Karnataka J. Agric. Sci., 21 (1), (12-16): 2008

Markov Chain Model Probability of Dry, Wet Weeks and Statistical Analysis of Weekly Rainfall for Agricultural Planning at Bangalore*

G. V. SRINIVASA REDDY, S. R. BHASKAR, R. C. PUROHIT AND A. K. CHITTORA
Department of SWE
CTAE, MPUAT, Udaipur - 313 001
E mail: gvsreddymtech@rediffmail.com

(Received : April, 2007)

Abstract : For successful agricultural management and planning of soil and water conservation measures it is necessary to know the sequence of dry and wet periods along with onset and withdrawal of rainy season. In this study Markov Chain Model has been extensively used to study spell distribution. 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 dry and wet weeks, onset and withdrawal of rainy season and weekly analysis of rainfall for Bangalore region. The successive dry weeks hint for the need of supplemental irrigations and moisture conservation practices whereas, successive wet weeks gives an idea of excessive runoff water availability for rainwater harvesting and to take up suitable measures to control soil erosion. Higher values of Coefficient of Variation of weekly rainfall indicate the erratic distribution of rainfall. The average annual rainfall of GKVK campus, Bangalore was found to be 923.9 mm and Coefficient of Variation (CV) of 25.4%. The data on onset and withdrawal rainy season indicated that the monsoon starts effectively from 24th SMW (11 - 17th June) and remains active up to 45th SMW (5 - 11th November). During rainy season the probability of occurrence of wet week is more than 35% except during 25th - 27th SMW and 44th - 48th SMW. During rainy season the mean weekly rainfall is found to be more than 40 mm during 36th - 41st SMW and found to be less than 20 mm during 20th SMW, 25th - 27th SMW and 44th - 48th SMW. The results through analysis have been used for agricultural planning at Bangalore region.

Key words: Markov Chain Model, Weekly rainfall, Onset and Withdrawal of rainy season

Introduction

The yield of crops particularly in rainfed condition depends on the rainfall pattern. Simple criteria related to sequential phenomena like dry and wet spells could be used for analyzing rainfall data to obtain specific information needed for crop planning and for carrying out agricultural operations. Pandharinath (1991) used the Markov Chain Model to study the probability of dry and wet spells. Another aspect useful for crop planning is forward and backward accumulation of rainfall to determine the onset and withdrawal of rainy season. The onset and the withdrawal of monsoon largely determine the success of rainfed agriculture. Pre-monsoon showers help in land preparation and sowing of kharif crops. Late onset of monsoon delays sowing of crops leading to poor yields. Similarly, early withdrawal of rains affects the yield due to severe moisture stress especially when the kharif crops are at critical growth stages of grain formation and grain development (Dixit et al., 2005). The annual and seasonal analysis of rainfall will give general idea about the rainfall pattern of the region, whereas the weekly analysis of rainfall will be of much use as far agricultural planning is concerned.

Material and Methods

Daily rainfall data recorded at the Meteorological Observatory of GKVK campus, University of Agricultural Sciences, Bangalore (12° 58' N, 77° 35' E and 930 m amsl) for a period of 31 years (1976 – 2006) were used for the present study. Weekly rainfall values have been computed from daily values and were used for the present analysis. The dry and wet spell analysis was carried out using weekly rainfall based on Markov Chain Model considering less than 20 mm rainfall in a week as a dry week and 20 mm or more as a wet week (Pandharinath, 1991). The different notations followed in this analysis are given below:Initial Probability:

$P_D = F_D / n$ .... 1 $\qquad P_W = F_W / n$ 2

Conditional Probabilities:

$P_{DD} = F_{DD} / F_D$ .... **3** $\qquad P_{WW} = F_{WW} / F_W$ **4**

$P_{WD} = 1 - P_{DD}$ ....**5** $\qquad P_{DW} = 1 - P_{WW}$ **6**

Consecutive dry and wet week probabilities:

$2D = P_{Dw1} . P_{DDw2}$ .... 7 $\qquad 2W = P_{Ww1} . P_{WWw2}$ 8

$3D = P_{Dw1} . P_{DDw2} . P_{DDw3}$ 9

$3W = P_{Ww1} . P_{WWw2} . P_{WWw3}$ 10

Where,

P_D - Probability of the week being dry

F_D - Probability of the week being wet

F_D - *Number of dry weeks*

F_W - *Number of wet weeks*

n - *Number of years of data*

P_{DD} - *Probability (conditional) of a dry week preceded*

* Part of Ph. D. thesis submitted by the senior author to the University of Agricultural Sciences, Udaipur - 313001, India.

by a dry week

P_{WW} - *Probability (conditional) of a wet*

P_{WD} - *Probability (conditional) of a wet week preceded by a dry week*

P_{DW} - *Probability (conditional) of a dry week preceded by a wet week*

F_{DD} - *Number of dry weeks preceded by another dry week*

F_{WW} - *Number of wet weeks preceded by another wet week*

$2D$ - *Probability of 2 consecutive dry weeks starting with the week*

$2W$ - *Probability of 2 consecutive wet weeks starting with the week*

$3D$ - *Probability of 3 consecutive dry weeks starting with the week*

$3W$ - *Probability of 3 consecutive wet weeks starting with the week*

P_{Dw1} - *Probability of the week being dry (first week)*

P_{DDw2} - *Probability of the second week being dry, given the preceding week dry*

P_{DDw3} - *Probability of the third week being dry, given the preceding week dry*

P_{Ww1} - *Probability of the week being wet (first week)*

$P_{WWw\ 2}$ - *Probability of the second week being wet, given the preceding week wet*

$P_{WWw\ 3}$ - *Probability of the third week being wet, given the preceding week wet*

Onset and withdrawal of rainy season was computed from weekly rainfall data by forward and backward accumulation methods respectively. In this method weekly rainfall was summed by forward accumulation (20+21+…+52 weeks) until a certain amount of rainfall was accumulated. Seventy five millimetres of rainfall accumulation has been considered as the onset time for the growing season of dry seeded crops and land preparation (Babu and Lakshminarayana, 1997; Panigrahi and Panda, 2002). The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+…+30 weeks) data. Twenty millimetres of rainfall accumulation was chosen for the end of rainy season, which is sufficient for ploughing of fields after harvesting the crops (Babu and Lakshminarayana, 1997).

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:

$$P = \frac{m}{N+1} \times 100 \qquad \text{.......... 11}$$

Where, m is the rank number and N is the number of years of data used. The weekly mean, maximum, minimum, standard deviation, coefficient of variation and percentage contribution to annual rainfall were also computed and tabulated.

Results and Discussion

The total annual rainfall (Fig.1) of GKVK campus, Bangalore ranged between 528.2 mm (1990) to 1363 mm (2005) with an average annual rainfall of 923.9 mm and Coefficient of Variation (CV) of 25.4%.

The data on onset, withdrawal and duration of the rainy season (difference between onset and withdrawal time) and its variability in Bangalore region are presented in Table 1. Weekly rainfall data of 31 years (1976 – 2006) indicated that the monsoon starts effectively from 24th SMW (11 – 17th June) and remains active up to 45th SMW (5 – 11th November). Therefore, mean length of rainy season was found to be 21 weeks (147 days). The earliest and delayed week of onset of rainy season was 21st SMW (21 – 27th May) and 32nd SMW (6 – 12th August) respectively. Similarly the earliest and delayed week of cessation of rainy season was 41st SMW (8 – 14th October) and 48th SMW (26th Nov – 2nd December) respectively. The longest and shortest length of rainy season was 27 and 14 weeks respectively. The probabilities of onset and withdrawal of rainy season was calculated by using Weibull's formula and results are presented in Table 2. The results reveal that there is a 75 % chance that the onset of rainy season and cessation of rainy season will occur during 25th and 46th SMW respectively.

The results pertaining to initial and conditional probabilities of dry and wet weeks and consecutive dry and wet weeks are presented in table 3 and 4 respectively for all the 52 standard meteorological weeks but, the results are discussed in relevance with rainy season (20th SMW – 48th SMW) only. The results from Table 3 reveal that, during rainy season the probability of occurrence of wet week is more than 35% except during 25th – 27th SMW and 44th - 48th SMW. The probability of occurrence of dry week preceded by another dry week during monsoon season is more than 75% during 20th SMW, 24th - 26th SMW, 29th SMW, 44th SMW and 47th - 48th SMW.

The analysis of consecutive dry and wet spells (Table 4) during rainy season reveal that there are more than 50 % chances that 2 consecutive dry weeks may occur during 24th - 26th SMW and 44th - 48th SMW. Similarly, the probabilities of occurrence of 3 consecutive dry weeks are also very high (more

Table.1: Characterization of the rainy season at Bangalore (1976 - 2006)

Particulars	Week No	Date
Mean week of onset of rainy season	24	11-17 June
Earliest week of onset of rainy season	21	21-27 May
Delayed week of onset of rainy season	32	6-12 August
Mean week of withdrawal of rainy season	45	5-11 November
Earliest week of withdrawal of rainy season	41	8-14 October
Delayed week of withdrawal of rainy season	48	26 Nov – 2 December
Mean length of rainy season	21 weeks (147 Days)	
Duration of rainy season		
Longest	27 Weeks (189 Days)	
Shortest	14 Weeks (98 Days)	

than 35%) during 23rd – 26th SMW and 44th - 48th SMW.

The probability of occurrence of 2 consecutive wet weeks are more than 35% during 37th – 41st SMW and the probability of occurrence of 3 consecutive wet weeks are more than 25% during 37th – 40th SMW. The weekly rainfall attributes showing mean, maximum, minimum, standard deviation, coefficient of variation and percentage of weekly rainfall contribution towards annual rainfall are presented in table 5. The results reveal that, there area total of 21 weeks (18th, 21st – 24th, 28th – 43rd SMW) where rainfall exceeds more than 20 mm.

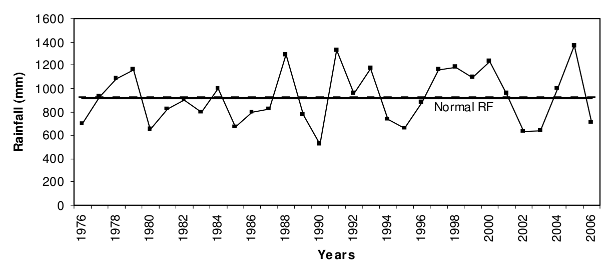

Fig.1: Annual rainfall pattern (1976 -2006) at GKVK, Bangalore

During rainy season the mean weekly rainfall is found to be more than 40 mm during 36th – 41st SMW and found to be less than 20 mm during 20th SMW, 25th – 27th SMW and 44th – 48th SMW. The coefficient of variation during rainy season vary from 87.1(40th SMW) to 297.4% (44th SMW). The weekly contribution of rainfall towards annual average rainfall is found to be highest during 36th – 41st SMW accounting to 33% of the average annual rainfall. With the above results derived from detail analysis of rainfall, one can use above results for agricultural planning. Here are some applications presented towards agricultural planning. It is clear from results that since, probability of occurrence of wet week is more than 35% during 20th – 22nd SMW(14th May - 3rd June) and average weekly rainfall ranges from 17.7 to 31.8 mm, this pre-monsoon rain can be utilized for summer ploughing and initial seed bed preparations. The mean onset of rainy season is found to be 24th SMW. So, during 23rd SMW(4th June – 10th June), the sowing operations can be taken up since, the probability of wet week is more than 45% and average weekly rainfall is more than 25 mm. Sowing operations taken at 23rd SMW helps for good germination of seeds and helps in avoiding moisture stress for germination period during 25th – 27th SMW. In the event of delayed start of rainy season, the sowing operations can be taken up latest by 27th SMW(2nd July – 8th July) and further delay in sowing mat cause very low productivity and crop failure. Since, mean length of rainy season is observed to be 21 weeks (147 days), during kharif, short duration crops of groundnut, pigeonpea, maize, sorghum, greengram, soyabean, sunflower, field bean, cowpea and other low water required crops which have high return value can be taken up. Another advantage of growing short duration cereals, pulses and oilseeds in first fortnight of June is that these can be harvested by the end of September (39th SMW) and short duration rabi crops can be sown during 40th – 43rd SMW (1st Oct – 28th October). Since, winter rainfall is uncertain and erratic than south west monsoon, growing of high value rabi crops without supplementary irrigation would be very high risky. The significant contribution of weekly rainfall (>40 mm) during 36th – 41st SMW and high consecutive wet week probability during 37th – 41st SMW, hints for potential scope of

Table.2: Probability of onset and withdrawal of rainy season at Bangalore

(a) Onset												
SMW	21	22	23	24	25	26	27	28	29	30	31	32
P (%)	15.6	46.9	53.1	68.8	75.0		84.4	90.6	93.8			96.9
(b) Withdrawal												
SMW	41	42	43	44	45	46	47	48				
P (%)	3.1	9.4	18.8	31.3	56.3	75.0	90.6	96.9				

SMW – Standard Meteorological Week, P – Probability in Percentage.

harvesting excess runoff water for future supplemental irrigations and also drives attention towards soil erosion measures to be taken up for soil erosion control. Similarly, high consecutive dry week probabilities after 44th SMW, hints for need of supplementary irrigations and moisture conservation practices to be take up. Even in the event of mid season dry weeks, mulching and other moisture conservation practices will help in reducing soil evaporation and conserve moisture in top layers of the soil.

Table.3: Initial and conditional probabilities of rainfall at Bangalore

SMW	Initial probabilities (%)		Conditional probabilities (%)			
	P_D	P_W	P_{DD}	P_{WD}	P_{WW}	P_{DW}
1	100.0	0.0	-	-	-	-
2	100.0	0.0	100.0	0.0	0.0	100.0
3	100.0	0.0	100.0	0.0	0.0	100.0
4	100.0	0.0	100.0	0.0	0.0	100.0
5	100.0	0.0	100.0	0.0	0.0	100.0
6	100.0	0.0	100.0	0.0	0.0	100.0
7	93.5	6.5	93.5	6.5	0.0	100.0
8	96.8	3.2	96.6	3.4	0.0	100.0
9	96.8	3.2	96.7	3.3	0.0	100.0
10	93.5	6.5	93.3	6.7	0.0	100.0
11	90.3	9.7	89.7	10.3	0.0	100.0
12	100.0	0.0	100.0	0.0	0.0	100.0
13	83.9	16.1	83.9	16.1	0.0	100.0
14	93.5	6.5	92.3	7.7	0.0	100.0
15	77.4	22.6	79.3	20.7	50.0	50.0
16	77.4	22.6	87.5	12.5	57.1	42.9
17	77.4	22.6	70.8	29.2	0.0	100.0
18	64.5	35.5	66.7	33.3	42.9	57.1
19	54.8	45.2	50.0	50.0	36.4	63.6
20	64.5	35.5	82.4	17.6	57.1	42.9
21	58.1	41.9	45.0	55.0	18.2	81.8
22	51.6	48.4	50.0	50.0	46.2	53.8
23	54.8	45.2	56.3	43.8	46.7	53.3
24	64.5	35.5	76.5	23.5	50.0	50.0
25	87.1	12.9	90.0	10.0	18.2	81.8
26	83.9	16.1	81.5	18.5	0.0	100.0
27	71.0	29.0	73.1	26.9	40.0	60.0
28	61.3	38.7	59.1	40.9	33.3	66.7
29	64.5	35.5	78.9	21.1	58.3	41.7
30	51.6	48.4	50.0	50.0	45.5	54.5
31	54.8	45.2	50.0	50.0	40.0	60.0
32	58.1	41.9	47.1	52.9	28.6	71.4
33	48.4	51.6	44.4	55.6	46.2	53.8
34	51.6	48.4	60.0	40.0	56.3	43.8
35	64.5	35.5	75.0	25.0	46.7	53.3
36	51.6	48.4	55.0	45.0	54.5	45.5
37	41.9	58.1	43.8	56.3	60.0	40.0
38	38.7	61.3	53.8	46.2	72.2	27.8
39	38.7	61.3	41.7	58.3	63.2	36.8
40	25.8	74.2	33.3	66.7	78.9	21.1
41	38.7	61.3	37.5	62.5	60.9	39.1
42	41.9	58.1	50.0	50.0	63.2	36.8
43	61.3	38.7	61.5	38.5	38.9	61.1
44	77.4	22.6	78.9	21.1	25.0	75.0
45	71.0	29.0	66.7	33.3	14.3	85.7
46	74.2	25.8	72.7	27.3	22.2	77.8
47	77.4	22.6	87.0	13.0	50.0	50.0
48	93.5	6.5	100.0	0.0	28.6	71.4
49	96.8	3.2	96.6	3.4	0.0	100.0
50	93.5	6.5	93.3	6.7	0.0	100.0
51	96.8	3.2	96.6	3.4	0.0	100.0
52	100.0	0.0	100.0	0.0	0.0	100.0

Table.4: Consecutive dry and wet week probabilities of rainfall at Bangalore

SMW	Consecutive Dry Probabilities (%) 2D	3D	Consecutive Wet Probabilities (%) 2W	3W
1	100.0	100.0	0.0	0.0
2	100.0	100.0	0.0	0.0
3	100.0	100.0	0.0	0.0
4	100.0	100.0	0.0	0.0
5	100.0	93.5	0.0	0.0
6	93.5	90.3	0.0	0.0
7	90.3	87.3	0.0	0.0
8	93.5	87.3	0.0	0.0
9	90.3	81.0	0.0	0.0
10	83.9	83.9	0.0	0.0
11	90.3	75.8	0.0	0.0
12	83.9	77.4	0.0	0.0
13	77.4	61.4	0.0	0.0
14	74.2	64.9	3.2	1.8
15	67.7	48.0	12.9	0.0
16	54.8	36.6	0.0	0.0
17	51.6	25.8	9.7	3.5
18	32.3	26.6	12.9	7.4
19	45.2	20.3	25.8	4.7
20	29.0	14.5	6.5	3.0
21	29.0	16.3	19.4	9.0
22	29.0	22.2	22.6	11.3
23	41.9	37.7	22.6	4.1
24	58.1	47.3	6.5	0.0
25	71.0	51.9	0.0	0.0
26	61.3	36.2	6.5	2.2
27	41.9	33.1	9.7	5.6
28	48.4	24.2	22.6	10.3
29	32.3	16.1	16.1	6.5
30	25.8	12.1	19.4	5.5
31	25.8	11.5	2.9	6.0
32	25.8	15.5	.4	10.9
33	29.0	21.8	.0	13.5
34	38.7	21.3	2.6	12.3
35	35.5	15.5	9.4	11.6
36	22.6	12.2	29.0	21.0
37	22.6	9.4	41.9	26.5
38	16.1	5.4	38.7	30.6
39	12.9	4.8	48.4	29.5
40	9.7	4.8	45.2	28.5
41	19.4	11.9	38.7	15.1
42	25.8	20.4	22.6	5.6
43	48.4	32.3	9.7	1.4
44	51.6	37.5	3.2	0.7
45	51.6	44.9	6.5	3.2
46	64.5	64.5	12.9	3.7
47	77.4	74.7	6.5	0.0
48	90.3	84.3	0.0	0.0
49	90.3	87.2	0.0	0.0
50	90.3	90.3	0.0	0.0
51	96.8	-	0.0	-
52	-	-	-	-

Table.5: Weekly rainfall attributes at Bangalore (1976 -2006)

SMW	Mean	Max	Min	SD	CV	% of ARF
1	0.8	16.6	0.0	3.1	411.6	0.1
2	0.4	5.5	0.0	1.1	314.5	0.0
3	0.2	2.6	0.0	0.7	312.6	0.0
4	0.4	10.2	0.0	1.9	471.4	0.0
5	0.1	1.8	0.0	0.3	556.8	0.0
6	0.5	7.8	0.0	1.8	367.6	0.1
7	3.7	47.7	0.0	11.2	300.8	0.4
8	2.3	56.7	0.0	10.3	449.6	0.2
9	4.8	133.2	0.0	23.9	494.8	0.5
10	5.3	86.4	0.0	19.0	357.4	0.6
11	5.2	80.6	0.0	15.6	299.7	0.6
12	1.0	8.6	0.0	2.4	244.7	0.1
13	6.1	45.6	0.0	12.4	204.4	0.7
14	3.9	35.6	0.0	8.4	213.9	0.4
15	11.7	95.4	0.0	22.2	190.0	1.3
16	16.4	147.6	0.0	29.7	181.0	1.8
17	11.5	53.8	0.0	17.5	151.3	1.2
18	20.9	102.6	0.0	25.7	122.9	2.3
19	19.0	66.2	0.0	17.7	93.1	2.1
20	17.7	73.2	0.0	19.8	111.6	1.9
21	24.8	89.2	0.0	26.4	106.7	2.7
22	31.8	129.3	0.0	36.3	114.5	3.4
23	26.9	111.7	0.0	32.8	121.9	2.9
24	22.8	83.4	0.0	26.5	116.4	2.5
25	9.9	77.8	0.0	17.5	177.3	1.1
26	9.1	47.6	0.0	10.5	115.2	1.0
27	18.3	135.4	0.0	28.9	158.2	2.0
28	24.9	106.4	0.0	28.0	112.6	2.7
29	23.2	180.6	0.0	36.5	157.1	2.5
30	25.6	76.6	0.0	22.8	89.2	2.8
31	27.1	146.0	0.0	31.8	117.3	2.9
32	23.6	89.5	0.4	23.1	98.0	2.6
33	28.8	142.2	0.0	28.8	100.2	3.1
34	31.5	104.2	0.4	31.4	99.8	3.4
35	28.7	156.4	0.0	39.7	138.3	3.1
36	40.3	213.7	0.0	52.7	130.6	4.4
37	52.4	306.8	0.0	66.6	127.0	5.7
38	59.5	187.6	0.0	64.7	108.7	6.4
39	44.5	223.0	0.0	49.1	110.3	4.8
40	66.2	265.0	1.5	57.6	87.1	7.2
41	40.2	115.8	0.0	35.3	87.9	4.3
42	29.8	114.6	0.0	29.5	99.0	3.2
43	23.3	233.4	0.0	42.4	182.2	2.5
44	18.6	308.4	0.0	55.2	297.4	2.0
45	16.1	82.6	0.0	21.3	132.4	1.7
46	15.4	150.4	0.0	29.5	191.9	1.7
47	12.9	112.8	0.0	25.9	200.1	1.4
48	4.3	46.5	0.0	11.2	259.0	0.5
49	3.8	65.4	0.0	11.8	314.4	0.4
50	3.4	59.0	0.0	11.4	329.2	0.4
51	2.2	25.3	0.0	5.9	271.8	0.2
52	2.3	17.1	0.0	4.9	214.4	0.2

SMW – Standard Meteorological Week, SD – Standard Deviation, CV – Coefficient of Variation, % of ARF – Percentage contribution of weekly rainfall towards Average Annual Rainfall.

References

Babu, P. N. and Lakshminarayana, P., 1997, Rainfall analysis of a dry land watershed-Polkepad: A case study. J. Indian Water Res. Society. 17:34-38.

Dixit, A.J., Yadav, S.T. and Kokate, K.D., 2005, The variability of rainfall in Konkan region. J. Agrometeo., 7: 322 – 324.

Pandharinath, N., 1991, Markov chain model probability of dry, wet weeks during monsoon period over Andhra Pradesh. Mausam, 42:393-400.

Panigrahi, B. and Panda, S.N., 2002, Dry spell probability by Markov Chain model and its application to crop planning. Indian J. Soil Consn. 30:95-100.