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Research Article

WEEKLY RAINFALL ANALYSIS USING MARKOV CHAIN MODEL FOR V.C. FARM, MANDYA DISTRICT, KARNATAKA

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Abstract: For success of agriculture under rainfed situation it is essential to know the onset and withdrawal of monsoon, the pattern of occurrence of dry and wet periods during monsoon season. The present study has been carried out at Zonal Agricultural Research Station which is located at Mandya district in Karnataka state under agro-climatic zone 6 (Southern dry zone) having longitude of 76°49.8' E and latitude of 12°34.3' N with an altitude of 697 meters above the mean sea level. Weekly Rainfall data of 26 years (1991-2018) obtained from Agromet observatory, ZARS, Mandya, University of Agricultural Sciences, Bangalore was studied for spell distribution using Markov Chain Model. For this purpose, a week period was considered as the optimum length of time. The present study has been carried out to find the probabilities of occurrence of wet week (P_w), dry week (P_d), wet week preceded by wet week (P_{ww}), dry week headed by dry week (P_{dd}), two and three succeeding wet and dry weeks (P_{2w}, P_{2d}, P_{3w} and P_{3d}) at a threshold rainfall limit of 20 mm/week. The results revealed that, the probability of occurrence of wet weeks during the pre-monsoon season starts effectively from 15th May to 15th June in the study area. The chance of occurrence of two or three consecutive wet weeks was high during rainy season, whereas, rest of the period during the year was more prone to have two or three consecutive dry weeks.

Keywords: *Probability, Dry spell, Wet spell, Markov chain model, Rainfall analysis*

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Introduction

In a predominant agricultural system, natural rainfall is the main source of water for agricultural sector. Rainfall variability is a major factor influencing, the agricultural production in a region and are of great importance in crop management practices and contingent crop planning. Markov-chain probability model is suitable for studying the long-term frequencies of wet and dry spells in the area of study [1]. The yield of crops in rain-fed condition depends on the rainfall pattern. Dry and wet spells could be used for analyzing rainfall data, for crop planning and for carrying out agricultural operations [2, 3]. The initial and conditional probability approach would be relatively good method for rainfall analysis, especially in the regions where rainfall is erratic or where short dry periods can be expected within the wet season. Markov Chain model was used for calculating the probability of rainfall at VC farm, Mandya. A week period was considered as an optimum length of time. The study has been carried out to find out the probabilities of occurrence of wet week (W) and wet week preceded by wet week (W/W) at different threshold limits of 20 mm. In this paper, Markov Chain Probability Model has been extensively used to study spell distribution and other properties of rainfall occurrence, long term frequency behaviour of wet and dry weather as well as for computation of probability of occurrence of weekly precipitation.

Materials and Methods

Study area

The present study has been carried out to find the probabilities of occurrence of dry and wet weeks, onset and withdrawal of rainy season and weekly analysis of rainfall for Zonal Agricultural Research Station, V.C. Farm located at Mandya district of Karnataka which lies under agro-climatic zone 6 (Southern dry zone) having longitude of 76° 49.8' E and latitude of 12°34.3' N with an altitude of 697 meters above mean sea level. Weekly Rainfall data of 26 years (1991-2018) obtained from Agromet observatory, ZARS, V.C. Farm, Mandya, University of Agricultural Sciences, Bangalore was used for analysis.

Forecasting of dry and wet spells using Markov chain model

The concept of estimating probabilities with respect to a given amount of rainfall is extremely useful for agricultural planning. In a crop growing season, many times decisions have to be taken based on the probability of receiving certain amount of rainfall during a given week [P(W)], which are called “initial probabilities”. Then the probability of rain next week, if we had rain this week [P(W/W)] *etc*. are very important and are called “conditional probabilities”. These initial and conditional probability becomes the basis for the analysis of rainfall using Markov chain process.

Markov chain model

Markov chain probability model has been found suitable to describe the long-term frequency behaviour of wet or dry spells. This model assumes that the probability of rainfall occurring on any week depends on whether the previous week was wet or dry. Rainfall amount is involved only in the definition of occurrence or non-occurrence of rain. In the first order Markov chain the probability of an event that would occur on any single day depends only on the conditions during the preceding day and is independent of events of further preceding days.

Karnataka State Map Mandya District Map V.C. Farm Mandya

Fig-1 Location of the study area

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 is given below;

Initial Rainfall Probability (%)

Initial rainfall probability of getting less than 20 mm rainfall of week W_x

$P_d = F_d/n$

Where P_d= probability of the period considered being dry;

F_d= number of dry periods observed and n= number of years of data used.

$P_w = F_w/n$

Where P_w is probability of the period considered being wet;

F_w= number of wet periods observed and n= number of years of data used.

Conditional Rainfall Probability (%)

Conditional rainfall probability is the per cent probability of getting rainfall less than 20 mm during next week, when rainfall received during this week is > 20 mm.

$$P_{dd} = F_{dd}/P_d$$

Where P_{dd}= probability of dry period preceded (conditional); F_{dd}= number of dry periods preceded by another dry period and P_d = probability of the period considered being dry.

$P_{ww} = F_{ww}/P_w$

Where P_{ww}= probability of wet period preceded (conditional); F_{ww}= number of wet periods preceded by another wet period and P_w = probability of the period considered being wet.

$P_{wd} = 1 - P_{dd}$

P_{wd}= probability (conditional) of a wet week preceded by a wet week;

P_{dd}= probability of dry period preceded (conditional).

$P_{dw} = 1 - P_{ww}$

P_{dw}= probability (conditional) of a dry week preceded by a wet week;

P_{ww}= probability of wet period preceded (conditional).

Using the above formulas, initial probabilities of dry weeks and wet weeks, conditional probabilities of dry weeks preceded by dry weeks and wet weeks preceded by wet weeks have been estimated.

Application of Markov Chain model for determination of initial and conditional probability of dry and wet spells of diverse durations for different climatic conditions to demonstrate the practical utility of it in agricultural planning has been studied by different scientists [4-10].

Consecutive Dry and Wet Week Probabilities

Probability of 2 consecutive dry weeks starting with the week.

$2D = P_{d1} \times P_{d2}$

2D = Probability of 2 consecutive dry period; P_{d1} = Probability of the period being dry (1st period); P_{d2} = Probability of 2nd consecutive dry period, given the preceding period dry.

$3D = P_{d1} \times P_{d2} \times P_{d3}$

3D = Probability of 3 consecutive dry period; P_{d1} = Probability of the period being dry (1st period); P_{d2} = Probability of 2nd consecutive dry period, given the preceding period dry; P_{d3} = Probability of 3rd being dry period, given the preceding period dry.

$2W = P_{w1} \times P_{w2}$

2W = Probability of 2 consecutive wet period; P_{w1} = Probability of the period being wet (1st period); P_{w2} = Probability of 2nd consecutive wet period, given the preceding period wet.

$3W = P_{w1} \times P_{w2} \times P_{w3}$

3W = Probability of 3 consecutive wet period; P_{d1} = Probability of the period being wet (1st period); P_{w2} = Probability of 2nd consecutive wet period, given the preceding period wet; P_{w3} = Probability of 3rd being wet period, given the preceding period wet.

Results and Discussion

Monthly rainfall variability

The average annual rainfall received over past twenty eight years at Zonal Agricultural Research Station, V.C.Farm, Mandya was 735.9mm. Mean monthly rainfall varied from 1.60 mm (lowest in January) to 162.98 mm (highest in October) [Table-1] and depicted in [Fig-1]. The overall variability analysis of rainfall revealed that receipt of rainfall during the first three months (January to March) was less than 2.57 per cent. In the subsequent months, April and May rainfall increased gradually to 22.62 per cent, whereas from June to October it reached maximum of 65.45 per cent. Similar results were observed from the findings of [11, 12].

Table-1 *Monthly rainfall variability of ZARS, Mandya (1991-2018)*

Month	Max.	Min.	Mean	SD	CV (%)	% Contribution
January	15.6	0.00	1.60	4.11	257.35	0.22
February	29.2	0.00	1.76	5.67	321.39	0.24
March	172.0	0.00	15.25	34.97	229.28	2.11
April	188.0	0.00	53.95	44.13	81.81	7.45
May	304.0	0.00	109.90	81.19	73.88	15.17
June	210.2	0.00	56.59	45.96	81.21	7.81
July	120.8	1.20	48.39	32.27	66.68	6.68
August	217.6	0.00	75.52	67.28	89.09	10.42
September	363.5	30.40	130.66	79.95	61.19	18.04
October	420.8	10.80	162.98	103.68	63.62	22.50
November	256.8	0.00	55.23	56.93	103.10	7.62
December	52.6	0.00	12.60	14.84	117.74	1.74

Max- Maximum Min-Minimum SD -Standard Deviation CV-Co-efficient of variance

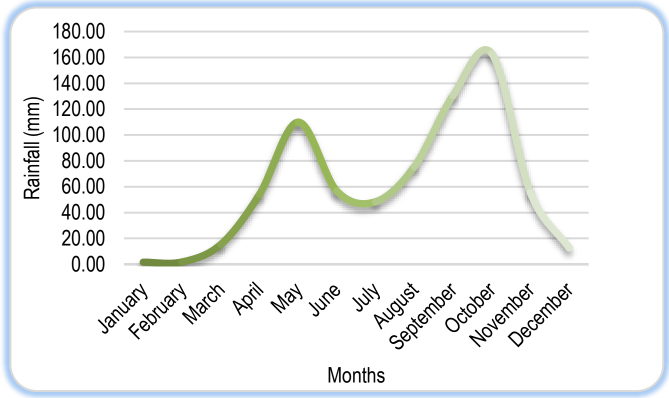

Fig-2 Rainfall trend at ZARS, Mandya (1991-2018)

Mean weekly rainfall analysis

Weekly rainfall distribution during the period (1993-2018) is presented in [Table-2]. The mean, minimum and maximum rainfall during different seasons and their statistical inferences are given.

Table-2 *Weekly rainfall attributes at ZARS, V.C. Farm, Mandya (1993-2018)*

SMW	Mean	Max	Min	SD	C.V. (%)	% ARF	SMW	Mean	Max	Min	SD	C.V. (%)	% ARF
1	0.4	6.0	0.0	1.2	293.9	0.1	27	6.0	32.4	0.0	8.5	142.3	0.8
2	0.1	2.0	0.0	0.5	360.3	0.0	28	15.3	87.0	0.3	21.1	138.0	2.0
3	0.7	15.0	0.0	2.9	435.8	0.1	29	13.0	77.8	0.0	16.8	129.6	1.7
4	0.4	6.4	0.0	1.4	370.5	0.1	30	13.6	69.4	0.0	18.6	136.8	1.8
5	0.9	9.6	0.0	2.6	299.2	0.1	31	12.2	90.0	0.0	18.4	150.6	1.6
6	0.7	7.8	0.0	2.0	290.0	0.1	32	10.6	66.0	0.0	15.9	150.4	1.4
7	0.4	4.6	0.0	1.6	361.9	0.1	33	27.9	119.6	0.0	33.8	120.9	3.7
8	1.4	25.8	0.0	5.1	363.9	0.2	34	25.1	140.8	0.0	31.7	126.3	3.3
9	2.1	25.6	0.0	5.9	286.2	0.3	35	12.9	65.7	0.0	18.0	139.4	1.7
10	2.0	24.0	0.0	6.1	305.1	0.3	36	24.7	117.2	0.0	34.5	139.6	3.2
11	9.7	74.2	0.0	21.0	216.0	1.3	37	28.8	134.0	0.0	38.3	133.1	3.8
12	4.8	89.6	0.0	17.4	364.5	0.6	38	21.6	97.6	0.0	27.9	129.4	2.8
13	3.2	15.2	0.0	4.5	143.6	0.4	39	46.8	223.4	0.0	63.9	136.4	6.1
14	8.2	103.7	0.0	21.1	256.5	1.1	40	39.3	136.6	0.0	37.2	94.5	5.2
15	12.4	89.0	0.0	22.3	179.1	1.6	41	42.5	170.2	0.0	38.2	89.9	5.6
16	20.7	73.8	0.0	23.3	112.7	2.7	42	48.2	173.2	0.0	43.9	91.1	6.3
17	17.2	102.4	0.0	26.1	152.1	2.3	43	35.7	149.8	0.0	39.0	109.1	4.7
18	20.8	87.8	0.0	25.7	123.9	2.7	44	22.7	108.2	0.0	27.0	118.8	3.0
19	20.7	71.5	0.0	23.4	112.7	2.7	45	16.5	42.8	0.0	16.7	101.2	2.2
20	27.4	93.6	0.0	31.7	115.8	3.6	46	8.5	72.0	0.0	16.6	194.1	1.1
21	27.6	227.2	0.0	46.4	167.9	3.6	47	15.1	98.0	0.0	25.1	166.8	2.0
22	24.9	118.7	0.0	35.2	141.4	3.3	48	10.0	56.8	0.0	16.2	162.3	1.3
23	15.8	72.2	0.0	20.7	130.5	2.1	49	6.4	33.8	0.0	13.0	202.9	0.8
24	8.7	73.0	0.0	15.4	176.9	1.1	50	6.4	38.8	0.0	13.6	212.2	0.8
25	10.3	58.0	0.0	14.7	143.5	1.3	51	3.0	13.4	0.0	10.0	332.0	0.4
26	5.4	31.2	0.0	8.0	147.1	0.7	52	2.8	13.2	0.0	10.2	368.6	0.4

SWM: Standard Meteorological week, SD: Standard deviation, CV: Co-efficient of variation, % of ARF : Percentage contribution of weekly rainfall towards average annual rainfall.

Since, South-West monsoon season is the main crop growing season in this station, it is most necessary to highlight the distribution of rainfall during south-West monsoon. In this place, monsoon starts during first week of June and ends during early October and receives about 298.7 mm rain during South West monsoon which is about 39.2 per cent of the annual rainfall.

Immediately after the cessation of south-west monsoon, north-east monsoon sets in during 2nd week of October and brings rains during October and November. Contribution from North-East monsoon is also important for the completion of the cropping period which is about 244.9 mm and add up to 32.1 per cent of the annual mean rainfall.

Winter months (15th December to February) on an average receive about 19.3 mm rainfall which is about 2.5 per cent of the mean annual rainfall. During summer months (March to May) it receives an average of about 217.4 mm rainfall contributing to an extent of 28.5 per cent of the annual rainfall.

Initial probability

The results pertaining to initial and conditional probabilities of dry and wet weeks of the station are presented in [Table-3] for all the 52 standard meteorological weeks. Probability of occurrence of dry week is higher from 1st week to 15th week, 24th to 32nd week and 46th week to 52nd SMW, respectively. The range of probability of occurrence of dry week in these weeks varied from 70 to 100 per cent. Similarly, occurrence of wet week was higher during 24th to 47th SMW, and it varied from 12 to 77 per cent.

Conditional probability

The conditional probability of dry followed dry (P_{dd}), dry followed by wet (P_{dw}), wet followed by wet (P_{ww}) and wet followed by dry weeks (P_{wd}) are discussed with special reference to rainy season starting from 20th SMW to 48th SMW only (*i.e.*, May 15 th to November 15 th).

The probability of occurrence of dry week preceded by another dry week ranged from 25% (42nd SMW) to 100 per cent (27th and 33rd SMW). The probability of occurrence of wet week preceded by another wet week ranged from 20% (during 30th and 47th SMW) to100 % (27th SMW). Similarly, the incidence of wet preceded by dry week was observed during 28th and 42nd SMW and it ranged from 5 to75 per cent whereas, the probability occurrence of dry preceded by wet week ranged from 22.2 percent (42nd SMW) to 100 per cent during 25th, 26th and 28th SMW).

Probability of consecutive dry and wet weeks

The probability of occurrence two consecutive dry and wet weeks is presented in [Table-4] and results are discussed for rainy season only. The results revealed that, chance of occurrence of two consecutive dry weeks ranged from 7.1 (42nd SMW) to 92.5 per cent (27th SMW) whereas, the probability of occurrence of three consecutive dry weeks ranged from 2.7 to 78.2 per cent (27th - 42nd SMW). Similarly, the probability of occurrence of two consecutive wet weeks varied from 0.1 to 53.3 per cent during 27th - 42nd SMW and the probability of occurrence of three consecutive wet weeks ranged from 0.0 per cent (during 27th and 28th SMW) to 32.8 per cent on 42nd SMW. The data also revealed that chance of occurrence of two or three consecutive wet weeks was high during rainy season, whereas, rest of the period during the year was more prone to have two or three consecutive dry weeks.

Conclusion

The pre-monsoon showers start from 15th May to 15th June which brings about 106.0 mm rain and contributes to 14.0 % of annual rainfall. This shower can be utilized for summer ploughing and initial seed bed preparation in this region. South-West monsoon season is the main crop growing season in this station, where monsoon starts during first week of June and ends during early October and receives about 298.7 mm which is about 39.2 per cent of the annual rainfall. Immediately after the cessation of south-west monsoon, north-east monsoon sets in during 2nd week of October and brings rains during October and November contributes 244.9 mm of rain and adds up to 32.1 per cent of the annual mean rainfall which is also important for the completion of the cropping period. Winter months (15th December to February) on an average receive about 19.3 mm rainfall which is about 2.5 per cent of the mean annual rainfall. During summer months (March to May) it receives an average of about 217.4 mm rainfall contributing to an extent of 28.5 per cent of the annual rainfall.

From the above analysis it is clear that chance of occurrence of two or three consecutive wet weeks was high during rainy season, whereas, rest of the period during the year was more prone to have two or three consecutive dry weeks. Hence, crop planning should be done in such a way that the critical growth stage of the crop should not coincide with 2 or 3 consecutive dry spell else the yield will be reduced. Therefore, the results obtained from this study will be useful for the farmers/growers of the region for better crop planning and water management.

Table-3 *Initial and conditional probabilities of rainfall at V.C. Farm, Mandya*

SMW	Initial probability		Conditional probability			
	PD	PW	P(W/W)	P(D/W)	P(D/D)	P(W/D)
1	100	0	0.0	0.0	0.0	100.0
2	100	0	0.0	0.0	100.0	0.0
3	100	0	0.0	0.0	100.0	0.0
4	100	0	0.0	0.0	100.0	0.0
5	100	0	0.0	0.0	100.0	0.0
6	100	0	0.0	0.0	100.0	0.0
7	100	0	0.0	0.0	100.0	0.0
8	96	4	0.0	100.0	100.0	0.0
9	96	4	0.0	100.0	96.0	4.0
10	96	4	0.0	100.0	96.0	4.0
11	85	15	0.0	100.0	95.5	4.5
12	96	4	100.0	0.0	88.0	12.0
13	100	0	0.0	0.0	96.2	3.8
14	88	12	0.0	100.0	100.0	0.0
15	81	19	0.0	100.0	85.7	14.3
16	62	38	40.0	60.0	93.8	6.3
17	73	27	28.6	71.4	57.9	42.1
18	62	38	30.0	70.0	75.0	25.0
19	65	35	55.6	44.4	70.6	29.4
20	54	46	41.7	58.3	71.4	28.6
21	65	35	44.4	55.6	52.9	47.1
22	65	35	22.2	77.8	58.8	41.2
23	69	31	25.0	75.0	61.1	38.9
24	88	12	33.3	66.7	73.9	26.1
25	85	15	0.0	100.0	90.9	9.1
26	96	4	0.0	100.0	84.0	16.0
27	96	4	100.0	0.0	100.0	0.0
28	77	23	0.0	100.0	95.0	5.0
29	81	19	40.0	60.0	81.0	19.0
30	81	19	20.0	80.0	85.7	14.3
31	88	12	33.3	66.7	82.6	17.4
32	85	15	25.0	75.0	86.4	13.6
33	58	42	36.4	63.6	100.0	0.0
34	62	38	60.0	40.0	68.8	31.3
35	81	19	60.0	40.0	66.7	33.3
36	73	27	42.9	57.1	89.5	10.5
37	65	35	33.3	66.7	76.5	23.5
38	73	27	42.9	57.1	68.4	31.6
39	54	46	25.0	75.0	71.4	28.6
40	38	62	43.8	56.3	50.0	50.0
41	23	77	60.0	40.0	33.3	66.7
42	31	69	77.8	22.2	25.0	75.0
43	50	50	76.9	23.1	38.5	61.5
44	65	35	66.7	33.3	58.8	41.2
45	65	35	44.4	55.6	70.6	29.4
46	88	12	66.7	33.3	69.6	30.4
47	81	19	20.0	80.0	90.5	9.5
48	88	12	66.7	33.3	87.0	13.0
49	88	12	33.3	66.7	91.3	8.7
50	85	15	25.0	75.0	90.9	9.1
51	100	0	0.0	0.0	84.6	15.4
52	100	0	0.0	0.0	100.0	0.0

Table-4 *Consecutive dry and wet week probabilities of rainfall at VC Farm, Mandya*

Std. Met. weeks	Consecutive dry and wet probabilities			
	2D	2W	3D	3W
1	100	0	100	0.0
2	100.0	0.0	100	0.0
3	100.0	0.0	100	0.0
4	100.0	0.0	100	0.0
5	100.0	0.0	100	0.0
6	100.0	0.0	100	0.0
7	100.0	0.0	100	0.0
8	96.2	0.0	96.2	0.0
9	92.5	0.1	92.5	0.0
10	92.5	0.1	88.9	0.0
11	81.4	0.6	78.2	0.0
12	81.4	0.6	78.2	0.0
13	96.2	0.0	81.4	0.0
14	88.5	0.0	85.1	0.0
15	71.4	2.2	71.4	0.0
16	49.7	7.4	44.0	0.9
17	45.0	10.4	36.3	2.0
18	45.0	10.4	27.7	4.0
19	40.2	13.3	29.4	3.6
20	35.2	16.0	21.7	6.1
21	35.2	16.0	23.0	5.5
22	42.8	12.0	23.0	5.5
23	45.3	10.7	29.6	3.7
24	61.2	3.6	40.0	1.2
25	74.9	1.8	51.8	0.5
26	81.4	0.6	72.0	0.1
27	92.5	0.1	78.2	0.0
28	74.0	0.9	71.1	0.0
29	62.1	4.4	59.7	0.2
30	65.2	3.7	50.2	0.9
31	71.4	2.2	57.7	0.4
32	74.9	1.8	60.5	0.3
33	48.8	6.5	43.2	0.8
34	35.5	16.3	30.0	2.5
35	49.7	7.4	28.7	3.1
36	59.0	5.2	36.3	2.0
37	47.8	9.3	38.6	1.8
38	47.8	9.3	34.9	2.5
39	39.3	12.4	25.7	4.3
40	20.7	28.4	15.1	7.6
41	8.9	47.3	4.8	21.8
42	7.1	53.3	2.7	32.8
43	15.4	34.6	3.6	26.6
44	32.7	17.3	10.1	12.0
45	42.8	12.0	21.4	6.0
46	57.8	4.0	37.8	1.4
47	71.4	2.2	46.7	0.8
48	71.4	2.2	63.2	0.3
49	78.3	1.3	63.2	0.3
50	74.9	1.8	66.2	0.2
51	84.6	0.0	74.9	0.0
52	100.0	0.0	84.6	0.0

Application of research: The study will be useful for the farmers/growers of the region for better crop planning and water management

Research Category: Rainfall Analysis

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