1.22	-2.75	0.55	0.94	-1.02	-2.3	-1.2	-2.76	-1.95	-5.66
26 SMW	-0.75	-1.62	0.64	1.00	-0.41	-0.71	-0.79	-1.56	-1.76	-4.5
28 SMW	-0.47	-0.97	0.81	1.31	-0.55	-0.94	-0.38	-0.73	-1.56	-4.22
30 SMW	-1.46	-2.17	0.026	0.05	-1.39	-2.20	-0.93	-1.3	-2.21*	-5.04

Significant at 5% (*)

Table 4: Sen's slope (Q) (mm/year), and Z statistics (with corresponding significance level) of M-K test for stable rainfall for rice transplanted at different weeks (SMW)

Transplanting week	Alipurduar		Falakata		Kalchini		Kumargram		Madarihat	
	Z-Value	Q-Trend	Z-Value	Q-Trend	Z-Value	Q-Trend	Z-Value	Q-Trend	Z-Value	Q-Trend
20 SMW	-2.46*	-0.32	-1.3	-0.16	-2.54*	-0.2	-0.22	-0.01	-2.14*	-0.15
22 SMW	-1.62	-0.20	-1.38	-0.15	-1.78	-0.0	0.52	0.06	-1.42	-0.07
24 SMW	-1.99*	-0.27	-0.45	-0.05	-1.62	-0.08	-0.13	-0.01	-0.85	0
26 SMW	-2.57*	-0.41	-0.40	-0.05	-1.93	-0.19	-0.24	-0.03	-0.97	-0.07
28 SMW	-2.82*	-0.49	-0.73	-0.12	-2.16*	-0.33	-0.49	-0.09	-1.32	-0.19
30 SMW	-2.51*	-0.52	-0.66	-0.1	-2.05*	-0.38	-0.22	-0.05	-1.65	-0.33

growing period in Alipurduar district was computed at 25, 50, and 75% probability levels for six transplanting scenarios (20, 22, 24, 26, 28, and 30 SMW; Fig. 1). Maximum total rainfall was generally obtained at 22 SMW for all probability levels across blocks, except at 24 SMW for 25% probability in Falakata and Madarihat. Madarihat shows the widest spread in total rainfall across probability levels, whereas, Kalchini and Madarihat sustain the highest stable rainfall (mm) at earlier transplanting weeks. Considering stable rainfall, 22 SMW was also the optimal transplanting week for most blocks, with minor deviations: 20 SMW at 75% probability in Alipurduar, 24 SMW at 75% probability in Falakata, Kalchini, and Madarihat, and 20 SMW at 25% probability in Madarihat. Across all blocks, both total and stable rainfall decline as transplanting is delayed from 20 SMW to 30 SMW, while stable rainfall (%) rises for later transplanting weeks - indicating that although the absolute rainfall received is lower with delayed transplanting, a larger share of it is stable. Rainfall amounts increased up to 24 SMW and declined thereafter, suggesting that transplanting within 22–24 SMW ensures optimal water utilization. Even if transplanting is delayed to 30 SMW, the crop can still receive >500 mm stable rainfall (>75% of requirement) in one out of two years (50% probability).

Trend of total and stable rainfall during different proposed rice growing period

The annual trend of total rainfall generally decreased across transplanting scenarios in all blocks, except Falakata, where it increased at 22, 24, 26, 28, and 30 SMW (Table 3). Most trends were not statistically significant, except in Alipurduar and Kumargram at 20 SMW) and in Madarihat at 20, 22, and 30 SMW. For stable rainfall, decreasing trends were observed across most scenarios and blocks, except at 22 SMW in Kumargram (Table 4). Significant declines were recorded in Alipurduar at 20, 24, 26, 28, and 30 SMW, in Kalchini at 20, 28, and 30 SMW, and in Madarihat at 20 SMW. Consistent with Unjan *et al.,* (2017), stable rainfall decreased with delayed transplanting, with a sharper decline in Alipurduar; in Madarihat, stable rainfall increased up to 24 SMW and then plateaued (Fig. 2).

Climatological water balance components and their temporal trend

The weekly dynamics of actual evapotranspiration (AET), potential evapotranspiration (PET), water surplus, deficit, soil moisture, and moisture adequacy index (MAI) for all blocks are shown in Fig. 3. Across blocks, similar patterns were observed: from 18–42 SMW, weekly rainfall exceeded both AET and PET, so AET ≈ PET; after 42 SMW, AET fell below PET but remained above rainfall. Soil moisture was low during 2–12 SMW, increased after 14 SMW, and peaked between 18–48 SMW. The MAI exceeded 0.5 at 12 SMW (crop season start) and remained above 0.33 until ~48 SMW, yielding a length of growing period of ~252 days, supporting multiple rainfed cropping.

Annual PET trends (1951–2020) were bimodal (Fig. 4), decreasing until 1990 and increasing thereafter, which is likely due to rising temperatures under climate change impact. AET showed a similar but less pronounced pattern, reflecting its dependence on the interaction between rainfall and soil moisture dynamics.

Start, end and length of crop growing period

Climatic risk for the start, end, and length of the crop growing period (LGP) at five blocks of Alipurduar district at 25% and 75% probability levels is presented in Table 5. The mean start

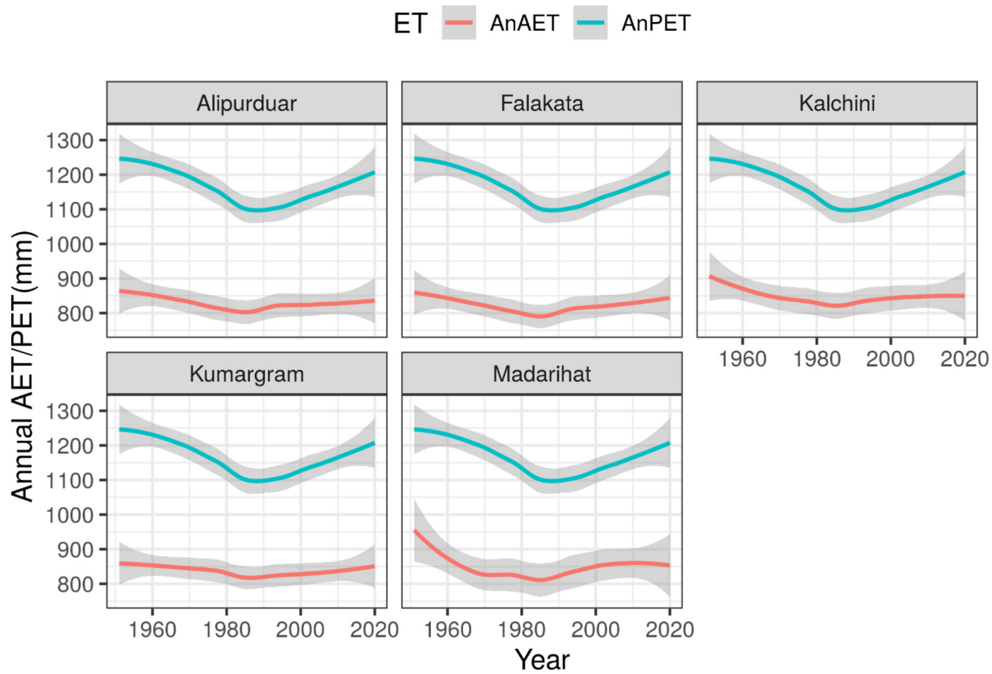

Fig. 4: Temporal trend of annual actual (AET) and potential evapotranspiration (PET) in different blocks of Alipurduar district

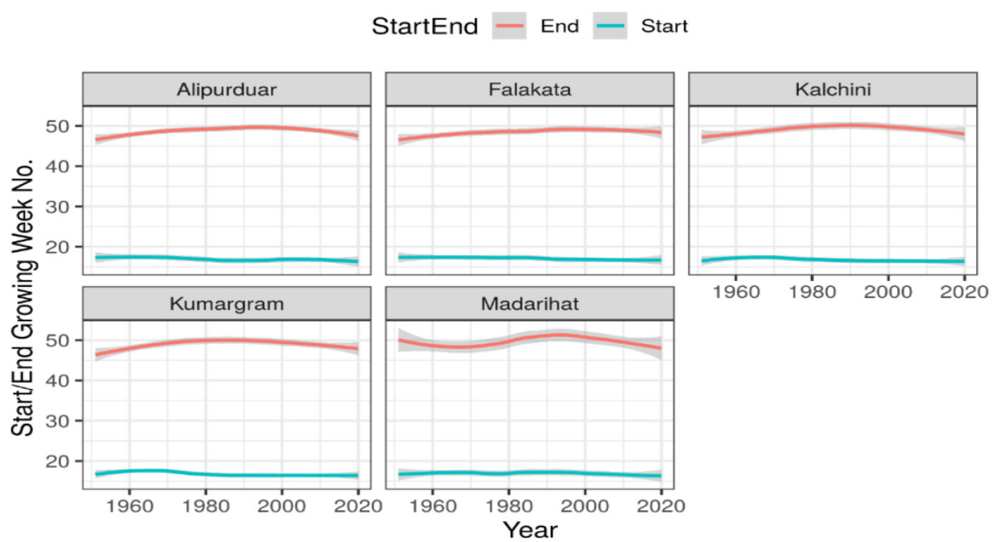

Fig. 5: Temporal trend of starting and ending weeks (Week No.) of rainfed crop growing season in different blocks of Alipurduar district

week was 16 SMW and mean end week 49 SMW, with the highest variability in Madarihat. At 25% probability, start weeks ranged 14–15 SMW and end weeks 50–51 SMW, giving LGP of 246–258 days; at 75% probability, start weeks ranged 17–18 SMW and end weeks 47–48 SMW, yielding 209–225 days. These results suggest farmers with supplementary irrigation can plan cropping based on the 25% probability LGP (Mugalavai *et al*., 2008; Kumari *et al*., 2019; Sattar *et al.,* 2019). The result indicates that farmers with lower risk bearing ability can sow upland rainfed crop as early as 17 SMW (23-29 May) where the success rate is assured for 3 out of 4 years (75% probability).

Temporal trends showed an advancing (earlier) start week and a delaying end week in most blocks, resulting in a significant increase in LGP (17–24 days/10 yr). In Alipurduar and Kumargram, the start week trend was significant, while in Falakata only the end week trend was significant (Table 6). End week increased slightly from 1980–2000 and then declined, particularly in Madarihat, whereas, start week remained relatively stable (Fig .5).

Box plot analyses indicated lowest LGP variability in Alipurduar and highest in Madarihat (Fig. 6a). LGP distribution was positively skewed in Kalchini and Kumargram and negatively

Table 5: Climatic risk of start, end and length of crop growing period at Alipurduar district at different probability levels

Station	Risk Levels	Start.Week	End Week	Length of Growing period (Days)
Alipurduar	Mean	16	49	233
	Standard Deviation	2.1	1.7	18.7
	At 25% probability	15	50	246
	At 75% probability	18	48	221
Falakata	Mean	16	48	232
	Standard Deviation	2.3	1.8	21.0
	At 25% probability	15	50	246
	At 75% probability	18	47	217
Kalchini	Mean	16	49	238
	Standard Deviation	2.1	2.1	19.8
	At 25% probability	14	50	251
	At 75% probability	17	48	225
Kumargram	Mean	16	49	241
	Standard Deviation	2.7	2.1	25.6
	At 25% probability	14	51	258
	At 75% probability	18	48	223
Madariat	Mean	16	49	231
	Standard Deviation	2.9	2.2	32.0
	At 25% probability	14	51	252
	At 75% probability	18	48	209

Table 6: Sen's slope (Q) (mm/year), and Z statistics (with corresponding significance level) of Mann-Kendall trend test for start, end and length of growing season in Alipurduar

Station	Rainfall	Z value	Q Trend	Significance
Alipurduar	Starting week (No)	-2.065	-	Yes
	Ending week (No)	1.439	-	No
	Length of Growing Period (Days)	2.267	0.171	Yes
Falakata	Starting week (No)	-1.759	-	No
	Ending week (No)	2.377	0.020	Yes
	Length of Growing Period (Days)	3.002	0.246	Yes
Kalchini	Starting week (No)	-1.712	-	No
	Ending week (No)	1.640	-	No
	Length of Growing Period (Days)	2.035	0.163	Yes
Kumargram	Starting week (No)	-2.184	-	Yes
	Ending week (No)	1.126	-	No
	Length of Growing Period (Days)	2.382	0.226	Yes
Madarihat	Starting week (No)	-1.011	-	No
	Ending week (No)	1.054	-	No
	Length of Growing Period (Days)	2.060	0.226	Yes

skewed in other blocks. Interannual trends (Fig. 6b) showed LGP of 200–220 days before 1960, increasing up to 1990 and then decreasing in Alipurduar, Falakata, Kumargram, and Kalchini. In Madarihat, interannual variability was higher, with decreasing LGP until 1970, increasing to 1990, and declining thereafter.

Profile soil moisture at the start of the Rabi crop growing season

In alternate years (50% probability), around 140 mm/m profile soil moisture at sowing can be expected for yellow sarson in all Alipurduar blocks if sown at the start of 42 SMW, satisfying up to 50% of its seasonal water requirement (~300 mm) (Table 7). Each fortnight delay from 42 to 48 SMW reduces profile moisture by 20–22 mm/m, resulting in 80–86 mm/m at 48 SMW. Results show that if sowing of yellow sarson is done early in the *Rabi* season (42 SMW) a farmer can expect a moderate yield only with initial profile stored moisture even without any winter rainfall. However, for delayed sowing of rainfed crops, moderate yield is not assured

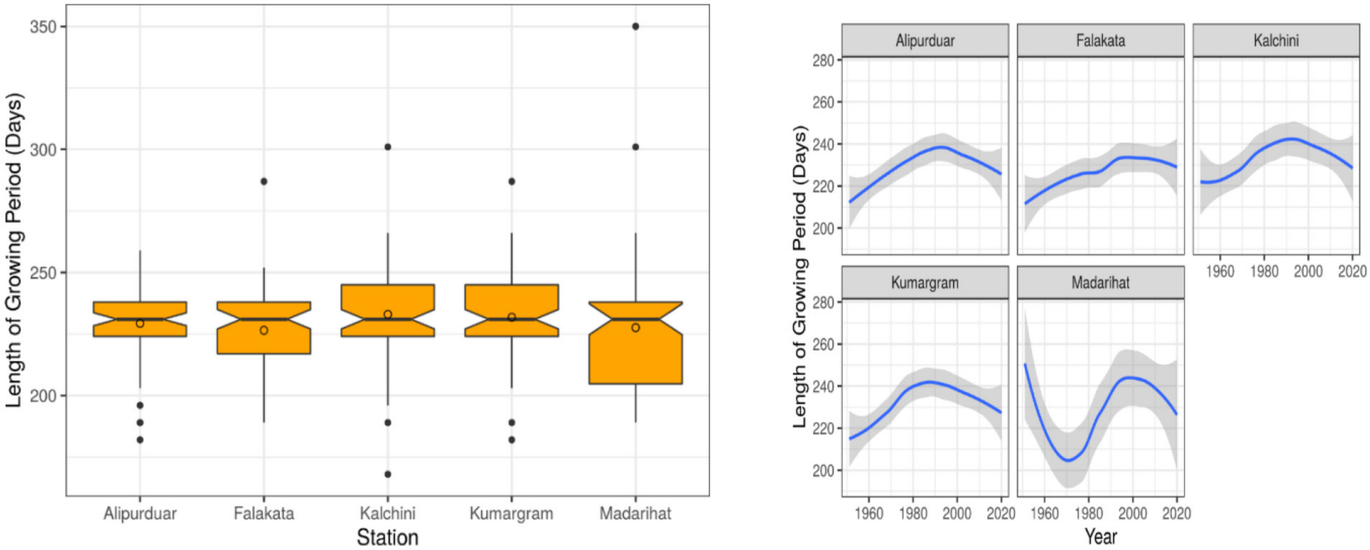

Fig. 6: Variability (a) and temporal trend (b) of length of crop growing period (days) under rainfed condition in different blocks of Alipurduar district

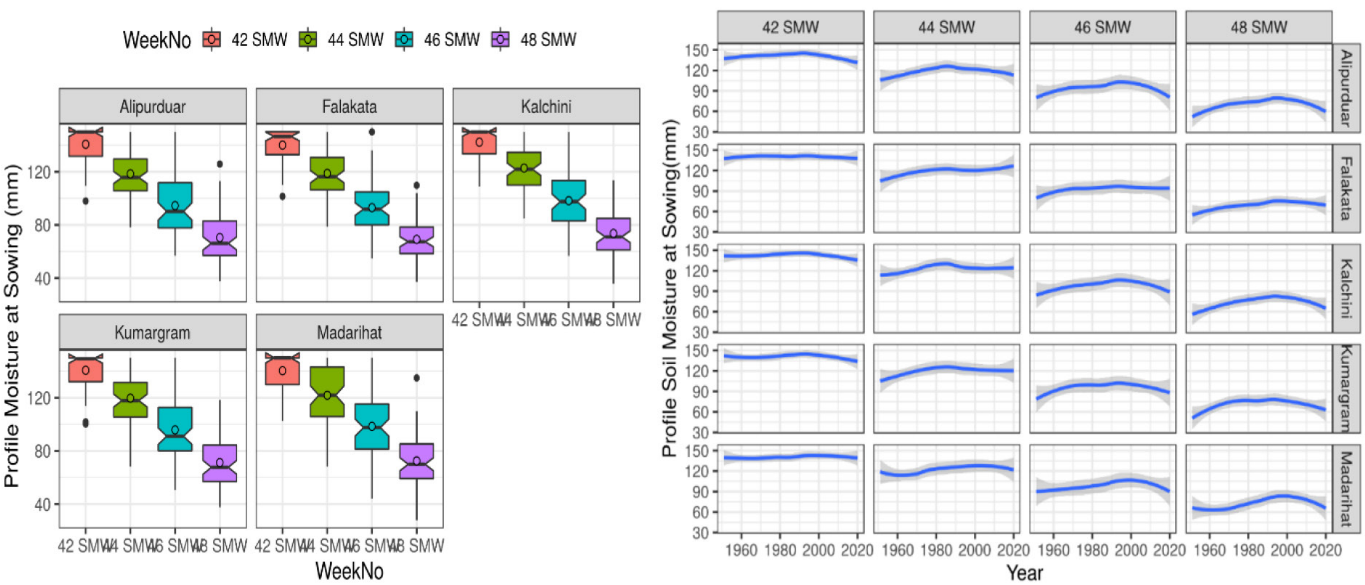

Fig. 7: Variability (a) and temporal trend (b) of profile soil moisture at various sowing weeks of rainfed *Rabi* crops in different blocks of Alipurduar district

without winter rainfall. Using a similar climatological water balance approach, reduction of profile soil moisture at sowing due to successive delay in sowing during *Rabi* season beyond 40 SMW at the Red and Laterite Zone of West Bengal was also obtained by Ghosal, (2025) and for Bankura district of West Bengal by Oraon, (2020).

Boxplot analysis (Fig. 7a) shows decreasing soil profile moisture with delayed sowing across all five blocks. The Figure also indicate that the extent of variabilities is almost similar for 44 to 46 SMW, whereas, it is comparatively much lower during 42 SMW indicating maximum soil moisture availability immediately after cessation of monsoon.

Temporal trends (1951–2020, Fig. 7b) indicate profile moisture decreases from 120–160 mm at 42 SMW to 50–60 mm at 48 SMW. Post-2000, moisture trends generally declined across all weeks and blocks, except in Falakata, where 42 and 46 SMW trends remained stable and 44 SMW increased.

CONCLUSION

Annual and seasonal rainfall showed a declining trend across all locations, significant only in Madarihat. *Kharif* rainfall decreased significantly in three of five locations. If transplanted up to first Week of July, 90-95% of water requirement of rainfed rice crop can be met from distributed stable rainfall assuring stable yield in most of the years. Assured LGP exceeds 200 days in three

Table 7: Climatic risk of profile soil moisture (mm/m) at the start of the rabi crop growing week

Block	Rabi Sowing Week	Probability levels for Initial Profile Moisture (%)		
		25	50	75
Alipurduar	42	149.2	140.7	132.2
	44	130.9	118.5	106.0
	46	109.7	94.5	79.3
	48	83.1	70.5	57.8
Falakata	42	148.4	140.1	131.8
	44	131.5	118.8	106.1
	46	107.1	93.0	79.0
	48	80.5	69.1	57.8
Kalchini	42	149.9	142.3	134.7
	44	135.4	122.8	110.3
	46	113.3	98.3	83.3
	48	86.3	73.6	60.9
Kumargram	42	149.1	140.7	132.2
	44	133.3	119.7	106.1
	46	111.3	95.8	80.4
	48	84.4	71.2	58.1
Madarihat	42	148.6	140.3	132.0
	44	135.8	121.9	107.9
	46	114.7	98.5	82.3
	48	86.5	72.5	58.6

out of four years, allowing double cropping (medium-duration rice 110–115 days followed by yellow sarson in medium–fine soils) under rainfed conditions with minimal risk. Annual LGP variability is slightly higher in Kumargram and Madarihat. The best sowing window for yellow sarson is 42 SMW (15-21 Oct) that provides initial profile moisture sufficient for 50% of crop water needs. However, successive delay in sowing reduces 20–22 mm per fortnight up to 48 SMW. Overall, water availability for rainfed crops, in terms of LGP, showed an increasing trend up to around year 2000 and then registered a little declining trend. Results of this study can be utilised for proper crop planning with respect to a rainfed rice-yellow sarson cropping system.

ACKNOWLEDGEMENT

The authors acknowledge the support received from the Department of Agricultural Meteorology and Physics, BCKV for providing necessary computation facilities for the proper conduction of the present work.

Author's certificate: The manuscript or its part is not under consideration for publication elsewhere and the same has been approved by all co-authors.

Conflict of Interests: The authors declare that there is no conflict of interest regarding the publication of this article.

Funding: No funding agency was involved.

Data Availability: Data to be provided on request.

Author's contribution: **A. Roy:** Data collection, Data analysis, Manuscript preparation, Visualization; **A. Saha:** Conceptualization, Supervision, Methodology; **M. Naskar:** Review collection, Manuscript preparation, Editing.

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