Wet and Dry Spell Analysis for Crop Planning in Central Plain Zone of Punjab Using Markov Chain Method

Shivani Chand✉ and L. K. Dhaliwal

Dept. of Climate change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab (141 004), India

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Corresponding ✉ shivushivani9@gmail.com

🆔 0000-0003-4927-1891

ABSTRACT

A study was conducted during 2017–2018 at department of climate change and agricultural meteorology, PAU, Ludhiana to find out the initial and conditional probability of occurrence of wet and dry spell of rainfall at different locations of Punjab, the analysis was carried out using Markov Chain Method (MCM). The historical data of rainfall for three locations of Punjab viz. Amritsar (1971–2017), Ludhiana (1971–2018) and Patiala (1971–2018) were collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana and Met Centre, India Meteorological Department, Chandigarh. At Amritsar the chances of occurrence of wet spell were highest during 28th SMW i.e., 72% followed by 68% during 30th and 31st SMW respectively. The conditional probability calculated at Ludhiana showed that the probability of wet spell followed by wet spell was highest (71%) during 28th SMW followed by 66 per cent during 30th and 32nd SMW. At Patiala the probability of wet spell was highest (69%) during 33rd week followed by 63% during 29th SMW. The conditional probability also showed that dry spell followed by dry spell occurred more frequently than wet spell followed by wet spell.

KEYWORDS: Markov Chain Method, probability, crop, Punjab

1. INTRODUCTION

Indian economy is enormously dependent on agriculture. It is the backbone of our food and nutritional security. Agriculture being rainfed in India depends upon rainfall pattern. The potential production of almost all crops depends upon the availability of. Many decisions related to agriculture farm operations are taken based on the amount and time of occurrence of rainfall during a particular crop season. The concept of probability is usually used to study the dry and wet spells of rainfall for agricultural planning which can be of great help in judicious and efficient use of rainwater, conservation of ground water and increasing the productivity of crops. If the dry spell coincides with critical moisture requiring stages of the crop, it is damaging whereas during ripening stage, it can be beneficial. On the other hand, if wet spell coincides with the critical moisture requiring stages of the crop, it will be most beneficial for increasing productivity vis-à-vis conserving ground water (Kingra et al., 2013). So, Markov Chain Model has been found suitable to describe the long-term frequency behaviour of wet or dry spells. Panigrahi and Panda (2002), Jat et al. (2003), Dabral and Jhajharia (2003), Dingre (2007), Dabral et al. (2014), Pali and Thakur (2015), Joseph and Tamilmani (2017) applied Markov chain model for calculating initial and conditional probability of dry and wet spells of different duration for various climatic situations and have evaluated its importance in crop planning. Mavale et al. (2022) found out that initial, conditional and consecutive dry- and wet-week probabilities showed that chances of occurrence of a week getting wet is high at the beginning and ending of kharif season excluding 25th to 33rd weeks. Practically, in a crop growing season, many times decisions have to be taken based on the probability of receiving certain amounts of rainfall during a given week [P(w)], which is called "initial probability," then the probability of rain next week if we had rain this week [P(w/w)], which is called "conditional probability" (Dabral et al., 2014), both of which are very important. Under initial probabilities, the probability of any given week being wet or dry is estimated, whereas in the case of conditional probabilities, if a given week „i" is wet, then the chances of (i+k)th period as wet, wet/wet or dry/dry are estimated (Senthilvelan, Ganesh and Banukumar, 2012). The initial and conditional probabilities form the basis for the analysis of rainfall using Markov Chain Method (Dabral et al., 2014).Punjab being almost fully irrigated state puts undue pressure over the other water resources in the absence of timely rainfall especially on groundwater. The variability of rainfall in Punjab is very high due to erratic behavior of monsoon. Hence, the probability analysis of occurrence of wet and dry spells is required for successful crop planning of a particular region. The sowing dates, irrigation schedule, crop insect pest infection prediction etc. can be done based on wet and dry spells of rainfall. Keeping this in view, the rainfall probability analysis on weekly basis was done for three different locations of central plain zone (Amritsar, Ludhiana and Patiala) of Punjab using Markov Chain Method (MCM).

2. MATERIALS AND METHODS

A study was conducted during 2017–2018 at department of climate change and agricultural meteorology, PAU, Ludhiana. Long term data of rainfall for different locations of Punjab viz. Amritsar (January, 1971– December, 2017), Ludhiana (January, 1971–December, 2018) and Patiala (January, 1971–December, 2018) were collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana and Met center India Meteorological Department Chandigarh. The geographical features of these different locations were mentioned in Table 1. In a crop growing season, many times decisions have to be taken based on the probability of receiving a certain amount of rainfall during a given week [P(W)], which are called "initial probabilities". Then the probability of rain next week, if there is rainfall this week [P(W/W)] etc. were very

Table 1. Period of study, latitude, longitude, height (m) of different locations

Location	Period of study	Latitude	Longitude	Height (m)
Amritsar	1971-2017	31.63°N	74.87°E	234
Ludhiana	1971-2018	30.90°N	75.85°E	247
Patiala	1971-2018	30.33°N	76.38°E	258

important and were called "conditional probabilities". These initial and conditional probabilities become the basis for the analysis of rainfall using Markov Chain Method. The weekly rainfall probability has been calculated by finding out the frequency of dry and wet spells using Markov chain method on long term rainfall data of different locations viz. Amritsar, Ludhiana and Patiala of Punjab. When rainfall received in a week was 20 mm or more then it was considered as wet week and less than 20 mm of rainfall was considered as dry week. The initial and conditional probability was calculated by using the formula given by Robertson, (1976).

Initial probability: $P(D) = F(D)/n$, $P(W) = F(W)/n$ (1)

Where,

P(D): Probability of occurrence of dry spells

P(W): Probability of occurrence of wet spells

F(D): Frequency of occurrence of dry spells during n number of years

F(W): Frequency of occurrence of wet spells during n number of years.

Conditional probability: P(D/D)=F(D/D)/ F(D), P(W/W) = F(W/W)/ F(W) (2)

Where,

P(D/D): Probability of occurrence of dry spell provided the last week was dry.

P(W/W): Probability of occurrence of wet spell provided the last week was also wet.

F(D/D): Frequency of occurrence of dry spell provided the last week was dry and

F(W/W): Frequency of occurrence of wet spell provided the last week was also wet

3. RESULTS AND DISCUSSION

Rainfall is a seasonal phenomenon in tropical country like India and it occurs in spells. The start and end of the rainy season; frequency, rainfall amount, rainfall intensity, and duration of wet spells and duration and severity of intervening (between two wet spells) dry spells are characterized by large spatial and temporal variations. The characteristics of wet spells and intervening dry spells are extremely useful for agriculture sector. It is of great importance in the wake of global climate change. The concept of estimating probabilities with respect to a given amount of rainfall is extremely useful for agricultural planning. The analysis of the initial and conditional probability of wet and dry weeks was done by Markov Chain Method for different locations viz. Amritsar, Ludhiana and Patiala representing the central plain zone of Punjab and discussed as under:

3.1. Amritsar

The initial probability of wet and dry weeks for Amritsar was calculated by Markov Chain Method (Table 2), the

Table 2: Initial probability (%) of wet (>20 mm) and dry (<20 mm rainfall) weeks at Amritsar (1971-2017) by Markov Chain Approach

SMW	F(D)	P(D)	F(W)	P(W)	SMW	F(D)	P(D)	F(W)	P(W)
1	43	0.91	4	0.09	27	24	0.51	23	0.49
2	44	0.94	3	0.06	28	13	0.28	34	0.72
3	44	0.94	3	0.06	29	17	0.36	30	0.64
4	39	0.83	8	0.17	30	15	0.32	32	0.68
5	43	0.91	4	0.09	31	15	0.32	32	0.68
6	40	0.85	7	0.15	32	18	0.38	29	0.62
7	39	0.83	8	0.17	33	17	0.36	30	0.64
8	38	0.81	9	0.19	34	28	0.60	19	0.40
9	40	0.85	7	0.15	35	26	0.55	21	0.45
10	41	0.87	6	0.13	36	31	0.66	16	0.34
11	37	0.79	10	0.21	37	31	0.66	16	0.34
12	38	0.81	9	0.19	38	42	0.89	5	0.11
13	44	0.94	3	0.06	39	39	0.83	8	0.17
14	44	0.94	3	0.06	40	46	0.98	1	0.02
15	45	0.96	2	0.04	41	44	0.94	3	0.06
16	43	0.91	4	0.09	42	42	0.89	5	0.11
17	44	0.94	3	0.06	43	47	1.00	0	0.00
18	42	0.89	5	0.11	44	46	0.98	1	0.02
19	44	0.94	3	0.06	45	46	0.98	1	0.02
20	45	0.96	2	0.04	46	47	1.00	0	0.00
21	45	0.96	2	0.04	47	47	1.00	0	0.00
22	44	0.94	3	0.06	48	47	1.00	0	0.00
23	38	0.81	9	0.19	49	47	1.00	0	0.00
24	33	0.70	14	0.30	50	43	0.91	4	0.09
25	32	0.68	15	0.32	51	46	0.98	1	0.02
26	26	0.55	21	0.45	52	44	0.94	3	0.06

initial probability of occurrence of dry spell was above 80% from 1st standard meteorological week (SMW) to 22nd SMW except 11th SMW when it was 79%. But after 22nd SMW, the probability of occurrence of dry spell started decreasing and reached up to 28% during 28th SMW. Thereafter it increased and approached 100% during 46th to 49th SMW. The chances of occurrence of wet spell were highest during 28th SMW i.e., 72% followed by 68% during 30th and 31st SMW respectively. The conditional probability for dry and wet spell was also calculated for Amritsar (Table 3). It was observed that the probability of wet spell followed by wet spell was highest during 29th SMW (67%) followed by 60% during 33rd SMW. The conditional probability of dry spell followed by dry spell was always around 90% from 1st to 22nd SMW after that it decreased up to 39th week and then again started increasing. The chances of dry spell were more prominent than wet spell.

Table 3: Conditional probability (%) of wet (>20 mm) and dry (<20 mm rainfall) weeks at Amritsar (1971–2017) by Markov Chain Approach

SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)	SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)
1	39	0.91	0	0.00	27	10	0.42	8	0.35
2	40	0.91	1	0.33	28	1	0.08	20	0.59
3	41	0.93	0	0.00	29	7	0.41	20	0.67
4	33	0.85	1	0.13	30	5	0.33	19	0.59
5	40	0.93	0	0.00	31	1	0.07	17	0.53
6	32	0.80	1	0.14	32	3	0.17	14	0.48
7	28	0.72	1	0.13	33	6	0.35	18	0.60
8	26	0.68	0	0.00	34	14	0.50	8	0.42
9	33	0.83	2	0.29	35	11	0.42	8	0.38
10	36	0.88	1	0.17	36	21	0.68	8	0.50
11	34	0.92	3	0.30	37	18	0.58	6	0.38
12	29	0.76	1	0.11	38	37	0.88	1	0.20
13	29	0.66	1	0.33	39	27	0.69	0	0.00
14	39	0.89	0	0.00	40	44	0.96	0	0.00
15	40	0.89	0	0.00	41	40	0.91	0	0.00
16	39	0.91	0	0.00	42	37	0.88	1	0.20
17	42	0.95	0	0.00	43	46	0.98	0	0.00
18	35	0.83	0	0.00	44	44	0.96	0	0.00
19	40	0.91	0	0.00	45	45	0.98	0	0.00
20	42	0.93	0	0.00	46	46	0.98	0	0.00
21	43	0.96	0	0.00	47	46	0.98	0	0.00
22	41	0.93	0	0.00	48	46	0.98	0	0.00
23	29	0.76	1	0.11	49	46	0.98	0	0.00
24	25	0.76	3	0.21	50	41	0.95	1	0.25
25	24	0.75	7	0.47	51	44	0.96	1	1.00
26	15	0.58	7	0.33	52	40	0.91	0	0.00

3.2. Ludhiana

At Ludhiana, the initial and conditional probabilities were calculated using Markov Chain Model (Table 4 and Table 5). It was found that the probability of dry spell was above 85% from 1st SMW to 22nd SMW except during 4th SMW (81%) and 7th SMW (79%). The lowest (27%) probability of dry spell was observed during 28th SMW. The probability of dry spell increased after 40th SMW and ranged between 92% to 100%. Wet spell probability was the highest (73%) during 28th SMW followed by 67% during 30th and 32nd SMW. The probability of occurrence of wet spell was found to be highest during monsoon weeks. The conditional probability

Table 4. Initial probability (%) of wet (>20 mm) and dry (<20 mm rainfall) weeks at Ludhiana (1971-2018) by Markov Chain Approach

SMW	F(D)	P(D)	F(W)	P(W)	SMW	F(D)	P(D)	F(W)	P(W)
1	44	0.92	4	0.08	27	19	0.40	29	0.60
2	45	0.94	3	0.06	28	13	0.27	35	0.73
3	43	0.90	5	0.10	29	17	0.35	31	0.65
4	39	0.81	9	0.19	30	16	0.33	32	0.67
5	44	0.92	4	0.08	31	17	0.35	31	0.65
6	41	0.85	7	0.15	32	16	0.33	32	0.67
7	38	0.79	10	0.21	33	22	0.46	26	0.54
8	43	0.90	5	0.10	34	22	0.46	26	0.54
9	42	0.88	6	0.13	35	24	0.50	24	0.50
10	43	0.90	5	0.10	36	31	0.65	17	0.35
11	44	0.92	4	0.08	37	32	0.67	16	0.33
12	44	0.92	4	0.08	38	34	0.71	14	0.29
13	45	0.94	3	0.06	39	39	0.81	9	0.19
14	44	0.92	4	0.08	40	45	0.94	3	0.06
15	46	0.96	2	0.04	41	45	0.94	3	0.06
16	42	0.88	6	0.13	42	46	0.96	2	0.04
17	47	0.98	1	0.02	43	48	1.00	0	0.00
18	45	0.94	3	0.06	44	46	0.96	2	0.04
19	43	0.90	5	0.10	45	48	1.00	0	0.00
20	43	0.90	5	0.10	46	48	1.00	0	0.00
21	43	0.90	5	0.10	47	48	1.00	0	0.00
22	43	0.90	5	0.10	48	48	1.00	0	0.00
23	36	0.75	12	0.25	49	47	0.98	1	0.02
24	36	0.75	12	0.25	50	45	0.94	3	0.06
25	35	0.73	13	0.27	51	44	0.92	4	0.08
26	21	0.44	27	0.56	52	44	0.92	4	0.08

Table 5. Conditional probability (%) of wet (>20 mm) and dry (<20 mm rainfall) weeks at Ludhiana (1971-2018) by Markov Chain Approach

SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)	SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)
1	39	0.89	0	0.00	27	8	0.42	17	0.59
2	40	0.89	0	0.00	28	4	0.31	25	0.71
3	37	0.86	0	0.00	29	6	0.35	19	0.61
4	31	0.79	2	0.22	30	5	0.31	21	0.66
5	36	0.82	1	0.25	31	3	0.18	17	0.55
6	32	0.78	0	0.00	32	4	0.25	21	0.66
7	28	0.74	1	0.10	33	9	0.41	16	0.62
8	37	0.86	0	0.00	34	9	0.41	14	0.54
9	36	0.86	0	0.00	35	11	0.46	11	0.46
10	37	0.86	1	0.20	36	18	0.58	5	0.29

SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)	SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)
11	40	0.91	1	0.25	37	20	0.63	5	0.31
12	39	0.89	1	0.25	38	21	0.62	3	0.21
13	41	0.91	1	0.33	39	32	0.82	3	0.33
14	41	0.93	1	0.25	40	39	0.87	0	0.00
15	41	0.89	0	0.00	41	41	0.91	0	0.00
16	39	0.93	1	0.17	42	43	0.93	0	0.00
17	45	0.96	0	0.00	43	47	0.98	0	0.00
18	38	0.84	0	0.00	44	44	0.96	0	0.00
19	35	0.81	1	0.20	45	44	0.92	0	0.00
20	37	0.86	0	0.00	46	46	0.96	0	0.00
21	36	0.84	0	0.00	47	46	0.96	0	0.00
22	39	0.91	0	0.00	48	47	0.98	0	0.00
23	24	0.67	3	0.25	49	45	0.96	0	0.00
24	25	0.69	2	0.17	50	41	0.91	0	0.00
25	19	0.54	3	0.23	51	40	0.91	1	0.25
26	8	0.38	13	0.48	52	39	0.89	0	0.00

calculated at Ludhiana showed that the probability of wet spell followed by wet spell was highest (71%) during 28th SMW followed by 66% during 30th and 32nd SMW. The probability of dry spell followed by spell ranged between 74% to 98% during 1st to 22nd SMW and 39th to 52nd SMW. Goyal et al. (2015) reported that the lowest rainfall probability at Ludhiana was observed during 22nd SMW for 5, 10 and 20 mm that falls in June month.

3.3. Patiala

The Markov Chain Model was used to calculate the initial and conditional probability of dry and wet spell at Patiala from 1971–2018 (Table 6 and Table 7). It was found that the probability of dry spell was above 85% during 1st to 23rd SMW except 9th SMW (81%). The probability of dry spell decreased thereafter and reached as low as 31% during 33rd SMW. After 39th SMW, it again increased to

Table 6. Initial probability (%) of wet (>20 mm) and dry (<20 mm rainfall) weeks at Patiala (1971-2018) by Markov Chain Approach

SMW	F(D)	P(D)	F(W)	P(W)	SMW	F(D)	P(D)	F(W)	P(W)
1	44	0.92	4	0.08	27	23	0.48	25	0.52
2	45	0.94	3	0.06	28	19	0.40	29	0.60
3	44	0.92	4	0.08	29	18	0.38	30	0.63
4	41	0.85	7	0.15	30	21	0.44	27	0.56
5	46	0.96	2	0.04	31	21	0.44	27	0.56
6	42	0.88	6	0.13	32	21	0.44	27	0.56
7	41	0.85	7	0.15	33	15	0.31	33	0.69
8	43	0.90	5	0.10	34	27	0.56	21	0.44
9	39	0.81	9	0.19	35	28	0.58	20	0.42
10	42	0.88	6	0.13	36	26	0.54	22	0.46
11	43	0.90	5	0.10	37	31	0.65	17	0.35
12	43	0.90	5	0.10	38	37	0.77	11	0.23
13	45	0.94	3	0.06	39	39	0.81	9	0.19
14	46	0.96	2	0.04	40	44	0.92	4	0.08

Table 6: Continue...

SMW	F(D)	P(D)	F(W)	P(W)	SMW	F(D)	P(D)	F(W)	P(W)
15	46	0.96	2	0.04	41	46	0.96	2	0.04
16	46	0.96	2	0.04	42	47	0.98	1	0.02
17	46	0.96	2	0.04	43	48	1.00	0	0.00
18	46	0.96	2	0.04	44	47	0.98	1	0.02
19	46	0.96	2	0.04	45	48	1.00	0	0.00
20	43	0.90	5	0.10	46	48	1.00	0	0.00
21	42	0.88	6	0.13	47	48	1.00	0	0.00
22	42	0.88	6	0.13	48	48	1.00	0	0.00
23	40	0.83	8	0.17	49	47	0.98	1	0.02
24	36	0.75	12	0.25	50	46	0.96	2	0.04
25	34	0.71	14	0.29	51	47	0.98	1	0.02
26	23	0.48	25	0.52	52	42	0.88	6	0.13

Table 7: Conditional probability (%) of wet (>20 mm) and dry (<20 mm rainfall) weeks at Patiala (1971–2018) by Markov Chain Approach

SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)	SMW	F(D/D)	P(D/D)	F(W/W)	P(W/W)
1	39	0.89	0	0.00	27	12	0.52	13	0.52
2	42	0.93	1	0.33	28	10	0.53	20	0.69
3	39	0.89	1	0.25	29	9	0.50	21	0.70
4	35	0.85	2	0.29	30	10	0.48	14	0.52
5	43	0.93	0	0.00	31	10	0.48	16	0.59
6	35	0.83	0	0.00	32	9	0.43	15	0.56
7	35	0.85	1	0.14	33	4	0.27	22	0.67
8	37	0.86	0	0.00	34	15	0.56	9	0.43
9	30	0.77	0	0.00	35	16	0.57	8	0.40
10	37	0.88	2	0.33	36	15	0.58	9	0.41
11	37	0.86	0	0.00	37	19	0.61	6	0.35
12	37	0.86	0	0.00	38	29	0.78	3	0.27
13	41	0.91	0	0.00	39	28	0.72	1	0.11
14	43	0.93	0	0.00	40	39	0.89	0	0.00
15	44	0.96	0	0.00	41	42	0.91	0	0.00
16	43	0.93	0	0.00	42	44	0.94	1	1.00
17	43	0.93	0	0.00	43	47	0.98	0	0.00
18	43	0.93	0	0.00	44	45	0.96	0	0.00
19	43	0.93	0	0.00	45	47	0.98	0	0.00
20	39	0.91	0	0.00	46	47	0.98	0	0.00
21	36	0.86	0	0.00	47	47	1.00	0	0.00
22	35	0.83	1	0.17	48	47	0.98	0	0.00
23	34	0.85	2	0.25	49	45	0.96	0	0.00
24	28	0.78	4	0.33	50	39	0.85	0	0.00
25	24	0.71	4	0.29	51	45	0.96	0	0.00
26	9	0.39	10	0.40	52	32	0.76	0	0.00

reach up to 100% during 43rd, 45th, 46th, 47th and 48th SMW. The probability of wet spell was highest (69%) during 33rd week followed by 63% during 29th SMW. The frequency of occurrence of dry spell was more compared to wet spell at Patiala. The computation of conditional probability showed that the probability of dry spell followed by dry spell was above 85% from 1st to 23rd SMW except during 7th SMW (77%). It was above 90% during 41st to 52nd SMW except 50th SMW when probability of dry spell followed by dry spell was 85%. The probability of wet spell followed by wet spell was highest (70%) during 29th SMW.

4. CONCLUSION

The probability of occurrence of dry week is higher from 1st to 25th SMW and also from 37th to 52nd. The probability of occurrence wet spell was found to be highest during 28th to 33rd SMW. Land preparation and sowing could be taken up between prior to 26–28 SMW for *kharif* season crop cultivation. Supplementary irrigation and moisture conservation practices need to be practiced after 36th SMW for short duration crops and it could be extended if the crop is of long duration.

5. REFERENCES

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