International Journal of Chemical Studies 2021; 9(4): 271-275

International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2021; 9(4): 271-275

Received: 04-05-2021
Accepted: 06-06-2021

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Dry and wet spell probability analysis by Markov chain model at Parbhani, Maharashtra

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Abstract

Sequence of dry and wet periods along with onset and withdrawal of rainy season is necessary for successful agricultural crop planning and soil and water conservation measures. In the present study, Markov chain probability model was performed to determine the dry and wet week probabilities was applied for Parbhani using 30 years (1991 to 2020) weekly rainfall. The data on onset and withdrawal of rainy season indicated that the monsoon starts on the 23rd SMW (04th June – 10th June) and remains active up to the 42nd week (15th – 21st October). The probability of getting dry week was observed more than 50 per cent in 23rd, 29th, 35th and 37th to 42nd SMW in crop growth period at 20 mm per week threshold limit. More than 50 per cent probability of getting wet week was observed in 23rd to 28th, 30th to 38th and 40th SMW, thus chances of rainwater harvesting in this period is more and it can be used as protective irrigation.

Keywords: Markov chain model, dry and wet week, weekly rainfall, onset and withdrawal of rainy season, standard meteorological week

1. Introduction

In a predominantly agricultural system, natural rainfall is the main source of water for agricultural sector. Rainfall determines the potential of any region in terms of crops to be grown, farming system to be adopted, the nature and sequence of farming operations to be followed and to achieve higher agricultural productivity (Singh and Dhillon, 1994; Chaudhary, *et al*. 2003) [17, 3]. South-west monsoon plays a vital role in rainfed area which impacts the nation's economy in various ways. Indian agriculture is predominantly influenced by rainfall, specifically by the south-west monsoon rainfall (June–October) (Mandal *et al.* 2013) [11]. Variation in rainfall distribution patterns is the major reason for increasing the probability of occurrence of drought like situation in the country.

The climatology and variability of the parameters of the rainy season and the wet and dry spells are valuable information for scientists, engineers, planners, and managers working in water-related sectors (agriculture, ecology, hydrology, and water resources). The stochastic analysis of consecutive dry and wet spells can also help to prepare crop planning, improve productivity and cropping intensity and develop agricultural operations during and after the cropping season. Like the stochastic analysis of rainfall, the forward and backward accumulation of rainfall data to establish the onset and withdrawal of monsoon also helps in crop planning. Delay in the onset of monsoon results in late sowing of rainy season crops, whereas pre-monsoon showers help in the land preparation and planting of wet season crops. Likewise, early withdrawal of rains causes a reduction in yield due to severe moisture stress at the critical growth stages like grain formation and seed development (Dixit *et al.* 2005) [4].

Markov chain probability model has been used extensively to find the long-term frequency behavior of wet and dry weather spells (Victor and Sastri 1979) [21]. Many researchers (Kar, 2003; Jat *et al*. 2003; Kumari *et al.* 2014; Kumar *et al.* 2015) [6, 5, 9, 10] used this model for agricultural planning of different region of India. Estimating the probabilities of occurrence of dry and wet spells and consecutive occurrence of dry and wet spells with respect to a threshold amount of rainfall is extremely useful for crop planning, farming operations and design/adoption of moisture conservation measures (Sudhishri *et al*. 2007; Subash *et al*. 2009; Khandelwal *et al*. 2013) [19, 18, 7].

2. Materials and Methods
2.1 Study area description
The study area is located at 19°16' N Latitude; 76°47' E Longitude; 409 meters above mean sea level (MSL) in Marathwada division of Maharashtra state. The climate of the study area is characterized as semi-arid and tropical. It comes under moderate to moderately high rainfall zone with an average annual rainfall of 947.5 mm. The soil of the command area is medium deep black clay. The mean maximum and minimum temperature of the study area is 44.6 ^{0}C and 21.8 ^{0}C, respectively. The mean relative humidity ranges from 30 to 98 per cent. (Tarate *et al.* 2017) [20].

2.2 Data collection
The data necessary for the present study is rainfall on daily basis. Daily rainfall data of 30 years from (1991 - 2020) were collected from Agricultural Meteorology Laboratory, Vasantrao Naik Marathawada Krishi Vidyapeeth, VNMKV, Parbhani, Maharashtra.

2.3 Computation of dry and wet spells using Markov chain probability model
Assessment of dry and wet spell has been carried out using weekly rainfall data based on Markov chain probability model. For calculation of meteorological weekly basis, the year was partitioned as per meteorological calendar, starting from 1st January of each year and ending on 31st December of the same year. A week is considered as a dry week when rainfall is less than 20 mm in a week and when rainfall is more than 20 mm it is a wet week (Pandharinath, 1991) [12]. Markov chain probability model assumes that the probability of rainfall occurring on any week depends on whether the previous week was wet or dry. The model calculates the initial probabilities of getting a dry spell / wet spell in a given standard meteorological week. The calculation of conditional probabilities provides the information on the dry spell followed by dry spell or wet spell vice-versa. The calculation of initial and conditional probabilities are given below.

2.3.1 Initial probability of dry and wet weeks
Based on historic data of weekly rainfall the initial probabilities of dry and wet weeks can be calculated as:

$$P(D) = F(D)/N \qquad \ldots(2.1)$$

$$P(W) = F(W)/N \qquad \ldots(2.2)$$

Where,
P (D) =Probability of occurrence of dry week,
P (W) =Probability of occurrence of wet week,
F (D) =Frequency of occurrence of dry week,
F (W) =Frequency of occurrence of wet week,
N = Total number of years.

2.3.2 Conditional probability of dry and wet weeks
Conditional probability of dry or wet week preceded by dry or wet week is calculated by using following formulae.

$$P(D/D) = F(DD)/F(D) \qquad \ldots(2.3)$$

$$P(W/W) = F(WW)/F(W) \qquad \ldots(2.4)$$

$$P(W/D) = 1-P(D/D) \qquad \ldots(2.5)$$

$$P(D/W) = 1-P(W/W) \qquad \ldots(2.6)$$

Where,
P (D/D) =Probability of a week being dry preceded by another dry week,
P (W/W) = Probability of a week being wet preceded by another wet week,
F (D/D) =Frequency of dry week preceded by another dry week,
F (W/W) =Frequency of a wet week preceded by another wet week,
P (W/D) =Probability of a wet week preceded by a dry week,
P (D/W) =Probability of a dry week preceded by a wet week.

2.3.3 Consecutive probability of dry and wet weeks
Consecutive probability of two and three dry and wet weeks is calculated by using following formulae.

$$P(2D) = P(DW1) \times P(DDW2) \qquad \ldots(2.7)$$

$$P(3D) = P(DW1) \times P(DDW2) \times P(DDW3) \qquad \ldots(2.8)$$

$$P(2W) = P(WW1) \times P(WWW2) \qquad \ldots(2.9)$$

$$P(3W) = P(WW1) \times P(WWW2) \times P(WWW3) \qquad \ldots(2.10)$$

Where,
P (2D) = Probability of two consecutive dry weeks starting with the week,
P (DW1) = Probability of the first week being dry,
P (DDW2) = Probability of the second week being dry, given the preceding week being dry,
P (3D) = Probability of three consecutive dry weeks starting with the week,
P (DDW3) = Probability of the third week being dry, given the preceding week dry, P (2W) = Probability of two consecutive wet weeks starting with the week,
P (WW1) = Probability of the first week being wet,
P (WWW2) = Probability of the second week being wet, given the preceding week being wet,
P (3W) = Probability of three consecutive wet weeks starting with the week, and P (WWW3) = Probability of the third week being wet, given the preceding week wet.

2.4 Computation method for the onset and withdrawal of rainy season
Onset and withdrawal of rainy season were computed from weekly rainfall data by forward and backward accumulation methods (Kothari *et al.* 2009) [8]. Each year was divided into 52 standard meteorological weeks (SMW). The first SMW of any year starts from 1st to 7th January and 52nd SMW are from 24th to 31st December. Weekly rainfall was summed up by forward accumulation (20+21+…+ 52 weeks) until 75 mm of rainfall was accumulated. An accumulation of 75 mm of rainfall has been considered as the onset time for summer monsoon which helps in land preparation and sowing of crops (Panigrahi and Panda 2002; Kothari *et al.* 2009) [13, 8]. The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+…+30 weeks) data. 20 mm of rainfall accumulation was chosen for the withdrawal of the rainy season, which is sufficient for ploughing of fields after harvesting the first crop (Babu and Lakshminarayana 1997; Reddy Srinivasa *et al.* 2008) [2, 15].
The percent probability (P) of each rank was calculated by arranging them in ascending order and by selecting highest rank allotted for particular week.

The following Weibull's formula has been used for calculating percent probability (Robert *et al.* 1971).

$$P = \frac{m}{N+1} \times 100 \ldots 2.11$$

Where,
m = Rank number, N = Number of years of data used.

3. Results and Discussion

3.1 Analyses of rainfall for onset and withdrawal of rainy season

Weekly rainfall data of 30 years (1991 – 2020) indicated that the monsoon starts effectively from 23rd standard meteorological week (SMW) (04th to 10th June) and remains active up to 42nd SMW (15th to 21st October). Therefore, mean length of rainy season was found to be 20 weeks (140 days) which include rainfall of both south-west and north-east monsoon. The earliest and delayed week of onset of rainy season was 20th SMW (14th to 20th May) and 30th SMW (23rd to 29th July) respectively. Similarly the earliest and delayed week of termination of rainy season was 38th SMW (17th to 29th September) and 48th SMW (26th to 02nd December) respectively are presented in Table 1 The probabilities of the onset and withdrawal of rainy season were calculated by using Weibull's formula considering forward and backward accumulation of weekly rainfall is presented in Table 2. The results forward accumulation starting from 20th week revealed that there was 96 per cent chance onset of effective monsoon i.e. probability of getting cumulative rainfall ≥ 75 mm in 30th week. Similarly, the 96 per cent chance of withdrawal i.e. the probability of getting cumulative rainfall ≤ 20 mm in 48th SMW, considering backward accumulation of weekly rainfall into account starting from week 48th are similar to the findings of Admasu *et al.* (2014) [1], Pawar *et al.* (2019) [14].

The weekly rainfall for mean, standard deviation and coefficient of variation of study area were calculated and the results are shown in Table 3 and Figure 1. There are 18 weeks (23rd to 38th 40th and 41st week) where the rainfall exceeds more than 20 mm and 2 weeks (39th and 42nd week) where rainfall is less than 20 mm during the main rainy season. The coefficient of variation during the main rainy season varies from maximum of 192.19 per cent at 42nd week to minimum of 85.34 per cent at the 24th week.

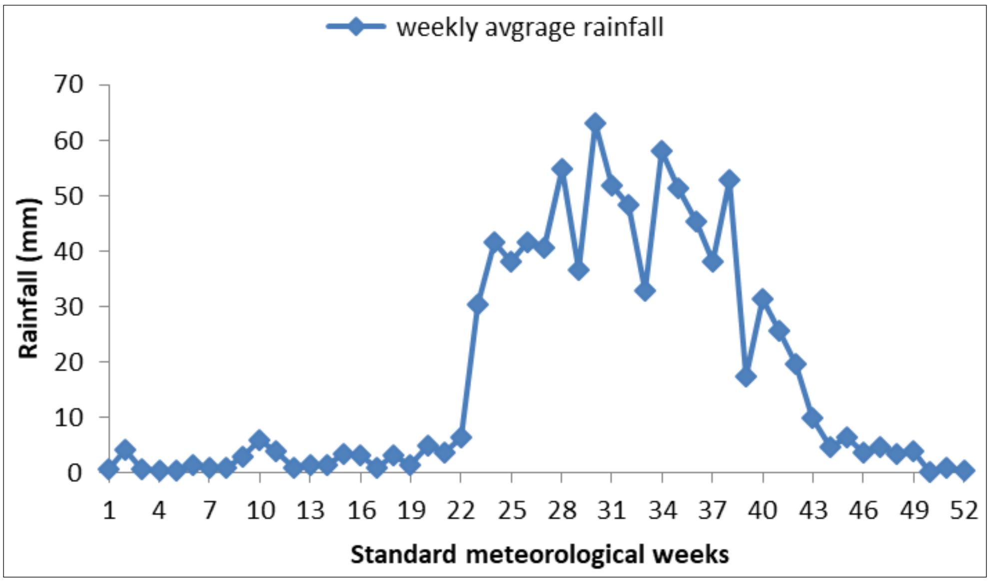

Fig 1: Distribution of mean weekly rainfall, mm

Table 1: Characterization of the rainy season at Parbhani

Sr. No.	Particulars	Standard week	Date
I.	Onset of rainy season		
1	Mean week	23	04th to 10th June
2	Earliest week	20	14th to 20th May
3	Delayed week	30	23rd to 29th July
II.	Withdrawal of rainy season		
1	Mean week	42	15th to 21st October
2	Earliest week	38	17th to 23rd September
3	Delayed week	48	26th to 02nd December

3.2 Analysis of dry and wet spells using Markov Chain model

The initial, conditional and consecutive probability of dry and wet week at threshold limit 20 mm of rainfall during the crop growth period (SMW 23rd to 42nd) is calculated using 'Weather Cock' software developed by CRIDA, Hyderabad. Results of initial, conditional and consecutive probabilities of dry and wet weeks are presented in Table (3). The initial probability of getting wet and dry week i.e. P (W) and P (D) ranges from 26.67 to 70.00 per cent and 30.00 to 73.33 per cent respectively. The initial probability of getting wet week is observed more than 50 per cent in SMW 24th to 28th and 30th to 38th. The conditional probability of wet and dry weeks P(W/W), P(D/W), P(D/D) and P(W/D) ranges from 20.00 to 100.0, 00.00 to 80.00, 30.00 to 90.91 and 9.09 to 70.00 per cent respectively. The probability of wet week preceded by another wet week is greater than 50 per cent in SMW 23rd to 26th, 28th, 30th to 38th and 40th whereas probability of dry week preceded by another dry week was observed more than 50 per cent in SMW 23rd, 29th, 35th and 37th to 42nd respectively. The consecutive two and three dry and wet weeks probability, P(2D), P(3D), P(2W) and P(3W) ranges from 10.00 to 70.00, 5.00 to 64.00, 6.67 to 53.33 and 1.67 to 35.69 per cent during crop growth period. The probability of two and three consecutive wet weeks was observed highest in 34th to 37th SMW. Thus in Parbhani, SMW 23rd to 26th, 28th, 30th to 38th and 40th are observed as wet week more probably, so there will be less moisture stress on crops during these weeks. From SMW 34th to 37th comparatively higher range of consecutive wet week is observed, therefore during these weeks harvesting of excess amount of runoff water for supplemental irrigation and soil erosion control measures are necessary to carry out in this period.

The mean onset of rainy season was found to be 23rd SMW (04th June to 10th June), the sowing operations can be taken up since 24th SMW because the probability of getting wet week is more than 50 per cent and average weekly rainfall is 41.5 mm. Sowing operations taken at 24th SMW helps for good germination and helps in avoiding moisture stress for germination period during 25th to 28th SMW. In the event of delayed monsoon, the sowing operation may be delayed up to 30th SMW and short duration crops may be taken with low water requirement. During kharif, short duration crops of groundnut, pigeon pea, maize, sorghum, green gram, soybean, sunflower, field bean, cowpea and other low water required crops which have high return value can be taken up. The main advantage of growing short duration crops is that these crops may be harvested on or before 38th SMW with almost no supplemental irrigation and short duration *rabi* crops can be sown during 39th to 42nd SMW.

Table 2: Probability of onset and withdrawal of effective monsoon

Probability of onset and withdrawal											
Onset of effective monsoon											
Week	20	21	22	23	24	25	26	27	28	29	30
P (%)	3.2	6.4	9.6	25.8	45.1	58.0	70.9	77.7	87.0	90.3	96.7
Withdrawal of effective monsoon											
Week	38	39	40	41	42	43	44	45	46	47	48
P (%)	6.4	9.6	19.3	45.1	58.0	61.2	70.9	80.6	87.0	93.5	96.7

Table 3: Descriptive statistics on weekly rainfall data for Parbhani

SMW	Mean (mm)	SD (mm)	CV (%)	SMW	Mean (mm)	SD (mm)	CV (%)
1	0.6	1.85	308.33	27	40.6	42.06	103.59
2	4.2	11.72	279.04	28	54.8	53.09	96.87
3	0.7	2.70	385.71	29	36.6	43.70	119.39
4	0.3	1.79	596.66	30	63.2	95.70	151.42
5	0.5	2.15	430.0	31	51.8	56.21	108.51
6	1.5	5.51	367.33	32	48.3	65.16	134.90
7	0.8	3.36	420.0	33	32.9	36.27	110.24
8	0.8	2.94	367.5	34	58.2	57.86	99.41
9	3.0	7.27	242.33	35	51.4	50.51	98.26
10	5.9	16.00	271.18	36	45.4	38.81	85.48
11	4.0	14.54	363.5	37	38.0	38.54	101.42
12	1.0	2.32	232.0	38	52.8	52.60	99.62
13	1.5	6.62	441.33	39	17.3	22.45	129.76
14	1.4	3.38	241.42	40	31.3	62.81	200.67
15	3.5	7.73	220.85	41	25.7	39.36	153.15
16	3.1	12.10	390.32	42	19.6	37.67	192.19
17	0.8	2.30	287.5	43	9.8	26.45	269.89
18	3.2	7.64	238.75	44	4.7	9.97	212.12
19	1.4	3.79	270.71	45	6.4	15.04	235.0
20	4.9	16.59	338.57	46	3.6	8.00	222.0
21	3.7	6.17	166.75	47	4.7	12.27	261.06
22	6.3	18.03	286.19	48	3.4	18.12	532.94
23	30.4	42.47	139.70	49	3.9	12.24	313.84
24	41.5	35.97	86.67	50	0.1	0.65	650.0
25	38.2	43.86	114.81	51	0.8	4.30	537.5
26	41.5	49.98	120.43	52	0.4	1.69	422.5

Table 4: Dry and wet weeks probability during crop growth period in Parbhani

SMW	Initial Probability (per cent)		Conditional Probability (per cent)				Consecutive Probability (per cent)			
	P(W)	P(D)	P(W/W)	P(D/W)	P(D/D)	P(W/D)	P(2D)	P(3D)	P(2W)	P(3W)
23	36.67	63.33	100.0	00.00	67.86	32.14	20.00	8.89	26.67	15.24
24	70.00	30.00	72.73	27.27	31.58	68.42	13.33	6.15	40.00	21.18
25	56.67	43.33	57.14	42.86	44.44	55.56	20.00	8.57	30.00	15.00
26	53.33	46.67	52.94	47.06	46.15	53.85	20.00	10.00	26.67	21.67
27	53.33	46.67	50.00	50.00	42.86	57.14	23.33	21.00	43.33	21.67
28	66.67	33.33	81.25	18.75	50.00	50.00	30.00	11.05	33.33	18.18
29	36.67	63.33	50.00	50.00	90.00	10.00	23.33	11.67	20.00	14.44
30	60.00	40.00	54.55	45.45	36.84	63.16	20.00	7.27	43.33	22.81
31	63.33	36.67	72.22	27.78	50.00	50.00	13.33	6.15	33.33	17.65
32	56.67	43.33	52.63	47.37	36.36	63.64	20.00	8.57	30.00	24.38
33	53.33	46.67	52.94	47.06	46.15	53.85	20.00	11.11	43.33	33.02
34	70.00	30.00	81.25	18.75	42.86	57.14	16.67	5.00	53.33	34.67
35	66.67	33.00	76.19	23.81	55.56	44.44	10.00	6.00	43.33	28.17
36	66.67	33.33	65.00	35.00	30.00	70.00	20.00	12.31	43.33	35.69
37	56.67	43.33	65.00	35.00	60.00	40.00	26.67	24.24	46.67	22.11
38	63.33	36.67	82.35	17.65	61.54	38.46	33.33	26.67	30.00	18.00
39	33.33	66.67	47.37	52.63	90.91	9.09	53.33	37.33	20.00	8.00
40	33.33	66.67	60.00	40.00	80.00	20.00	46.67	32.67	13.33	2.67
41	33.33	66.67	40.00	60.00	70.00	30.00	46.67	44.55	6.67	1.67
42	26.67	73.33	20.00	80.00	70.00	30.00	70.00	64.81	6.67	2.22

4. Conclusion

Monsoon starts effectively from 23rd SMW (04th to 10th June) and remains up to 42nd SMW (15th to 21st October. Therefore, we expected good monsoon shower for about 20 weeks in the study area. Based on Markov-chain initial, conditional and consecutive dry and wet week's probability, more than 50 per cent probability of occurrence of dry week is observed in 23rd, 29th, 35th and 37th to 42th SMW in crop growth period at 20 mm per week threshold limit. More than 50 per cent probability of getting wet week is observed in SMW 23rd to 28th, 30th to 38th and 40th. Thus, chances of rainwater harvesting in this period is more and it can be used as protective irrigation.

5. Acknowledgement

Daily rainfall data of 30 years from (1991 - 2020) were collected from Agricultural Meteorology Laboratory, Vasantrao Naik Marathawada Krishi Vidyapeeth, VNMKV, Parbhani, Maharashtra

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