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Use of Markov Chain for Dry and Wet week Analysis for Crop Planning at Aduthurai, Tamil Nadu, India

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Abstract: Knowledge of rainfall occurrence pattern is very important for making decision on crop planning and soil water conservation studies. Markov chain probability model was used to enlighten the long term frequency behavior of wet or dry weather spells during the main rainy season. This study used 35 years (1981-2015) of rainfall data and aggregated weekly rainfall data (52 weeks) was considered as standard week to study the probability of occurrence of wet and dry weeks. The probability of occurrences of initial and conditional probability is more than 50 % on 35 th week with threshold limit of 20 mm per week. Therefore the land preparation for sowing or planting could be undertaken in 35 th week respectively for the main rainy season crop cultivation. Study area dominated by North East Monsoon with mean annual rainfall of about 1100 mm. At Aduthurai region there is more chance for intermittent wet spell and hence drought resistant short duration pulse may be suggested. In addition, this analysis can be very helpful in identify the cropping pattern including cropping and intercropping system during that period.

Introduction

To meet the future demands for food and emerging competition for water among various sectors, more efficient use of water in will be essential in rainfed agriculture. In eastern Indian ecosystem, more than 70 % of net sown area is rainfed where the yield of the predominant rainy season crop, i.e. rice, is very low as compared to that of irrigated ecosystem. The most important predominant factor for low yield is the lack of assured water supply (Panigrahi and Panda 2002).

Goyal (2013) studied the weekly analysis was done for initial and conditional probabilities for standard weeks. Using this information in crop planning can be of great help in shrewd and efficient use of rainwater, soil and water conservation and in increasing the productivity of crops.

Agricultural production from rainfed agricultural system mainly depends on all climatic parameters. Excess and shortage of rainfall during the length of the crop growing period can lead to scale of crop failure. However, production can be increased and risk minimized by identifying the correct time for onset and withdrawal of rainfall based on the decision adopted by analyzing the long term rainfall variability (Wubengeda Admasu et al., 2014). Cropping strategies greatly influenced by variability of the onset and termination of rainy season. Accumulation of 75 mm rainfall has been considered as the onset time for growing dry seeded crops in sandy loam soil and accumulated rainfall of 200 mm considered for rice transplantation (WMO, 1982).

Monthly rainfall analysis are useful and important for crop planning purpose, However, such analysis do not give any indication of risk involved in farming practices as the rainfall is highly variable from year to year. Initial and conditional probability analysis revealed some

knowledge on risk involved in crop planning based on weekly rainfall. An attempt has been made to analyze weekly rainfall by Markov chain probability model (Vaidya et al.,2008).

The Northeast monsoon (NE) sets in Tamil Nadu on 20th October based on 100 years of rainfall data (1901- 2000). The earliest onset and late onset of the rainy season is 4th October and 11th November. In 75 per cent of the years onset of North East monsoon took place between 13th October and 27th October. In 51 per cent of the years, the withdrawal is between 14th December and 4th January. (Asokan, 2007).

Materials and Methods

Initial probability and Conditional probability

The study area located at $11^{o}00^{'}$ 55" N latitude, 79^{o} 28' 51" E longitude and at an altitude of 25 m above mean sea level. The standard seven day period has been taken to establish the wet and dry spell frequency analysis based on Markov chain model. The week receiving rainfall of about less than 20 mm as dry week and 20 mm or more as a wet week. The average annual rainfall of the study area is 1100 mm out of which 75 percent occurs in the rainy season from October to January. Cultivation of dry crops during summer is also not possible because of the shallow groundwater table. Even during the peak of the rainy season, where there is continuous period of heavy rainfall the area remains inundated because of lack of proper drainage facility. The initial probability analysis was taken up to find the probability of occurrence of wet and dry over the weekly rainfall analysis with threshold limit of 20 mm. Different notations followed in this analysis were given below

$$P_d = \frac{N_d}{Y_n} \qquad (1)$$

Where, P_d is Probability of the period considering being dry, N_d is number of dry week observed and Y_n is number of years of rainfall data used.

$$P_w = \frac{N_w}{Y_n} \quad (2)$$

Where, P_w is Probability of the period considering being wet, N_w is number of wet week observed and Y_n is number of years of rainfall data used**.**

Conditional proability

$$P_{dd} = \frac{N_{dd}}{N_d}$$

Where P_{dd} is probability of dry week preceded by another dry week (Conditional) and N_{dd} is number of dry week preceded by another dry week.

$$P_{ww} = \frac{N_{ww}}{N_w}$$

Where P_{ww} is probability of wet week preceded by another wet week (Conditional) and N_{ww} is number of wet week preceded by another wet week.

Consecutive wet and dry week probabilities

$P(2d) = P(dw_1) \times P(ddw_2)$

$P(3d) = P(dw_1) \times P(ddw_2) \times P(ddw_3)$

$P(2w) = P(ww_1) \times P(www_2)$

$P(3w) = P(ww_1) \times P(www_2) \times P(www_3)$

Where,

2w - Probability of 2 consecutive wet weeks

2d - Probability of 2 consecutive dry weeks

3w - Probability of 3 consecutive wet weeks

3d - Probability of 3 consecutive dry weeks

$P(dw_1)$ - Probability of the first week being dry

$P(ddw_2)$ - Probability of the second week being dry given the preceding week being dry

$P(ddw_3)$ - Probability of the third week being wet given the preceding week being dry

$P(ww_1)$ - Probability of the first week being wet

$P(www_2)$ - Probability of the second week being wet given the preceding week being wet

$P(www_3)$ - Probability of the third week being wet given the preceding week being wet

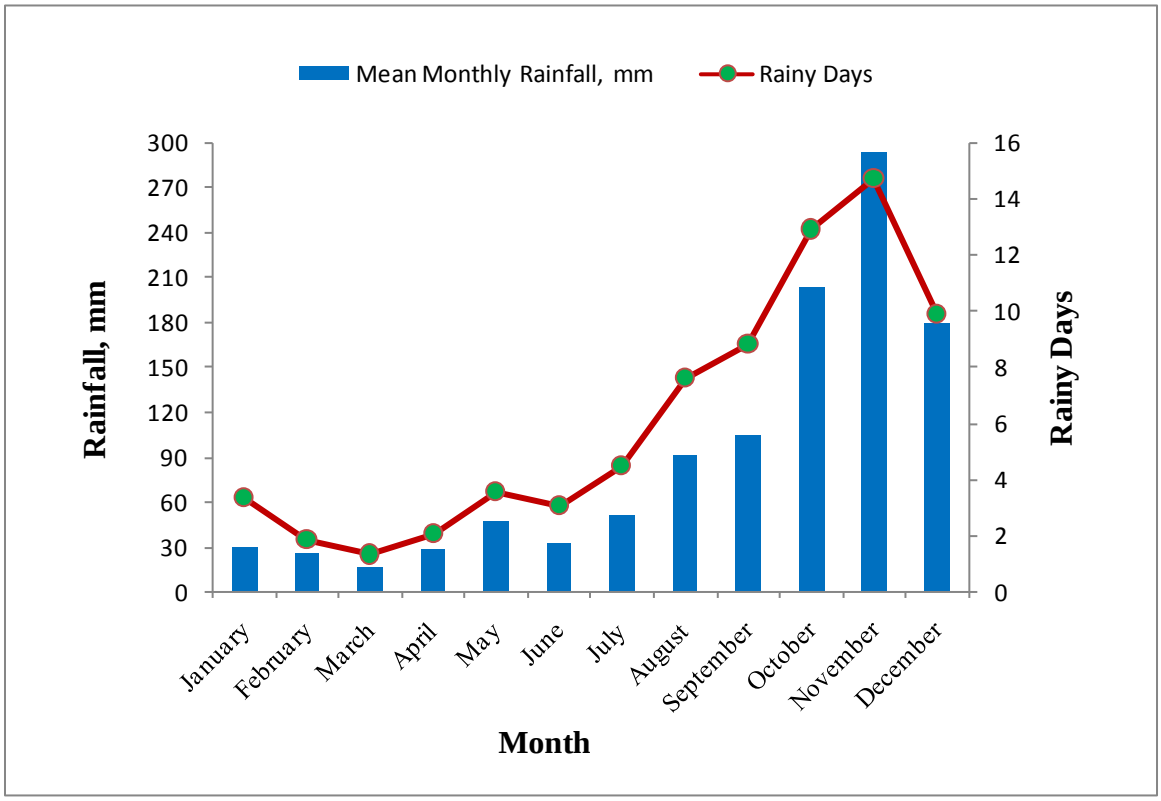

Fig 1. Mean Monthly Rainfall (mm) and rainy days for the period (1981-2015)

The mean monthly rainfall at Aduthurai (Figure 1) was found to be high in November (293 mm) and the minimum rainfall of 16 mm was received in the month of March, it was followed by June (32 mm). The average monthly rainy day was high during themonth of November followed by October. The average annual rainfall was about 1096 mm Analysis of seasonal rainfall showed that the rainfall contributed to the annual rainfall during the winter (Jan-Feb), summer (March-May), southwest (Jun-Sep) and northeast monsoon (Oct-Dec) were 4.9, 8.3, 25.3 and 61.5 per cent respectively. The maximum rainy days were in the month of November (15 days) followed by October (13 days), December (10 days) and the minimum rainy days were in the month March. The weekly mean rainfall, rainy days and coefficient of variation were also computed and tabulated (Table 1). The maximum monthly rainfall was recorded in the 48th week (465.8 mm) followed by 50 th week (433.6 mm) and the minimum monthly rainfall was recorded in the 4 th week followed by 13 th week.

Table.1 Mean, Standard deviation and Coefficient of variation of Weekly Rainfall at Aduthurai

Std.Weeks	Max	Min	Mean	Standard deviation	Coefficient of variation
1	158.2	0.0	7.4	26.9	363.3
2	106.0	0.0	6.7	19.4	289.2
3	42.8	0.0	4.7	10.6	225.0
4	5.6	0.0	0.5	1.3	270.0
5	152.2	0.0	5.7	26.1	454.4
6	92.4	0.0	6.7	21.1	313.9
7	130.4	0.0	7.3	28.3	384.7
8	70.2	0.0	6.0	16.9	279.9

9	35.6	0.0	1.9	6.6	339.9
10	67.6	0.0	5.1	15.1	294.6
11	82.0	0.0	3.2	14.1	437.6
12	63.2	0.0	2.3	10.8	474.9
13	12.2	0.0	0.6	2.5	417.8
14	101.4	0.0	3.5	17.1	486.2
15	41.8	0.0	7.2	14.0	195.1
16	87.4	0.0	7.0	17.8	254.4
17	83.2	0.0	7.6	18.5	242.5
18	259.8	0.0	16.6	45.7	275.4
19	110.2	0.0	10.9	24.8	226.9
20	63.6	0.0	10.4	17.3	167.1
21	72.0	0.0	6.8	16.3	238.7
22	35.5	0.0	6.6	11.3	172.6
23	33.6	0.0	7.6	10.5	138.9
24	170.4	0.0	13.0	37.6	288.7
25	56.0	0.0	5.7	13.8	240.3
26	52.8	0.0	3.5	9.4	264.9
27	59.4	0.0	9.2	17.7	192.6
28	71.2	0.0	9.5	17.1	179.9
29	63.2	0.0	8.3	16.6	199.0

30	73.2	0.0	16.2	23.0	142.1
31	104.0	0.0	16.0	27.2	169.9
32	103.6	0.0	14.9	23.7	158.7
33	125.0	0.0	23.2	34.0	146.4
34	89.4	0.0	24.6	27.6	112.1
35	120.0	0.0	25.6	29.1	113.8
36	170.8	0.0	25.8	34.5	133.5
37	64.6	0.0	21.8	21.8	100.0
38	63.0	0.0	13.7	17.0	124.3
39	115.0	0.0	28.3	33.1	117.0
40	120.2	0.0	25.3	31.4	124.3
41	97.2	0.0	25.4	31.4	123.4
42	298.6	0.0	43.1	59.9	139.1
43	322.4	0.0	65.6	80.3	122.5
44	279.8	0.0	72.6	73.7	101.6
45	281.8	0.0	88.6	94.2	106.4
46	325.4	0.0	42.5	63.8	149.9
47	310.4	0.0	70.5	86.6	122.8
48	465.8	0.0	68.2	97.4	142.9
49	415.9	0.0	57.6	96.6	167.7
50	433.6	0.0	41.4	83.2	201.2

51	254.4	0.0	36.1	57.6	159.5
52	170.2	0.0	15.8	33.5	212.1

The coefficient of variation (CV) in percentage is an indicator of dependability of rainfall. Threshold limit of 20 mm per week at more than 50% of initial probability during the rainy season is adequate for crop activities like land preparation and the conditional probability of occurrence of rainfall at 20mm per week above 50% is the right week for sowing/planting. The estimation of co-efficient of variation (CV) of rainfall is more suited for agricultural purposes. The higher the CV, the lesser the dependability of rainfall and *vice-versa*., The threshold limit for CV for weekly rainfall should be less than 150% (Senthilvelen et al., 2012).

Table. 2 Rainfall Characteristics of Aduthurai

S.No.	Particulars	Standard Weeks
I	Onset of Rainy Season	
1	Mean week	35
2	Earliest week	31
3	Delayed week	38
II	Withdrawal of Rainy Season	
1	Mean week	5
2	Earliest week	54
3	Delayed week	6

Onset and withdrawal of rainfall was calculated based on forward and backward accumulation procedure. For calculation of forward accumulation 35 th week which has been considered as the mean onset period of North East Monsoon. For early onset week, the rainfalls are added backward from mean onset week to the corresponding week number in which the cumulative rainfall has reached a sum total of 75 mm. Similarly, delayed onset week can be calculated by rainfalls are added forward from mean onset week to the corresponding week number in which the cumulative rainfall has reached a sum total of 75 mm. Then the years are assigned with rank number, i.e. 1981-2015 as 1 to 35.

Table.3 Initial, Conditional and Consecutive probability of wet and dry weeks at Aduthurai

Standard Weeks	Initial Probabilities (%)		Conditional Probabilities (%)				Consecutive Probabilities (Dry and Wet Week) (%)			
	Pw	Pd	Pww	Pdd	Pwd	Pdw	2w	2d	3w	3d
1	9	91	0	88	12	100	0	75	0	56
2	9	91	0	88	12	100	0	72	0	63
3	14	86	0	83	17	100	0	70	0	60
4	0	100	0	97	3	100	0	94	0	91
5	6	94	0	94	6	100	0	82	0	73
6	9	91	0	88	12	100	0	75	0	63
7	6	94	0	91	9	100	0	82	0	73

8	9	91	33	91	9	67	0	81	0	72
9	3	97	0	94	6	100	0	88	0	82
10	9	91	0	88	12	100	0	75	0	59
11	3	97	0	94	6	100	0	88	0	82
12	3	97	0	94	6	100	0	88	0	82
13	0	100	0	97	3	100	0	94	0	89
14	3	97	0	94	6	100	0	88	0	82
15	20	80	14	75	25	86	0	50	0	25
16	14	86	0	83	17	100	0	67	0	50
17	14	86	0	83	17	100	0	67	0	50
18	23	77	0	67	33	100	0	52	0	44
19	14	86	0	83	17	100	0	77	0	57
20	26	74	22	73	27	78	11	54	0	38
21	11	89	0	87	13	100	0	71	0	58
22	11	89	0	87	13	100	0	74	0	61
23	14	86	20	83	17	80	0	67	0	53
24	14	86	20	87	13	80	0	73	0	63
25	14	86	0	87	13	100	0	70	0	60
26	3	97	0	97	3	100	0	94	0	88
27	20	80	14	82	18	86	0	71	0	68
28	20	80	29	79	21	71	14	68	0	57

29	9	91	0	91	9	100	0	78	0	75
30	29	71	40	72	28	60	20	56	10	40
31	23	77	25	74	26	75	13	48	0	33
32	26	74	22	69	31	78	0	46	0	27
33	31	69	45	71	29	55	18	50	9	33
34	40	60	50	71	29	50	36	48	29	33
35	49	51	47	44	56	53	24	28	12	22
36	40	60	29	52	48	71	0	19	0	14
37	43	57	60	70	30	40	27	45	7	25
38	23	77	13	74	26	88	0	56	0	41
39	43	57	47	50	50	53	20	25	7	5
40	46	54	44	53	47	56	25	37	6	21
41	34	66	33	61	39	67	0	43	0	30
42	57	43	55	40	60	45	25	7	5	0
43	60	40	62	43	57	38	43	14	33	0
44	74	26	62	22	78	38	27	0	8	0
45	71	29	64	30	70	36	44	10	24	0
46	49	51	35	44	56	65	12	17	0	6
47	60	40	57	36	64	43	43	14	29	7
48	63	37	64	38	62	36	32	0	18	0
49	51	49	44	41	59	56	22	12	6	6

50	40	60	50	62	38	50	21	38	14	14
51	37	63	38	59	41	62	15	32	8	14
52	23	77	38	78	22	63	13	74	0	56

Results and Discussions

Initial probability and Conditional probability

Initial probabilities of 20 mm threshold limit rainfall for all 52 weeks were recapitulated in table 3. Initial and conditional probability of dry and wet weeks ranges from 26 to 100 % and 0 to74 %. The first week of main rainy season was 44, probability of occurrence of dry week and dry week preceded by dry week are 26 and 22% and the end week of the main rainy season was 6, probability of occurrence of dry week and dry week preceded by dry week are 91 and 88%. At the first week of the main rainy season, the chance of occurrence of wet week and wet week preceded by wet week is 74 and 62 % and the probability of occurrence of wet week and wet week preceded by wet week is 9 and 0%. At 20 mm threshold rainfall, more than 70 % probability level of dry week and dry week preceded by dry week occurs during 1 st to 6 th and 52 nd week and the dry weeks were taken in to consideration for soil moisture conservation practice. More than 70 % probability level of wet week ^{44} and 45 th week. Therefore, this week was taken in to consideration for harvesting of runoff water for supplemental irrigation and soil conservation practices need to be accomplished. Various workers (Singh et al., 2004 and 2008) were used Markov chain model for probability analysis for their respective region.

Probability of occurrence of wet and dry spells during the monsoon period and co-efficient of variation (CV) of rainfall is a primary factor for planning of agricultural crops. The forward and backward accumulation of rainfall revealed that 75 mm of rainfall at 75 % probability occurs by 35 th week and 200 mm of rainfall at the same probability level occurs by 39 th week.

Table.4 Forward and backward accumulation of weekly rainfall

YEAR	Forward accumulation		Backward accumulation			Forward accumulation				Backward accumulation				
	75 mm	**200 mm**	**500 mm**	**300 mm**	**100 mm**	**Rn**	**f(p)**	**75 mm**	**200 mm**	**Rn**	**f(p)**	**500 mm**	**300 mm**	**100 mm**
	Accumulated on week		To be expected from week					Ranked				Ranked		
1981	32	36	43	45	47	1	2.8	31	34	35	97.2	41	44	46
1982	35	39	44	47	48	2	5.6	31	35	34	94.4	42	44	46
1983	32	38	45	47	48	3	8.3	31	35	33	91.7	42	44	46
1984	32	35	44	46	48	4	11.1	32	36	32	88.9	42	44	46
1985	35	39	44	45	46	5	13.9	32	36	31	86.1	43	45	47
1986	33	37	43	47	49	6	16.7	32	36	30	83.3	43	45	47

1987	33	38	45	46	49	7	19.4	32	36	29	80.6	43	45	47
1988	35	36	44	45	48	8	22.2	32	36	28	77.8	43	45	47
1989	37	40	46	48	50	9	25.0	32	36	27	75.0	43	45	47
1990	32	34	45	45	47	10	27.8	32	37	26	72.2	43	45	48
1991	36	38	46	48	50	11	30.6	33	37	25	69.4	44	45	48
1992	37	39	45	46	50	12	33.3	33	37	24	66.7	44	45	48
1993	37	40	47	49	50	13	36.1	33	38	23	63.9	44	45	48
1994	37	39	48	51	52	14	38.9	33	38	22	61.1	44	46	48
1995	34	39	45	47	48	15	41.7	33	38	21	58.3	44	46	48
1996	34	36	45	46	49	16	44.4	33	38	20	55.6	44	46	48
1997	32	38	43	44	48	17	47.2	33	38	19	52.8	44	46	49
1998	35	39	44	45	49	18	50.0	34	38	18	50.0	44	46	49
1999	33	36	43	45	47	19	52.8	34	38	17	47.2	45	46	49
2000	32	38	42	44	46	20	55.6	34	38	16	44.4	45	46	49
2001	35	39	48	50	51	21	58.3	34	39	15	41.7	45	47	49

2002	33	39	41	45	47	22	61.1	34	39	14	38.9	45	47	49
2003	31	38	43	44	47	23	63.9	35	39	13	36.1	45	47	49
2004	31	35	42	44	46	24	66.7	35	39	12	33.3	45	47	49
2005	31	36	46	47	49	25	69.4	35	39	11	30.6	45	47	50
2006	35	39	47	50	50	26	72.2	35	39	10	27.8	45	47	50
2007	34	38	44	46	51	27	75.0	35	39	9	25.0	46	47	50
2008	35	40	46	47	49	28	77.8	35	39	8	22.2	46	47	50
2009	34	39	46	48	51	29	80.6	35	39	7	19.4	46	48	50
2010	33	36	45	47	51	30	83.3	36	39	6	16.7	46	48	50
2011	33	37	42	45	48	31	86.1	36	40	5	13.9	46	48	51
2012	36	38	43	45	46	32	88.9	37	40	4	11.1	47	49	51
2013	32	37	44	47	49	33	91.7	37	40	3	8.3	47	50	51

Agricultural Crop Planning

Proper prediction about chances of occurrence of wet and dry spells during the monsoon period and co-efficient of variation (CV) of rainfall should be the adequate knowledge for planning of agricultural crops and water management. Some of the known applications towards

agricultural planning are presented below. Where the threshold limit of 20 mm per week at more than 50% of initial probability during the rainy season is passable for crop activities like land preparation and the conditional probability of occurrence of rainfall at 20 mm per week above 50% is the precise time for sowing / planting. The estimation of co-efficient of variation (CV) of rainfall is more suited for agricultural purposes. The higher the CV, the lesser the dependability of rainfall and *vice-versa* the threshold limit for CV for weekly rainfall be supposed to be less than 150% (Senthilvelen et al., 2012). Paddy crop is mostly suggested in this area due of receiving high rainfall and to overcome waterlogging problem during the north east monsoon for the month of October- December. Black gram is suggested for rice fallow pulse at the withdrawal of rainy season.

Conclusions

Rainfall pattern of Coastal area, Aduthurai was analyzed by using of Markov chain model. Knowledge of dry and wet spell occurrence could be very useful in scheduling the cropping pattern and managing the critical water requirement period of the crop. Probability of wet week more than 50 % was occurred on 35 th week .From knowledge of rainfall probability analysis, crop sowing dates can be adjusted in such a way that water deficit stage of the crop should coincide with the period of higher rainfall probability. Apart from water saving disease occurrence can also be predicted based on this succession of dry and wet spell.

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