Received: 09 April 2026 | Accepted: 08 July 2026 | Published online: 24 August 2026

DOI: 10.53550/ijsc.v54.i2.225

ORIGINAL ARTICLE

Indian Journal of Soil Conservation

Dry and Wet Spells Probabilities Analysis Using Markov Chain Model: A Case Study of Lamphelpat, Imphal (West), Manipur

Parmendra Prasad Dabral[1,*] | Alina Kakoti[1] | Roshni Singh[1] | Priyakshree Chutia[1]

[1]Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology (Deemed to be University, Under MoE, Govt. of India), Nirjuli, Itanagar, Arunachal Pradesh-791109

Corresponding Author:
E-mail: ppdabral1962@gmail.com

Handling Editor:
Dr. Rajesh K. Singh

Key words:
Dry and wet spell probability
Markov chain model
Lamphelpat, Imphal (West), Manipur

ABSTRACT

In the present study, weekly rainfall data of Lamphelpat, Imphal (West), Manipur for the year 2011-2024 were used to forecast dry and wet spells probabilities using Markov Chain Model and to find out the time of onset and termination of monsoon. The average annual rainfall was found to be 1522 mm, with the monsoon season contributing the highest proportion (68.60%), followed by pre-monsoon (25.93%) and post-monsoon (5.51%) rainfall. The coefficient of variation indicated relatively stable rainfall during the monsoon and pre-monsoon seasons, while the post-monsoon period exhibited high variability. The analysis revealed that dry weeks were predominant during the 1st to 15th and 41st to 52nd standard meteorological weeks, whereas wet weeks were more frequent during the monsoon period. The probability of consecutive dry and wet weeks highlighted critical periods of moisture stress and adequate water availability. Forward and backward accumulation analysis indicated that the effective onset of the pre-monsoon and monsoon occurred during the 17th and 24th weeks, respectively, with the monsoon extending up to the 40th week, providing an active rainy period of approximately 17 weeks. The outcome of study provides useful insights for optimizing sowing time, irrigation scheduling, and crop planning in the study area.

1 | INTRODUCTION

Crop growth is significantly influenced by the occurrence of dry spells, particularly during critical phenological stages, where moisture stress can lead to substantial yield reduction. Conversely, relatively dry conditions during the ripening stage may prove beneficial for crop maturity and harvesting. Therefore, for efficient crop planning and the timely implementation of agricultural operations, it is crucial to analyze and understand the sequence and occurrence of wet and dry periods (Pandarinath, 1991). Furthermore, the design of water harvesting systems and other soil conservation structures also necessitates a probabilistic analysis of the occurrence and sequence of wet and dry spells.

The Markov chain model has been widely applied to analyze the distribution of dry and wet spells, as well as various characteristics of rainfall occurrence (Gabriel and Neumann, 1962). For sustainable agricultural development, precise understanding and efficient utilization of natural resource, particularly rainfall, are essential. In this context, the Markov chain model provides a reliable framework for describing the long-term frequency behaviour of wet and dry spells. Several researchers, including Victor and Sastry (1979), Saxena and Tewari (1988), Singh and Bhandari (1998), Singh *et al*., (2019), Agnihotri *et al*., (1993), Rath *et al*., (1996), Panigrahi and Panda (2002), Jat *et al*., (2003), Dabral and Jhajharia (2003), Subash *et al.,* (2009), Dabral *et al*., (2014), Pali and Thakur (2015), Dabral *et al*., (2019), Mavale *et al*. (2021),Sinha *et al*., (2023), Barman *et al*., (2024) have successfully employed this model to estimate the probabilities of wet and dry spells at shorter time scales, such as weekly intervals, for effective crop planning across different regions of India.

A critical rainfall characteristic that strongly influences rainfed agriculture is the onset of the effective monsoon is. In India, most agricultural operations commence with the arrival of the southwest monsoon, making accurate forecasting of its onset essential. Even a slight delay in the onset can postpone sowing and adversely impact subsequent crops. Typically, farmers begin sowing or broadcasting seeds only after sufficient rainfall has adequately moistened the topsoil. To determine the onset of effective monsoon, cumulative weekly rainfall is analyzed by summing rainfall forward or backward from the peak dry season until a specified threshold is reached. This approach enables estimation of the probability of receiving a given amount of rainfall within selected time intervals. In practice, an accumulation of about 75 mm of rainfall is often considered adequate for sowing rainfed crops, while approximately 200 mm is required to initiate puddling operations for wetland rice cultivation. Similarly, the end of the wet season can be identified through backward accumulation of rainfall data. It is generally assumed that cumulative rainfall thresholds of 500 mm and 300 mm indicate the period after which sufficient moisture is available to support a second rice crop following the monsoon season, provided the soil profile is fully recharged at the time of planting (WMO, 1982). Several researchers like Panigrahi and Panda (2002), Dabral and Jhajharia (2003), Dingre (2007) Dabral *et al.*, (2014) and Mavale *et al.*, (2021) determined the time for onset and termination of monsoon using above said method across different regions of India.

HIGHLIGHTS

- Study is focussed to forecast dry and wet spells probabilities using Markov chain model for Lamphelpat, Imphal (West), Manipur.
- Study finds out the time of onset and termination of monsoon for study site.
- The study provides useful insights for optimizing sowing time, irrigation scheduling, and crop planning in the study area.

The determination of dry and wet spells is essential for characterizing crop suitability, developing efficient cropping systems, and designing appropriate soil and water conservation structures. In addition, the forward and backward accumulation of rainfall plays a vital role in crop planning by utilizing precipitation data to accurately identify the onset and withdrawal of the wet season. However, systematic information on dry and wet spell analysis, as well as on the onset and withdrawal of the monsoon, is lacking for Lamphelpat, Imphal (West), Manipur. Therefore, the present study was undertaken with the objectives of estimating the initial and transitional probabilities of dry and wet spell weeks and determining the probabilities of two and three consecutive dry and wet spells using a Markov chain model. Furthermore, the study aims to identify the precise timing of the onset and termination of the monsoon in the study area.

2 | MATERIALS AND METHODS

2.1 | Study Area and Collection of Data

Daily rainfall data recorded at ICAR Research Complex (2011-2024) for NEH region Manipur Centre, Lamphelpat, Imphal (West) which is located at 24^0 45' N latitude and 93^0 54' E longitude at an altitude of 774 m above mean sea level (Fig. 1) were used in this analysis. The daily data for a given year were aggregated and converted into weekly data.

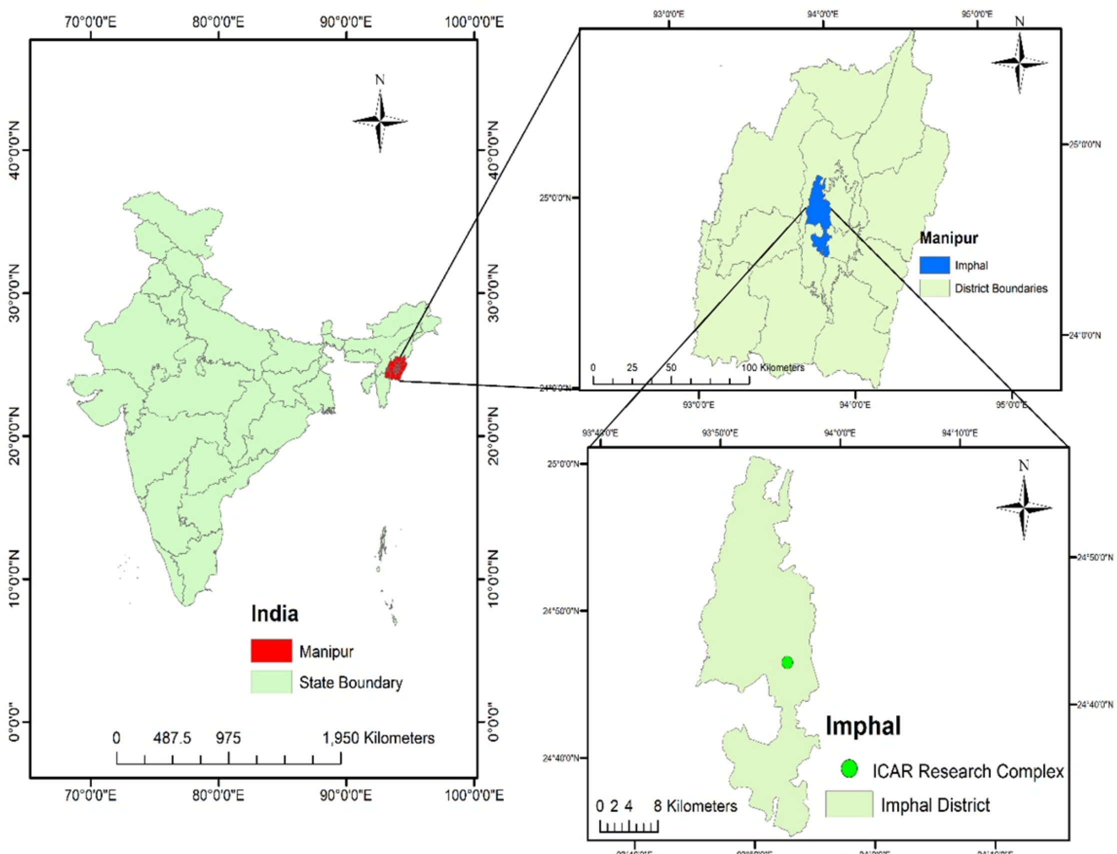

FIGURE1 ICAR Research Complex, NEH region Manipur Centre, Lamphelpat, Imphal (West), Manipur.

2.2 | Forecasting of Dry and Wet Spells using Markov Chain Model

A first-order Markov chain is a stochastic process in which the probability of transitioning to the next state depends only on the current state, satisfying the Markov property (Ross, 2019). The concept of estimating probabilities with respect to a specified amount of rainfall is highly useful in agricultural planning. During the crop growing season, decisions often depend on the likelihood of receiving a certain amount of rainfall in a given week, denoted as P(W), and referred to as "initial probabilities." Similarly, the probability of rainfall in the following week, given that the current week is wet, denoted as P(W/W), and other related measures are termed "conditional probabilities." These initial and conditional probabilities form the basis for rainfall analysis using a Markov chain process (Ross, 2019).

The following definitions have been adopted in this study:

1. A day receiving 2.5 mm or more rainfall between 08:30 am IST to 08:30 am IST of the next day is defined as a wet day; otherwise, it is considered a dry day (Agarwal *et al*., 1984).
2. A week is classified as wet if it receives 20 mm or more rainfall; otherwise, it is considered a dry week (Pandarinath, 1991; Dash and Senapati, 1992).

The initial probability of a week being dry is defined by,

$$P(D) = F(D)/N \qquad (1)$$

Where, P(D) = probability of the week being dry; F(D) = Frequency of dry weeks; and N= total number of years of data being used.

Thus initial probability of the week being wet is given as:

$$P(W) = F(W)/N \qquad (2)$$

Where, P(W) = probability of the week being wet; F(W)= Frequency of dry weeks; and N= total number of years of data being used.

The transitional probability of week being dry that is preceded by another dry week is denoted as:

$$P(D/D) = F(DD)/F(D) \qquad (3)$$

Where, P(D/D) = probability of the week being dry preceded by another dry week; F(DD)= Frequency of dry weeks preceded by another dry week, F(D)= Frequency of dry weeks

The transitional probability of week being wet preceded by another wet week is:

$$P(W/W) = F(WW)/F(W) \qquad (4)$$

Where, P(W/W) = probability of the week being wet preceded by another wet week;

F(WW)= Frequency of wet weeks preceded by another wet week, F(w)= Frequency of wet weeks.

The transitional probability of week being dry preceded by another wet week, is expressed as:

$$P(D/W) = 1\text{-}P(W/W) \qquad (5)$$

Similarly, the transitional probability of week being wet preceded by another dry week, is expressed as:

$$P(W/D) = 1\text{-}P(D/D) \qquad (6)$$

Where, P(D/W) = probability of week being dry, given that the it is preceded by another wet week and similarly, P(W/D) = probability of week being we, given that it is preceded by another dry week.

The probabilities of consecutive dry probabilities are computed as follows:

$$P(2D) = P(Dw_1)xP(DDw_2) \qquad (7)$$
$$P(3D) = P(Dw_1)xP(DDw_2)xP(DDw_3) \qquad (8)$$

Where, P(2D)= probability of 2 consecutive dry weeks: $P(Dw_1)$= probability of the first week being dry : and P (DDw_2)= the probability of the 2^{nd} consecutive dry week given the preceding week being dry, P(3D)= the probability of 3 consecutive dry weeks: P(DDw_3)= Probability of 3^{rd} week being dry given that preceding week dry.

Similarly, the probabilities of consecutive wet weeks are given by:

$$P(2W) = P(Ww_1) \text{ x } P(WWw_2) \qquad (9)$$
$$P(3W) = P(Ww_1) \text{ x } P(WWw_2) \text{ x } P(WWw_3) \qquad (10)$$

Where, P(2W)= probability of 2 consecutive wet weeks: $P(Ww_1)$= probability of the first week being wet : and P (WWw_2)= the probability of the 2^{nd} consecutive wet week given the preceding week being wet, P(3W)= the probability of 3 consecutive wet weeks: $P(WWw_3)$= Probability of 3^{rd} week being wet given that preceding week wet.

2.3 | Wilson Score Method

The weekly probabilities of dry and wet spells along with their corresponding 95% confidence intervals were estimated using the Wilson score method (Wilson,1927). This method is a statistical technique used to estimate the confidence interval of a population proportion. It was an improvement over the traditional normal approximation interval. The method provides more reliable estimates, particularly when the sample size is small or when the observed proportion is close to 0 or 1. It reduces the risk of obtaining impossible confidence limits below 0 or above 1.

For a sample of size **n**, with observed proportion p̂, and critical value **z** corresponding to the desired confidence level, the Wilson confidence interval is given by equation (11):

$$\bar{p} = \frac{\bar{p} + \frac{z^2}{2n} \pm z\sqrt{\frac{\hat{p}(1-\hat{p})}{n} + \frac{z^2}{4n^2}}}{1 + \frac{z^2}{n}} \quad \textbf{(11)}$$

2.4 | Time for Onset and Termination of Monsoon

The beginning and end of the rainy season were determined from weekly rainfall data using the forward and backward accumulation techniques proposed by Morris and Zandstra (1979). The date of onset of the effective monsoon is a critical rainfall characteristic influencing rainfed agriculture. In India, most agricultural operations commence with the onset of the southwest monsoon. Therefore, accurate estimation of the onset date is essential, as even a slight delay in sowing rainfed crops can adversely affect subsequent crop performance. Farmers generally prefer sowing or broadcasting seeds only after sufficient rainfall has adequately moistened the topsoil. In this approach, weekly rainfall is accumulated either forward or back ward from the peak of the dry season until a specified threshold amount is reached. This method enables the estimation of the probability of receiving a given amount of rainfall within selected time intervals, thereby helping to identify the onset and withdrawal of the effective rainy season. However, 75 mm accumulation of rainfall has been considered as the onset time for sowing of rainfed crop and 200 mm accumulated rainfall for initiation of puddling for wet land preparation of rice fields. Similarly end of season is determined by backward summing of rainfall data. It is considered that 500-mm and 300-mm accumulated rainfall values represent the week after which sufficient rain would be expected to sustain a second rice crop after monsoon.

In the present study, the onset of the rainy season was determined using weekly rainfall data. An accumulated rainfall of 75 mm, obtained through forward accumulation starting from the 22nd week, was considered as the criterion for the onset of the monsoon. Similarly, an accumulated rainfall of 200 mm, obtained through backward accumulation starting from the 52nd week, was taken as the criterion for the termination of the monsoon. For both forward and backward accumulation, weekly rainfall data were organized such that weeks were arranged in columns and years in rows. In the forward accumulation method, rainfall amounts were summed sequentially from the 22nd week onwards (i.e., 22, 23, 24, …, 52 weeks) until the threshold value of 75 mm was reached. For determining the withdrawal of the monsoon, backward accumulation was carried out from the 52nd week backwards (i.e., 52, 51, …, 41 weeks) until 200 mm of rainfall was accumulated. For each year, week no. and forward and backward accumulated rainfall(actual) was noted and arranged in descending order and assigned with rank number. The probability of each rank is calculated by the Weibull's formula:

$$P = \left[\frac{m}{n+1}\right] x100 \qquad (12)$$

Where, P= Probability(%), m= Rank number and n= No. of years observation.

Additionally, the onset of the pre-monsoon season was determined using a threshold of 75 mm rainfall accumulated from the 9th week onward. The probability of occurrence was similarly estimated using equation (12).

3 | RESULTS AND DISCUSSION

3.1 | Rainfall Analysis

3.1.1 | Annual rainfall

The average annual rainfall of Imphal (West), Manipur was recorded as 1522 mm, with a coefficient of variation (CV) of 51.51%, indicating high variability in annual rainfall. The region experiences noticeable fluctuations in rainfall distribution from year to year. The average number of annual rainy days was found to be 96, with a CV of 35.41%, suggesting high variability in the occurrence of rainy days (Table 1).

3.1.2 | Seasonal rainfall

The mean seasonal rainfall during the pre-monsoon (March–May), monsoon (June–October), and post-monsoon (November–February) periods was recorded as 394.7 mm, 1044 mm, and 83.8 mm, respectively. The corresponding mean number of rainy days was 27.4, 62.3, and 4.4. The seasonal contribution to total annual rainfall indicated that the monsoon season accounted for the highest share (68.60%), followed by the pre-monsoon (25.93%) and post-monsoon (5.51%) periods. The relatively low rainfall during the post-monsoon season reflects predominantly dry conditions, thereby necessitating supplementary irrigation. The coefficient of variation (CV) of rainfall for the pre-monsoon, monsoon, and post-monsoon seasons was 14.96%, 16.53%, and 61.36%, respectively. These results suggest that rainfall distribution is relatively stable during the pre-monsoon and monsoon seasons, whereas it is highly erratic during the post-monsoon period. During monsoon, pre-monsoon and post-monsoon period value of mean rainy days were observed to be 62.3 (CV=16.53%, 64.9% of mean annual value), 27.4 (CV=14.96%, 28.54% of mean annual value) and 4.4 (CV=61.36%, 4.58% of mean annual value) with medium coefficient of variation during monsoon, pre-monsoon and high during post-monsoon. The low variability in rainy days during the monsoon and pre-monsoon seasons further indicates a more consistent rainfall pattern compared to the post-monsoon period (Table 1).

TABLE 1 Mean monthly, seasonal and annual rainfall (mm)/ rainy days.

Monthly/Seasonal/ Annual	Rainfall			Rainy days		
	Mean (mm)	SD	CV (%)	Mean	SD	CV (%)
January	15.6(1.02)	20.1	128.84	1.5 (1.56)	1.5	100
February	19.6(1.29)	18.3	93.34	1.9(1.98)	1.8	94.74
March	60.2(3.95)	57.9	96.2	4.9(5.10)	1.6	32.65
April	117.4(7.71)	72.0	61.34	9.6(10)	3.4	35.42
May	217.1(14.26)	118.3	54.5	12.8(13.3)	3.8	29.69
June	258.3(16.97)	90.0	34.84	15.3(15.9)	3.7	24.18
July	265.0(17.41)	98.0	37.0	15.2(15.83)	4.6	30.26
August	207.9(13.66)	93.8	45.12	13.6(14.1)	3.6	26.47
September	188.4(12.38)	83.9	44.53	10.8(11.25)	3.8	35.18
October	124.4(8.17)	61.7	49.60	7.4(7.7)	3.1	41.89
November	29.2(1.92)	35.7	122.3	1.6(1.67)	1.8	112.5
December	19.3(1.27)	33.8	175.12	1.3(1.35)	1.6	123.08
Pre-monsoon (March to May)	394.7(25.93)	174.0	44.1	27.4(28.54)	4.1	14.96
Monsoon (June to October)	1044.0(68.60)	341.5	32.71	62.3(64.9)	10.3	16.53
Post-monsoon (November, December, January & February	83.8(5.51)	51.1	61.34	4.4(4.58)	2.7	61.36
Annual	1522	784	51.51	96	34	35.41

(Figures in parenthesis indicate a per cent contribution to annual rainfall).

3.1.3 | Monthly rainfall

The minimum and maximum mean monthly rainfall were recorded in January (6.9 mm, representing 1.02% of the mean annual rainfall) and July (265 mm, accounting for 17.41%), respectively. The coefficient of variation (CV) exhibited high monthly variability, ranging from 34.84% in June to 175.12% in December (Table 1). The mean number of rainy days was highest in June (15.3 days) and lowest in December (1.3 days), reflecting a pronounced seasonal contrast in rainfall distribution.

3.1.4 | Weekly rainfall

Table 2 presents the statistical parameters of weekly rainfall. The mean weekly rainfall ranged from 0 mm (48th week) to 144.1 mm (25th week). The coefficient of variation (CV) exhibited a wide range, varying from 52.52% to 374.17%, indicating considerable high variability in weekly rainfall distribution. The period from the 16th week (16 to 22 April) to the 41st week (8–14 October) received an average weekly rainfall exceeding 20 mm, representing a relatively low-risk period suitable for crop growth and development. In contrast, the weeks from the 44th to 52nd and 1st to 12th weeks, with rainfall ranging from 0 to 18.2 mm, were identified as unfavourable for crop growth due to insufficient moisture availability.

3.2 | Weekly Dry and Wet Spells

3.2.1 | Initial and transitional dry and wet weeks probability analysis

The weekly probabilities of dry and wet spells along with their corresponding 95% confidence intervals are presented in (Table 3). The confidence intervals were estimated using the Wilson score method (as discussed in section 2.3) to account for the uncertainty associated with binomial proportions, particularly for extreme probabilities (0 and 1). Wider intervals indicate greater uncertainty in the estimated probabilities, particularly during transition periods between dry and wet seasons, whereas narrower intervals suggest more consistent rainfall behaviour across years. It is observed from (Table 3) that the confidence intervals are relatively wide for probabilities near 0.5, indicating higher uncertainty during transition periods between dry and wet conditions. In contrast, weeks with extreme probabilities (close to 0 or 1) also exhibit notable interval widths due to the limited sample size (n = 14).

The probability of occurrence of a dry week was found to be higher during the 1st to 15th and 41st to 52nd standard meteorological weeks (Table 3), with values ranging from 57.1% to 100%. The conditional probability of a dry week preceded by another dry week was also high during weeks 1 to 12, 19, 24, and 44 to 52, varying between 70% and 92.9%. Similarly, the probability of occurrence of a dry week preceded by a wet week was observed to be high during weeks 1 to 10, 12 to14, 36, 42, and 44 to 52, with values ranging from 71.4% to 100% (Table 4).

In contrast, the probability of occurrence of a wet week was higher during weeks 18, 21 to 23, 26 to 27, 29 to 32, 34 to 35, 38, and 40, with probabilities ranging from 71.4% to 100%. The conditional probability of a wet week preceded by another wet week was notably high during weeks 20–21, 25–27, 29–30, 32, 35, 38, and 40, with values ranging from 75% to 100% (Table 4). Furthermore, the probability of a wet week preceded by a dry week was higher during weeks 20 to 21, 23, 25 to 27, 32, 35 to 36, 38, and 40, with probabilities ranging from 75% to 100% (Table 4).

TABLE 2 Value of statistical parameters of weekly rainfall.

Week No.	Mean	SD	CV (%)
1	6.5	14.43	222
2	2.8	3.93	140.45
3	3.6	6.49	182.44
4	1.1	3.93	374.17
5	3.7	7.20	194.33
6	2.9	6.43	225.07
7	0.3	0.88	255.22
8	7.5	11.90	158.15
9	6.0	10.55	176.33
10	7.2	12.01	167.74
11	7.2	15.89	222.23
12	15.7	13.75	87.44
13	34.2	65.27	190.86
14	21.0	26.29	125.38
15	14.9	16.65	112.15
16	26.0	20.17	77.61
17	32.8	35.62	108.61
18	51.0	41.15	80.65
19	32.5	51.76	159.35
20	54.0	59.97	111.15
21	44.5	45.63	102.53
22	65.4	66.45	101.54
23	35.6	32.14	90.27
24	75.0	70.45	93.90
25	144.1	282.28	195.88
26	62.2	37.30	59.93
27	74.9	63.18	84.40
28	39.9	27.91	69.91
29	55.5	36.68	66.07
30	75.3	39.54	52.52
21	43.5	32.44	74.51
32	57.8	46.96	81.19
33	60.0	85.13	141.87
34	54.5	42.99	78.92
35	43.3	27.69	64.00
36	29.0	36.21	124.97
37	33.0	43.72	132.48
38	65.9	46.55	70.62
39	37.1	30.74	82.91
40	30.7	23.79	77.58
41	37.6	47.47	126.29
42	14.5	18.34	126.16
43	31.8	35.38	111.17
44	18.2	35.79	196.67
45	14.3	26.17	183.38
46	0.8	1.97	255.97
47	4.0	13.80	346.31
48	0.0	0.08	374.17
49	7.2	18.27	254.22
50	7.1	23.45	330.33
51	2.0	6.07	300.25
52	2.5	5.93	235.35

TABLE 3 Weekly probabilities of dry (P(D)) and wet (P(W)) spells along with their 95% confidence intervals estimated using the Wilson score method (n = 14 years).

Week	P(D) (%)	CI for P(D)	P(W) (%)	CI for P(W)
1	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
2	100.0	(0.785, 1.000)	0.0	(0.000, 0.215)
3	100.0	(0.785, 1.000)	0.0	(0.000, 0.215)
4	100.0	(0.785, 1.000)	0.0	(0.000, 0.215)
6	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
6	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
7	100.0	(0.785, 1.000)	0.0	(0.000, 0.215)
8	85.7	(0.601, 0.960)	14.3	(0.040, 0.399)
9	85.7	(0.601, 0.960)	14.3	(0.040, 0.399)
10	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
11	85.7	(0.601, 0.960)	14.3	(0.040, 0.399)
12	71.4	(0.442, 0.880)	28.6	(0.120, 0.558)
13	64.3	(0.367, 0.829)	35.7	(0.171, 0.633)
14	64.3	(0.367, 0.829)	35.7	(0.171, 0.633)
15	64.3	(0.367, 0.829)	35.7	(0.171, 0.633)
16	35.7	(0.171, 0.633)	64.3	(0.367, 0.829)
17	57.1	(0.297, 0.771)	42.9	(0.229, 0.703)
18	21.4	(0.076, 0.479)	78.6	(0.521, 0.924)
19	71.4	(0.442, 0.880)	28.6	(0.120, 0.558)
20	35.7	(0.171, 0.633)	64.3	(0.367, 0.829)
21	28.6	(0.120, 0.558)	71.4	(0.442, 0.880)
22	21.4	(0.076, 0.479)	78.6	(0.521, 0.924)
23	28.6	(0.120, 0.558)	71.4	(0.442, 0.880)
24	78.6	(0.521, 0.924)	21.4	(0.076, 0.479)
25	7.1	(0.013, 0.314)	92.86	(0.686, 0.987)
26	0.0	(0.000, 0.215)	100.0	(0.785, 1.000)
27	7.14	(0.013, 0.314)	92.86	(0.686, 0.987)
28	35.7	(0.171, 0.633)	64.3	(0.367, 0.829)
29	7.1	(0.013, 0.314)	92.9	(0.686, 0.987)
30	0.0	(0.000, 0.215)	100.0	(0.785, 1.000)
31	14.3	(0.040, 0.399)	85.7	(0.601, 0.960)
32	14.3	(0.040, 0.399)	85.7	(0.601, 0.960)
33	42.9	(0.229, 0.703)	57.1	(0.297, 0.771)
34	21.4	(0.076, 0.479)	78.6	(0.521, 0.924)
35	21.4	(0.076, 0.479)	78.6	(0.521, 0.924)
36	50.0	(0.289, 0.711)	50.0	(0.289, 0.711)
37	42.9	(0.229, 0.703)	57.1	(0.297, 0.771)
38	28.6	(0.120, 0.558)	71.4	(0.442, 0.880)
39	35.7	(0.171, 0.633)	64.3	(0.367, 0.829)
40	28.6	(0.120, 0.558)	71.4	(0.442, 0.880)
41	57.1	(0.297, 0.771)	42.9	(0.229, 0.703)
42	64.3	(0.367, 0.829)	35.7	(0.171, 0.633)
43	57.1	(0.297, 0.771)	42.9	(0.229, 0.703)
44	85.7	(0.601, 0.960)	14.3	(0.040, 0.399)
45	78.6	(0.521, 0.924)	21.4	(0.076, 0.479)
46	100.0	(0.785, 1.000)	0.0	(0.000, 0.215)
47	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
48	100.0	(0.785, 1.000)	0.0	(0.040, 0.399)
49	85.7	(0.601, 0.960)	14.3	(0.040, 0.399)
50	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
51	92.9	(0.686, 0.987)	7.1	(0.013, 0.314)
52	100.0	(0.785, 1.000)	0.0	(0.000, 0.215)

Note: The 95% confidence intervals for binomial proportions were computed using the Wilson score method with a confidence level of 95% (z=1.96). The probabilities are based on 14years of weekly rainfall data.

TABLE 4 Transitional probabilities of dry and wet weeks.

Week	Transitional Probabilities (%)			
	P(D/D)	P(W/W)	P(D/W)	P(W/D)
1	84.6	0.0	100.0	15.4
2	92.9	0.0	100.0	7.1
3	92.9	0.0	100.0	7.1
4	92.9	0.0	100.0	7.1
6	92.3	0.0	100.0	7.7
6	84.6	0.0	100.0	15.4
7	92.9	0.0	100.0	7.1
8	83.3	0.0	100.0	16.7
9	75.0	0.0	100.0	25.0
10	84.6	0.0	100.0	15.4
11	83.3	50.0	50.0	16.7
12	70.0	0.0	100.0	30.0
13	55.6	20.0	80.0	44.4
14	44.4	20.0	80.0	55.6
15	55.6	40.0	60.0	44.4
16	40.0	66.7	33.3	60.0
17	50.0	50.0	50.0	50.0
18	33.3	72.7	27.3	66.7
19	70.0	50.0	50.0	30.0
20	20.0	66.7	33.3	80.0
21	25.0	60.0	40.0	75.0
22	33.3	72.7	27.3	66.7
23	25.0	70.0	30.0	75.0
24	90.9	33.3	66.7	9.1
25	0.0	92.31	7.69	100.0
26	0.0	92.9	7.1	100.0
27	0.0	84.6	15.4	100.0
28	40.0	66.7	33.3	60.0
29	0.0	84.6	15.4	100.0
30	0.0	92.9	7.1	100.0
31	50.0	83.3	16.7	50.0
32	0.0	75.0	25.0	100.0
33	33.3	37.5	62.5	66.7
34	33.3	72.7	27.3	66.7
35	0.0	72.7	27.3	100.0
36	28.6	28.6	71.4	71.4
37	50.0	37.5	62.5	50.0
38	0.0	60.0	40.0	100.0
39	40.0	55.6	44.4	60.0
40	0.0	50.0	50.0	100.0
41	62.5	50.0	50.0	37.5
42	66.7	20.0	80.0	33.3
43	50.0	33.3	66.7	50.0
44	75.0	0.0	100.0	25.0
45	63.6	0.0	100.0	36.4
46	92.9	0.0	100.0	7.1
47	92.3	0.0	100.0	7.7
48	92.9	0.0	100.0	7.1
49	75.0	0.0	100.0	25.0
50	84.6	0.0	100.0	15.4
51	84.6	0.0	100.0	15.4
52	92.9	0.0	100.0	7.1

3.2.2 | Consecutive Dry and Wet Weeks Probability Analysis

The probability of occurrence of two consecutive dry weeks was found to be higher during the 1st to 8th, 10th to 11th, and 46th to 48th as well as 50th to 52nd weeks, with values ranging from 71.4% to 92.9%. Similarly, the probability of occurrence of three consecutive dry weeks was higher during the 2nd to 5th, 7th, 46th to 48th, and 52nd weeks, with probabilities varying from 72.5% to 92.9% (Table 5).

In contrast, the probability of occurrence of two consecutive wet weeks was higher during the 25th to 27th and 29th to 31st weeks, with values ranging from 71.4% to 92.9%. The probability of three consecutive wet weeks was observed to be higher during the 25th to 26th and 30th weeks, ranging from 79.6% to 85.7% (Table 5).

Mishra (2007), who reported that the occurrence of two or more consecutive dry weeks during germination or immediately after sowing, 2 to 4 dry weeks during the vegetative stage, two or more dry weeks during flowering, and four or more consecutive dry weeks during grain filling or maturity can be highly detrimental to crop growth and yield.

The results obtained in the present study differ from those reported by Dabral and Jhajharia (2003), Dabral *et al.,* (2014), and Dabral *et al.*, (2019), who conducted similar analyses for Doimukh (Itanagar), North Lakhimpur (Assam), and Kohima (Nagaland), respectively for North East region of India. The present findings indicate that weeks 1 to 15 and 41 to 52 are characterized by moisture stress conditions. While analysing the weekly rainfall data in section 3.1.4, the weeks from the 44th to 52nd and 1st to 12th weeks, with rainfall ranging from 0 to 18.2 mm, were identified as unfavourable for crop growth due to insufficient moisture availability. Consequently, supplementary irrigation is required for major crops (vegetables and mustard) grown in the study area during the period from 8th October to 15th April.

This study is based on 14 years weekly rainfall data only; the outcomes of this study may provide first hand valuable insights for effective water resource management and crop planning in the region.

3.3 | Analyses of Forward and Backward Accumulation of Rainfall for Determining the Onset and Termination of Monsoon

3.3.1 | Forward Accumulation of Rainfall (starting from 9th week)

The results of forward accumulation (commencing from 9th week) of rainfall indicate a 93.33 percent probability of getting 75 mm cumulative rainfall in 17th week (23rd April to 29th April) and 93.33 per cent probability of attaining 200 mm cumulative rainfall in 18th week (30th April to 6th May) (Table 6). These findings suggest that the effective onset of the pre-monsoon season occurs around the 17th week.

Based on this, the 17th week is considered suitable for sowing of rainfed summer maize, while the 18th week is identified as the optimum period for initiating wet land preparation in rice fields, particularly for long-duration rice varieties.

3.3.2 | Forward and Backward Accumulation (starting 22nd week) of Rainfall

The results of forward and backward rainfall accumulation analyses indicate that, based on forward accumulation starting from the 22nd standard meteorological week, there is a 93.33% probability of receiving 75 mm cumulative rainfall by the 24th week (11 to17 June). Similarly, backward accumulation from the 52nd week shows a 93.33% probability of attaining 200 mm cumulative rainfall by the 40th week (1–7 October) (Table 7).

These findings suggest that the effective onset of the monsoon in Imphal (West), Manipur occurs around the 24th week (11 to 17 June) and persists up to the 40th week (1 to October), indicating an active monsoon period of approximately 17 weeks.

Based on this rainfall pattern, the 26th week (25 June to 1 July) is considered the optimum period for initiating wet land preparation for short-duration rice varieties. Such varieties can be harvested before the withdrawal of the monsoon, thereby minimizing the risk of yield reduction due to terminal moisture stress. Furthermore, the residual soil moisture following rice harvest can be effectively utilized for cultivating a subsequent short-duration winter crop.

4 | CONCLUSIONS

The major conclusions drawn from the present study are as follows:

1. The average annual rainfall of Lamphelpat, Imphal (West), Manipur was 1522 mm. The mean seasonal rainfall during the pre-monsoon (March–May), monsoon (June–October), and post-monsoon (November–February) periods was 394.7 mm, 1044 mm, and 83.8 mm, respectively, with corresponding mean rainy days of 27.4, 62.3, and 4.4. The post-monsoon season was characterized by low rainfall and predominantly dry conditions, necessitating supplementary irrigation.
2. The probability of occurrence of a dry week was higher during the 1st to 15th and 41st to 52nd standard meteorological weeks, ranging from 57.1% to 100%.
3. The probability of occurrence of a wet week was higher during weeks 18, 21 to 23, 26 to 27, 29 to 32, 34 to 35, 38, and 40, with values ranging from 71.4% to 100%.
4. The conditional probability of a dry week preceded by another dry week was higher during weeks 1 to 12, 19, 24, and 44 to 52, ranging from 70% to 92.9%.

TABLE 5 Consecutive dry and wet weeks probability analysis.

Week	Consecutive Dry Probabilities (%)		Consecutive Wet Probabilities (%)	
	P(2D)	P(3D)	P(2W)	P(3W)
1	78.6	48.4	0.0	0.0
2	92.9	73.0	0.0	0.0
3	92.9	73.0	0.0	0.0
4	92.9	73.0	0.0	0.0
6	85.7	72.5	0.0	0.0
6	78.6	54.4	0.0	0.0
7	92.9	73.0	0.0	0.0
8	71.4	41.7	0.0	0.0
9	64.3	37.5	0.0	0.0
10	78.6	54.4	0.0	0.0
11	71.4	41.7	7.1	0.0
12	50.0	25.0	0.0	0.0
13	35.7	4.0	7.1	0.0
14	28.6	6.3	7.1	0.0
15	35.7	4.0	14.3	0.0
16	14.3	2.9	42.9	23.8
17	28.6	7.1	21.4	3.6
18	7.1	0.0	57.1	31.2
19	50.0	20.0	14.3	0.0
20	7.1	0.0	42.9	14.3
21	7.1	0.0	42.9	17.1
22	7.1	0.0	57.1	31.2
23	7.1	0.0	50.0	25.0
24	71.4	58.4	7.1	0.0
25	0.0	0.0	85.71	72.53
26	0.0	0.0	92.9	79.6
27	0.0	0.0	78.6	54.4
28	14.3	2.9	42.9	14.3
29	0.0	0.0	78.6	54.4
30	0.0	0.0	92.9	79.6
31	7.1	0.0	71.4	47.6
32	0.0	0.0	64.3	37.5
33	14.3	0.0	21.4	2.7
34	7.1	0.0	57.1	31.2
35	0.0	0.0	57.1	26.0
36	14.3	0.0	14.3	0.0
37	21.4	7.1	21.4	0.0
38	0.0	0.0	42.9	17.1
39	14.3	2.9	35.7	11.9
40	0.0	0.0	35.7	7.1
41	35.7	13.4	21.4	7.1
42	42.9	19.0	7.1	0.0
43	28.6	10.7	14.3	0.0
44	64.3	32.1	0.0	0.0
45	50.0	18.2	0.0	0.0
46	92.9	79.6	0.0	0.0
47	85.7	72.5	0.0	0.0
48	92.9	79.6	0.0	0.0
49	64.3	32.1	0.0	0.0
50	78.6	54.4	0.0	0.0
51	78.6	54.4	0.0	0.0
52	92.9	79.6	0.0	0.0

5. The probability of a dry week preceded by a wet week was high during weeks 1 to 10, 12 to 14, 36, 42, and 44 to 52, with values ranging from 71.4% to 100%.
6. The probability of a wet week preceded by another wet week was higher during weeks 20 to 21, 25 to 27, 29 to 30, 32, 35, 38, and 40, ranging from 75% to 100%.
7. The probability of a wet week preceded by a dry week was higher during weeks 20 to 21, 23, 25 to 27, 32, 35 to 36, 38, and 40, with values ranging from 75% to 100%.
8. The probability of occurrence of two consecutive dry weeks was higher during weeks 1 to 8, 10 to 11, 46 to 48, and 50 to 52, ranging from 71.4% to 92.9%.
9. The probability of occurrence of three consecutive dry weeks was higher during weeks 2 to 5, 7, 46 to 48, and 52, with values ranging from 72.5% to 92.9%.
10. The probability of occurrence of two consecutive wet weeks was higher during weeks 25 to 27 and 29 to 31, ranging from 71.4% to 92.9%.
11. The probability of occurrence of three consecutive wet weeks was higher during weeks 25 to 26 and 30, with values ranging from 79.6% to 85.7%.
12. The effective onset of the pre-monsoon was observed in the 17th week (23 to 29 April), which is suitable for sowing of rainfed summer maize, while the 18th week (30 April to 6 May) is ideal for initiating wet land preparation for long-duration rice varieties.
13. The monsoon season effectively commenced in the 24th week (11 to 17 June) and continued up to the 40th week (1 to 7 October), providing an active monsoon period of approximately 17 weeks. The 26th week (25 June to 1 July) is considered optimal for initiating wet land preparation for short-duration rice varieties.
14. This study is based on 14 years weekly rainfall data only; the outcomes of this study may provide first hand valuable insights for effective water resource management and crop planning in the region.

TABLE 6 Probability of having 75 and 200 mm (forward accumulation from 9th week).

Forward Accumulation (from 9th week)			
*75 mm (Onset of pre-monsoon)	Probability (%)	** 200 mm	Probability (%)
14th week	73.30	16th week	80.00
15th week	86.67	17th week	86.70
17th week	93.33	18th week	93.33

*75 mm accumulation of rainfall is considered as the onset time of sowing of rainfed crops
**200 mm accumulation rainfall for initiation for puddling time of wet land preparation of rice field.

TABLE 7 Probability of having 75 mm (Forward Accumulation from 22nd week) and 200 mm, 300 mm and 500 mm (Backward Accumulation from 52nd week).

Forward Accumulation (from 22ndweek)				Back ward Accumulation (From 52nd week)					
	Probability (%)	+ 200 mm	Probability (%)	+ 200 mm (TEM)	Probability (%)	** 300 mm	Probability (%)	** 500 mm	Probability (%)
	73.33	22nd week	80	37th week	80	34th week	80.00	32th week	80
	93.33	25th week	86.67	39th week	86.67	35th week	86.67	34th week	86.67
		26th week	93.33	40th week	93.33	36th week	93.33	35th week	93.33

75 mm accumulation of rainfall is considered as the onset time of sowing of rainfed crops.
+ 200 mm accumulated rainfall for initiation of puddling time of wet land preparation of rice field.
*200 mm accumulated rainfall (Back ward accumulation starting from 52nd week) is the time for termination of monsoon.
** It is considered that 500- and 300-mm accumulated rainfall values represent the week after which sufficient rain would be expected to sustain a second rice crop after monsoon crop assuming fully charged soil at planting.

ACKNOWLEDGEMENTS

The authors express their profound gratitude to the Director, ICAR Research Complex for NEH Region, Umiam (Barapani), and the Joint Director/Head, ICAR Research Complex for NEH Region, Manipur Centre, Lamphelpat, Imphal for providing the rainfall data used in this study.

DATA AVAILABILITY STATEMENT

Data will be made available on the request.

CONFLICT OF INTEREST

The contributing authors have driven the manuscript and the study in unison hence no conflict of interest exists.

FUNDING

The study did not receive funding from any entity or institution.

AUTHOR'S CONTRIBUTION

All authors equally contributed to preparing the manuscripts and data analysis.

REFERENCES

Agarwal, A., Singh, R. V. and Chauhan, H. S. (1984). Probability of sequence of wet and dry days in Nainital Tarai region. *J. Agril. Engineering (ISAE)*, 21(4):61-70.

Agnihotri (1993). A study on occurrence of wet/dry spells and weather cycles at Chandigarh using Markov chain model. *Indian J. Soil Cons*., 21(1):71-79.

Dabral, P. P. and Jhajharia, D. (2003). Dry and wet spell probability by Markov chain model and its application to crop planning in Doimukh (Itanagar), Arunachal Pradesh. *J. Soil & Water Conservation, India,* 2(1 &2): 32-39.

Barman, D., Kar, G., Mitra S., Alam, N. M., Manna, T., Kheroar, S., Zaman, A.S.N., , and Jena, S. (2024). Dry and wet spell probability analysis using Markov chain model for planning jute-based cropping systems in eastern India. *Indian J. Soil Cons.,* 52(1): 1-8. DOI : 10.59797/ijsc.v52.i1.143.

Dabral, P. P., Dada, M. and Odi, H. (2019). Dry and wet spell probability analysis by Markov Chain Model for Kohima (Nagaland), India. *Agric. Eng. Int*.: CIGR Journal, 21(4): 43-47.

Dabral, P.P., Purkyastha, K. and Aram, M. (2014). Dry and wet spell probability by Markov chain model-a case study of North Lakhimpur (Assam), India. *Int. J. Agric. & Biol. Eng.,*7(6):8-13.

Dingre, S. (2007). Markov chain model of probability for dry spell and its application to crop planning in Kashmir valley. *J. Soil Water Conserv*., 6(4): 194-199.

Gabriel, K. R. and Newmann, J. (1962). A Markov chain model for daily rainfall occurrence at Tel Aviv. *J. R. Met. Soc*., 88.

Jat, M. L., Singh, R. V., Baslyan , J. K. and Jain, L. K. (2003). Dry and wet spells for agricultural planning at Bhilwara. *Indian J. Soil Cons.,* 31(3):291-294.

Mishra, A. K. (2007). Rainfall analysis for crop planning at Umiam in Meghalaya. J. Soil Water Conserv., (India),6(2):56-63.

Morris, R. A. and H. G. Zandstra, (1979). Land and climatic in relation to cropping patterns. In: *Rainfed Lowland Rice: Selected Papers from 1970.Int. Rice Research Conf*., IRRI, pp 225-274.

Mavale, D. P., Shindhe, M. G., Malunjkar, V. S. and Barf, V. N. (2021). Wet and dry spell analysis for crop planning using Markov's chain model. *J. Soil Water Conser*., 20(4):436-446.

Pali, A. K. and Thakur, H. (2015). Dry and wet spell analysis for agricultural planning in Durg District of Chhattisgarh. *Indian J. Soil Cons.*, 43(3) :277-283.

Panigrahi, B. and Panda, S. N. (2002). Dry spell probability by Markov chain model and its application to crop planning in Kharagpur. *Indian J. Soil Cons*. 30(1):95-100.

Rath, Haripriya, Jena, G. N. and Senapati, P. C. (1996). Forecasting of dry and wet spells at Boudh for agricultural planning. *Indian J. Soil Cons*.,24(1):28-36.

Ross, S. M. (2019). *Introduction to Probability Models* (12th ed.). Academic Press.

Pandarinath, N. (1991). Markov chain model probability of dry and wet weeks during monsoon period over Andhra Pradesh. *Mausam*,42(4):393-400.

Saxena, A. K. and Tiwari, K. N. (1988). Water harvesting ponds- Capacity calculation and design-II. *Indian J. Power and River Valley Dev*., Jan-Feb.,12-16.

Singh, Mohan and Bhandari, A. R. (1998). Wet and dry spells analysis using Markov chain model for mid hill region of Himachal Pradesh. *Indian J. Soil Cons*., 26(2):147-152.

Singh, G., Singh, R. M., Chandola, V. K., and Nema, A. K. (2019). Rainfall analysis for crop planning under rainfed condition at Mirzapur district in Vindhya plateau of Indo-Gangetic Plain. *Indian J. Soil Cons., 47(1): 30-36.*

Sinha, B. L., Deo, R. K. and Sinha J. (2023). Dry and wet spell analysis for crop planning in Chhattisgarh plain using Markov's Chain Model. J. Soil Water Cons., 22(2) :152-160.

Subash, N. Sikka, A. K. and Haris, A. A. (2009). Markov chain approach-dry and wet spell rainfall probabilities for rice-wheat planning. *Indian J. Soil Cons*., 37(2):91-99.

Victor, U. S. and Sastry, P.S. N. (1979). Dry spell probability by Markov chain model and its application to crop development stage. *Mausam*, 30:479-484.

Wilson, E. B. (1927). Probable inference, the law of succession, and statistical inference. *J. Am. Stat. Assoc.*,, 22(158), 209–212.

W. M. O (1982). Technical Note No. 179. pp 149-158.

How to cite this article: Dabral, P. P., Kakoti, A., Singh, Roshni., Chutia, P., 2026. Dry and Wet Spell Probabilities Analysis using Markov Chain Model: A Case Study of Lamphelpat, Imphal (West), Manipur *Indian J. Soil Cons*., 54(2): 130-141.