



Climate-smart agriculture: Leveraging weekly rainfall trends for rainfed crops in West Bengal

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ABSTRACT

Rainfall variability has a significant impact on rainfed agriculture, crop planning and cropping patterns in diverse agro-climatic zones. Considering this important aspect of agriculture the present study, was carried out to analyse previously available meteorological data and find out different weather trends regarding rainfall and determine suitable time periods for agricultural activities in the study area. The study used incomplete gamma probability, initial and conditional probability and consecutive probability of weekly rainfall across Baharampur, Midnapore, Darjeeling, Sagar Island and Sriniketan regions of West Bengal. Conditional probability analysis was helpful for identifying the transition period from dry spell to wet spell and vice versa while consecutive probability analysis helped in identifying sustained rainfall or dry period. The study revealed that Baharampur had high probability of dry spell and limited sowing opportunities, while Midnapore recorded early and extended wet spell suitable for rainfed agriculture starting from 13th standard meteorological week (SMW). Darjeeling experienced concentrated monsoon from 22nd–40th SMW and Sagar Island had wet spell from 23rd–39th SMW followed by long dry spell whereas Sriniketan depicted a widespread monsoon week starting from 16th SMW to 43rd SMW. Thus, the findings could help in planning crop cycle adjustment as well as contingency plans for a climate resilient agriculture.

Keywords: Conditional probability, Initial probability, Markov chain model, Rainfall probability, Wet and dry spell

A significant part of Asia relies heavily on monsoonal rains for agricultural production. Additionally, evidences suggest that substantial climatic variations occur at the micro-regional level, impacting the distribution of rainfall across various parts of Asia. Precipitation, specifically rainfall, stands out as the most crucial climatic variable for hydrologists and water professionals. The analysis of rainfall data properties and trends holds significant interest for hydrologists, meteorologists and anyone seeking insights into the impact of climate change on water availability and management (Jain *et al.* 2023). The timing of the onset and withdrawal of the rainy season is intricately connected with the preparation of the crop-weather calendar. This linkage enhances the comprehension of the crop growing period, the optimal dates for sowing and harvesting of specific crops in each region and the critical growth stages of the crop that will encounter either rainfall or dry conditions (Manna 2023). Therefore, conducting research on climate change,

particularly focusing on changes in rainfall patterns and their distribution, is essential for sustainable water resource management (Meshram *et al.* 2017).

Taking into consideration the studies by Singh *et al.* (2008) in Pusa, Bihar, Dugal *et al.* (2018), Kumar *et al.* (2018) and Ray (2016) in Odisha, Kumar and Bharadwaj (2015) in Ludhiana, Punjab, Alam *et al.* (2016) in Bundelkhand, Madhya Pradesh and Ghosh *et al.* (2014) in Raghunathpur and Manna (2023) in districts of Nadia, North 24 Parganas, Purba Bardhaman, Howrah and Hooghly in West Bengal as well as reports of Fujibe *et al.* (2005) and Gadedjisso-Tossou *et al.* (2021) outside India, our present research work was based on the probability analysis of rainfall covering Baharampur, Midnapore, Darjeeling, Sagar Island and Sriniketan with the aim to find out different weather trends regarding rainfall and determine suitable time periods for agricultural activities.

MATERIALS AND METHODS

The study mainly focused on major agro-climatic zones of West Bengal i.e. Hill zone (Darjeeling), Gangetic alluvial zone (Sriniketan, Baharampur), Red and lateritic zone (Midnapore) and Coastal saline zone (Sagar Island).

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Daily weather data (rainfall, maximum and minimum temperature) from 1969 to 2007 for Darjeeling, Midnapore and Sagar Island; 1969–2008 for Sriniketan and 1970–2007 for Baharampur were collected from Indian Meteorological Department. Analysis of weekly dry spell and wet spell was carried out by using the weekly rainfall data on Markov chain statistical model considering 10 mm rainfall as baseline, which means <10 mm rainfall was considered as dry week and >10 mm as wet week. Probability of occurrence of rainfall at 90%, 75%, 50%, 25% and 10% levels were analysed using incomplete gamma probability distribution by using WEATHER COCK software developed by ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana for weather data analysis (Rao 2011). Wet week preceded by a wet week (W/W) and dry week preceded by dry week (D/D) denotes continuity of rainy weeks and dry spells, respectively. Wet week preceded by dry week and dry week preceded by wet week are denoted as (W/D) and (D/W), respectively. Different notations mentioned under this analysis are elaborated as follows:

Initial probability: Initial probability was calculated using the formula:

$$P(W_i) = \frac{F(W_i)}{N}$$

$$P(D_i) = \frac{F(D_i)}{N}$$

Where, $P(W_i)$, Initial probability of i^{th} week being wet; $P(D_i)$, Initial probability of i^{th} week being dry; $F(W_i)$, Frequency of i^{th} week being wet; $F(D_i)$, Frequency of i^{th} week being dry; N , Total number of years data considered for analysis.

Conditional probability:

$$P(W/W) = \frac{F(WW_i)}{F(W_i)}$$

$$P(D/D) = \frac{F(DD_i)}{F(D_i)}$$

Where, $P(W/W)$, Probability of a wet week preceded by another wet week in i^{th} week of the year; $P(D/D)$, Probability of a dry week preceded by another dry week in i^{th} week of the year; $F(WW_i)$, Frequency of wet week preceded by a wet week in i^{th} week of the year; $F(DD_i)$, Frequency of a dry week preceded by another dry week in i^{th} week of the year.

Incomplete gamma probability: Incomplete gamma probability was analysed according to Victor (2000) using the formula:

$$f(x) = \frac{\left(\frac{x-\alpha}{\beta}\right)^{\gamma-1} \exp\left(-\frac{x-\alpha}{\beta}\right)}{\beta\Gamma(\gamma)} \quad X \geq \alpha, \gamma, \beta > 0$$

Where γ , Shape parameter; α , Location parameter; β , Scale parameter and Γ , Gamma function.

Gamma function was derived using the formula:

$$\Gamma(\alpha) = \int_0^\infty t^{\alpha-1} e^{-t} dt$$

Where α , 0; β , Standard gamma distribution.

The equation of standard gamma distribution reduces to,

$$f(c) = \frac{x^{\gamma-1} e^{-x}}{\Gamma(\gamma)} \quad x \geq \gamma > 0$$

Analysis of weekly rainfall probability: Weekly rainfall probabilities were calculated through module named ‘Incomplete gamma probabilities.exe’ and ‘Initial and conditional probabilities of rainfall’. The later is commonly known as Markov chain probability analysis. Station-wise weekly rainfall data was used as an input to obtain the weekly probability of rainfall at a level of 90%, 75%, 50%, 25% and 10%.

Analysis of consecutive dry and wet weeks: The ‘Probability of wet and dry weeks’ module in the software calculates the probability of experiencing two, three or four consecutive weeks as wet weeks, defined by receiving a given amount of rainfall. Conversely, it also assesses the likelihood of encountering consecutive dry weeks, characterised by receiving less than the specified amount of rainfall, over two, three or four weeks. By analysing weekly rainfall data into the module, the software analysed the percentage probability of experiencing either consecutive wet weeks (2W, 3W or 4W) or dry weeks (2D, 3D or 4D) accordingly.

RESULTS AND DISCUSSION

Incomplete gamma probability: For Baharampur, most of the weeks [up to Standard Meteorological Week (SMW) 22], rainfall at 90% probability was below 5 mm, suggesting high risk of dry period which implies that farmers’ should not rely on rainfall during these weeks for sowing of seeds unless supported by irrigation. From 23rd to 37th, week assured rainfall at 90% probability ranged from 5.4–17.5 mm while during 23rd–40th week, rainfall was assured to happen for each probability levels, suggesting peak monsoon season and a proper sowing window for rainfed crops. From week 41st, rainfall amount at all the probability levels decreased gradually, signifying the withdrawal of the monsoon season (Fig. 1A).

In Midnapore, at 90% probability, weeks 13th–25th is expected to have rainfall more than 7 mm. According to the previous data records during this period, at 50%, 25% and 10% probability, expected rainfall varied from 48–71 mm, 73–123 mm and 103–189 mm suggesting the peak monsoon season. Thus, in Midnapore, week 13th–17th can be identified as sowing window, where the vegetative stage will fall within 18th–22nd week, followed by reproductive phase (Fig. 1B).

In Darjeeling, expected rainfall at 90% probability was found to be <5mm for the weeks 1st–17th and from 37th–52nd. Sowing seed without having irrigation facility should be avoided during this period. From week 22nd–40th, assured rainfall varied from 2.0–8.6 mm at 90% probability and 32.8–67.9 mm at 50% probability with an expectation

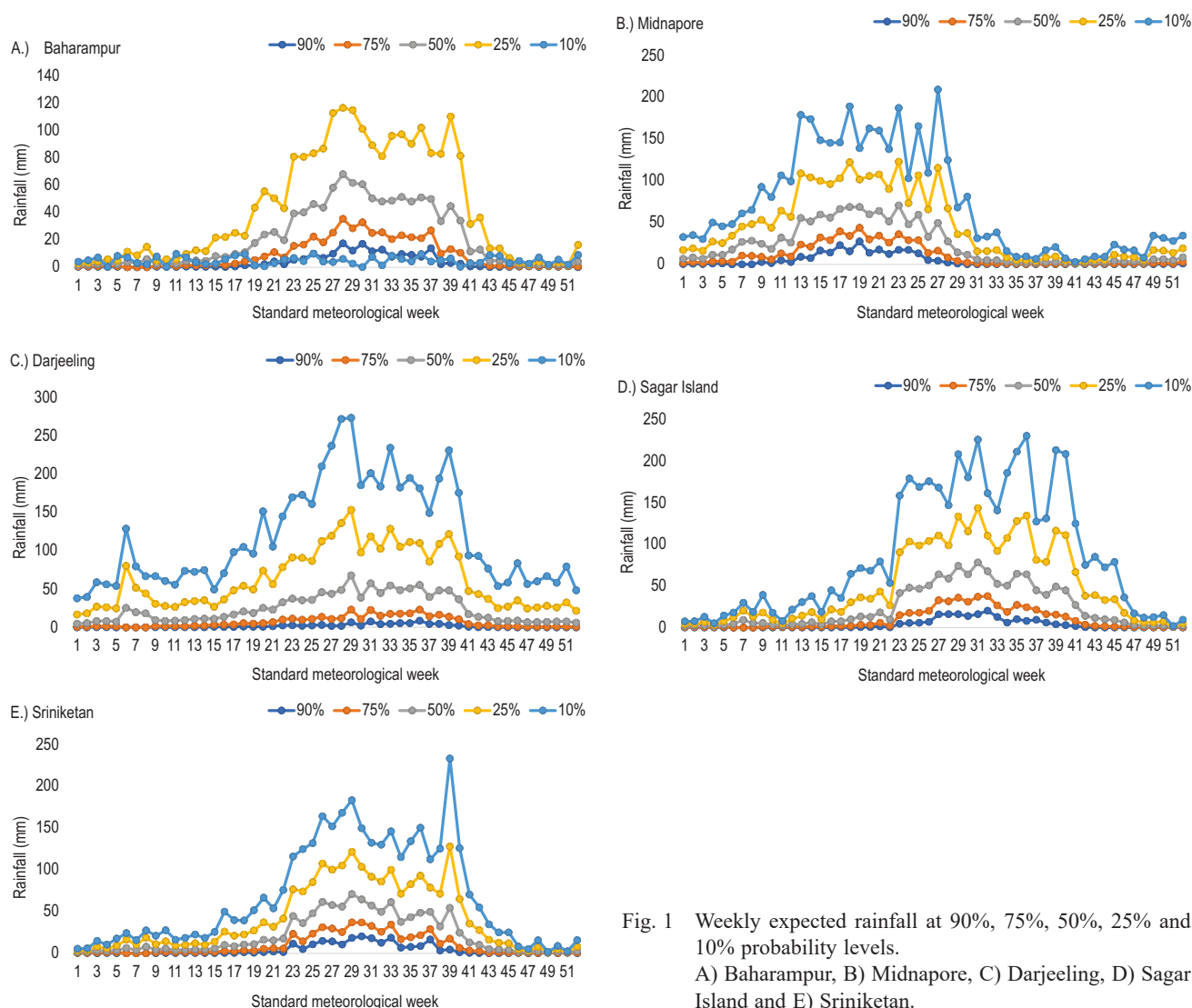


Fig. 1 Weekly expected rainfall at 90%, 75%, 50%, 25% and 10% probability levels. A) Baharampur, B) Midnapore, C) Darjeeling, D) Sagar Island and E) Sriniketan.

of 78.6–153.4 mm at 25% probability and 144–273 mm of rainfall at 10% probability (Fig. 1C).

In Sagar Island, 1st–16th and 47th–52nd weeks received <5 mm of rainfall at 90% probability while 23rd–37th weeks received 4.6 mm to 20.3 mm of rainfall with 90% assurance establishing 23rd–39th weeks as monsoon window. Meanwhile, in Sriniketan, 1st–14th and 44th–52nd weeks registered assured rainfall at 50% and 10% probability with 1.6–7.9 mm and 1.1–4.6 mm at 50% probability and 5.4–27.5 mm and 5–24.9 mm of rainfall at 10%, respectively. From week 16th–43rd, rainfall amount in all probability levels increased, indicating active monsoon period whereas amount of rainfall during 23rd–33rd week rose to 44–71 mm at 50% probability level. Week 29 had the chance of getting 70.9 mm rainfall at 50% probability and 183.2 mm rainfall at 10% probability indicating possibility of severe weather condition. Towards the end of the monsoon season, week 39 showed last heavy rainfall of 54.4 mm at 50% probability, with extreme event reaching 233 mm with 10% probability (Fig. 1D and E). Thus, probability-based analysis of rainfall is very much useful for identifying the

sowing window and accordingly planning for rainfed crops can be done (Manna 2023).

Initial probability: The probability of occurrence of 10 mm of assured rainfall ranged from 0–97% in Baharampur where 70% of the weeks had <30% probability of having 10 mm rainfall indicating a predominance of dry condition. Probability of dry spell was more frequent with an average of 70% while in Midnapore, 28 out of 52 weeks had more than 50% probability of wet spells, suggesting higher wet spell probability than Baharampur in which 13th to 25th week data showed distinct phases of wet spells with 85–100% probability of 10 mm of rainfall while 35th–48th SMW had 90–100% probability of having dry spell (Supplementary Table 1A and B).

Probability of wet spells ranged from 21% to 92% with 75% of the weeks having probability of wet spells more than 40% in Darjeeling. The wettest spell was identified between 22nd to 38th week with 74–92% probability of assured rainfall while the probability of dry weeks were mostly limited between 47th–7th meteorological week (Supplementary Table 1C).

In Sagar Island, the probability of wet weeks ranged from 0–100%, the probability of wet spells was low i.e. 8–18% and 0–18% during 1st–4th SMW and 47th–52nd week, respectively whereas higher chances of occurrence of wet spells was observed between 23rd to 39th week (with 82–100% chances of occurrence) whereas in Sriniketan, dominance of dry spell was observed from 1st–7th week and from 46th–52nd week but occurrence of wet spells was predominant from 23rd–37th week (Supplementary Table 1D and E). The assessment of initial probability for dry and wet spell using weekly rainfall values provides a useful contribution for understanding rainfall persistence and requirement of irrigation if any (Barman *et al.* 2024).

Conditional probability: The persistence of wet days was observed with more than 75% probability in 12th, 18th and 21st–37th SWM in Baharampur while continuity of dry spell was observed from 1st–14th week with more than 80% chances of occurrence and from 45th–52nd week with 85–100% probability. Chances of dry week after a rainy week with a probability of 75–100% was observed from

6th–11th week and the severity of dry week continuation was observed in 46th, 47th, 49th and 51st week. Chances of rainy week after a dry spell were observed from 20th–32nd week with 67–100% probability level and from 34th–40th week with 78%–100% probability (Supplementary Table 1A).

In Midnapore, continuation of wet spell was observed from 7th–15th Week (66–94% chance), 17th–24th week (89–100% chance) and 25th–27th week (80–89% chance), while continuation of dry spell was observed to occur from 32nd–45th week (83–100% chance) with peak dry season (100% probability) in 41st week. Probability of dry spell after a rainy week was observed from 31st–33rd week, 35th–36th, 40th–41st, 43rd and from 45th–48th week. Confirmed wet spell after a dry week (100% probability) was expected on 15th, 17th, 19th–21st and 23rd–25th week (Supplementary Table 1B).

In case of Darjeeling, continuous wet spell occurrence was observed during 17th–18th and 21st–40th weeks with 85–100% probability while continuous dry spells with >85% probability were observed from 47th–52nd weeks

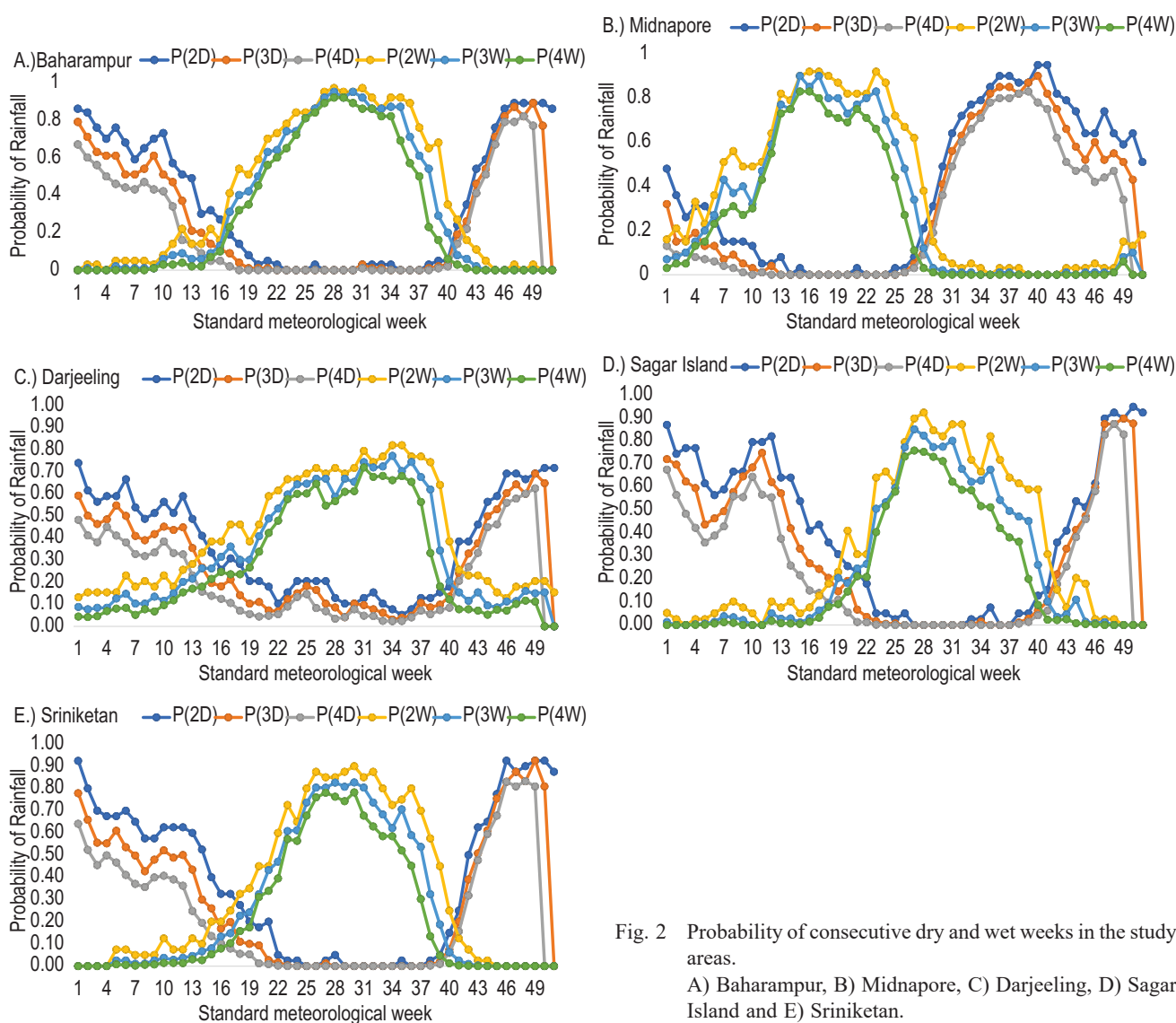


Fig. 2 Probability of consecutive dry and wet weeks in the study areas.

A) Baharampur, B) Midnapore, C) Darjeeling, D) Sagar Island and E) Sriniketan.

and 1st–2nd week. The chances of getting a wet spell after dry period varied from 0 to 75% probability and chances of getting a dry spell after wet spell varied from 25% to 100%. This signifies the dominance of persistent wet season in Darjeeling (Supplementary Table 1C).

In Sagar Island, strong tendency of persistence of wet spell was observed between 23rd–39th week with 82–100% probability whereas persistent dry spell was observed from 1st–5th week (85–91% probability), 11–13th week (88–93% probability) and from 48th–52nd week (90–100% probability), signifying the prolonged dry spell before and after the monsoon season in Sagar Island. Occurrence of wet period after a dry spell was observed in segregated manner starting from 23rd–27th week (80–100% chances) whereas week 29th–34th and 37th–40th were severely wet (100% chances). Assured dry spell after a wet week was expected on 1st, 4th, 50th and 51st week with 100% probability (Supplementary Table 1D).

In Sriniketan, dominance of dry spell was observed in the 49th and 51st week, with probability reaching 100%. High chances of getting consistent wet spell were expected from 23rd–37th week with >90% probability. The consistency of dry week followed by a wet spell was observed from 46th–49th, 51st and 1st–5th weeks and wet week followed by a dry spell was observed during 26th–27th, 30th–35th and 37th–38th SMW with 100% chances of occurrence (Supplementary Table 1E). The persistence and transition between dry and wet spells provide essential information regarding stable rainy period, dry spells in between two wet spells for effective crop management decisions (Dabral *et al.* 2026).

Probability of consecutive dry and wet weeks: Figure 2 depicts the probability of consecutive dry and wet weeks in all the study areas. Two and three consecutive dry weeks with 89% probability level chances were observed from 47th–50th weeks and 49th week respectively, whereas chances of four consecutive dry weeks were observed in 48th week with 82% probability. Similarly, probability of consecutive two and three wet weeks were observed with higher probability levels in 28th week (97%), 31st, 28th and 30th week (95%) and 28th–29th week (92%), respectively in Baharampur (Fig. 2A).

In Midnapore, consecutive 2, 3 and 4 dry weeks were recorded in 40th–41st week, 40th week and 39th week with 95%, 90% and 83% probability, respectively. Here the probability of consecutive wet weeks was similar to that of dry periods. With 92%, 90% and 83% probability levels, consecutive 2, 3, 4 wet weeks were observed during 16th–17th, 15th–17th and 15th weeks. In Darjeeling, maximum probability of consecutive 2, 3 and 4 dry weeks prevailed in 1st, 50th and 51st week (74%), 49th week (69%) and 49th week (63%), respectively, signifying stronger probability of prevalence of wet situation. Maximum probability of consecutive 2, 3 and 4 wet weeks prevailed during 34th–35th (82%), 34th (77%) and 31st week (72%), respectively (Fig. 2B and C).

The occurrence of consecutive dry weeks was observed

to be dominant than consecutive wet weeks in Sagar Island. The probability of consecutive 2, 3 and 4 dry weeks prevailed in week 50th, 49th and 48th week with 95%, 90% and 87% surety, whereas the occurrence of 2, 3 and 4 consecutive wet weeks was assumed in week 28th, 27th and 27th with 92%, 85% and 76% assurance. Similarly, in Sriniketan, probability of dry situation was stronger than wet situation. Here, 2, 3 and 4 consecutive dry weeks prevailed in 46th, 49th and 50th weeks (93%), 49th week (93%) and 46th–48th weeks (83%), respectively while wet weeks prevailed during 30th, 30th and 27th weeks with 90%, 83% and 78% probability levels, respectively (Fig. 2D and E). The probability of consecutive wet and dry spell can assist the end-users to identify the period of assured moisture availability in soil or the spell when soil and plant can face moisture stress and irrigation cannot be ignored for optimum productivity (Choudhury and Bhattacharya 2023).

The present study utilising incomplete gamma probability, initial and conditional probability, and probability of consecutive wet and dry weeks for five regions namely Baharampur, Midnapore, Darjeeling, Sagar Island and Sriniketan has revealed significant spatial and temporal variation in weekly rainfall distribution patterns. By analysing initial and conditional probabilities of weekly rainfall, the persistence pattern of dry spell at the beginning and end of the year was confirmed for all the locations which was further confirmed by the analysis of consecutive wet and dry spells. These findings are crucial for planning a rainfed cropping system, crop cycle adjustment, contingency crop planning and managing risks of wet and dry spell in between a crop duration. This may all together lead us to support climate resilient agriculture.

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