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Weekly Rainfall Analysis for Crop Planning Using Markov's Chain Model for Kandhamal District of Odisha, India

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ABSTRACT
Weekly rainfall analysis of Kandhamal district during the period of 1965 to 2010 were taken for analysis purpose, the analysis is very much important for crop planning and analyzing the probability of occurrence of dry and wet periods. This will act as bench mark for crop planning as well as sustainable agricultural management of Kandhamal district which comes under the agro-climatic zone of East-coast hill region. Markov chain model has been utilized to derive the probability of dry or wet weeks and also forward and backward accumulation of rain water suitable for crop production. This analysis can be helpful to find out different cropping system including intercropping and sequence cropping suitable during that period.
Key words : Markov chain, dry spell, wet spell, weekly, rainfall

I. INTRODUCTION

Phulbani is located at 20.47°N 84.23°E. It has an average elevation of 485 meters in the North Eastern Ghat zone. The geographical area of the Kandhamal district is 7654 sq.km. 76.4 % of this area is coming under forest. According to 2011 census the population of Kandhamal is 7,33,110, rural population is around 93 %. Among of total population 15 % are Scheduled caste and 54 % are Scheduled tribe. So this district is a tribal dominated and rural dominated district, so Agriculture development needs important for development and increase per capita income of the people of the district. So proper crop planning and time of sowing and harvesting will increase their crop yield, for further development of the district and state. So following rainfall models were tried to find out the crop planning.

Markov chain probability model has been used extensively to find the long-term frequency behaviour of wet and dry weather spells (Victor and Sastri 1979). Another aspect of crop planning is backward and forward accumulation of rainfall to determine the onset and termination of wet season based on precipitation data.

A number of studies have been conducted for location specific agricultural planning in general and crop planning in particular by analyzing daily, weekly, monthly, seasonal and annual rainfall data. Stern and Coe (1982) analyzed daily rainfall data for crop planning in semi-arid, tropics. Similar analysis of rainfall data has been done for crop planning in coastal, semi-arid, dry farming, sub-humid and Himalayan foothill regions, Panigrahi(1998); Sharda and Das (2005).

Farmer's cropping strategies are greatly influenced by the variability of the onset and termination of rainy season. Accumulation of 75 mm rainfall has been considered as the onset time for growing season for dry-seeded crops in sandy loam soil and 200 mm accumulated rainfall for initiation of paddling i.e. transplanting of rice *(Oryza sativa* L.). Similarly end of wet season is determined by backward summing of rainfall data. It is considered that 500 mm and 300 mm accumulated values represent the week after which sufficient rain would be expected to sustain a second rice crop or other short duration field crops assuming a fully charge soil profile at planning (WMO 1982).

II. MATERIALS AND METHODS

Daily rainfall data for 30 years (1981-2010) were collected from rain gauge stations Khurda (18°46'N to 20°95' N latitude, 83°48'E to 87°46' E longitude and 42 m altitude). The standard 7 day period (weekly) has been taken to establish the dry and wet spell frequency based on Markov Chain Model considering a week receiving rainfall less than 20mm as a dry period and 20 mm or more as a wet period. The different notations followed in this analysis are given below:

$$f(P_d)=\frac{n_d}{y_n} \quad \ldots(1)$$

where f (P_d) probability of the period considered being dry , n_d number of dry periods observed, y_n number of years of data used.

$$f(P_{dd})=\frac{n_{dd}}{n_d} \quad \ldots(2)$$

Where f (P_{dd}), probability of dry period preceded by another dry period (conditional) and n_{dd} , number of dry period preceded by another dry period.

$$f(P_{d2})=f(P_d)\times f'(P_d) \quad \ldots(3)$$

where $f(P_{d2})$,probability of 2 consecutive dry period; $f(P_d)$, probability of the period being dry (1st period) and $f'(P_d)$,probability of 2nd consecutive dry period, given the preceding period being dry.

$$f(P_{d3})=f(P_d)\times f(Pd) \times f''(P_d) \quad \ldots(4)$$

where $f(P_{d3})$, probability of 3 consecutive dry period; and $f''(P_d)$, probability of 3rd being dry given the preceding period dry.

$$f(P_w)=\frac{n_w}{y_n} \quad \ldots(5)$$

where $f(P_w)$, probability of the period considered being wet and n_w number of wet periods observed.

The $f(P_{ww})$, $f(P_{w2})$ and $f(P_{w3})$ have been estimated in the same manner as $f(P_{dd})$, $f(P_{d2})$ and $f(P_{d3})$ and the notations used are having the same meaning except the period being wet. Using the above formulas, probabilities of dry weeks and wet weeks; conditional probabilities of dry weeks preceded by dry weeks and wet weeks preceded by wet weeks and probability of consecutive 2 and 3 dry or wet weeks starting with weeks dry or wet have been estimated.

For the calculation of forward and backward accumulation, weekly rainfalls are arranged in column and the year in rows. For calculation of forward accumulation 22nd week has been considered as the starting period due to start of monsoon rain. The rainfalls are added week wise from 22nd week onwards to find the corresponding week number in which the cumulative rainfall has reached a sum total of 75 mm and 200 mm. Similarly, week -wise rainfalls are added backward from 52nd week (52nd week + 51st week + ...) to get 100 mm, 300 mm and 500 mm total and the corresponding week numbers are noted. Then the years are assigned with rank number, i.e. 1981-2010 as 1 to 30. The probability of each rank is calculated by the simple statistical formula.

$$f(P)=\frac{R_n}{y_n+1} \quad \ldots(6)$$

Where f(P), probability (%); R_n, rank number and y_n, number of years of observation .

For forward accumulation the rank order and probability level are arranged in ascending order and the corresponding week numbers are arranged in the same manner. Similarly, for backward accumulation the rank order and probability level are arranged in descending order and the corresponding week number for 500 mm, 300 mm and 100 mm respectively are arranged in ascending order.

Table1 Analysis of weekly rainfall pattern

	Initial Probability(%)		Conditional probability(%)			
SMW	PD	PW	PDD	PWD	PWW	PDW
1	96.2	3.7	92.3	7.7	0	100
2	92.5	7.4	80	20	0	100
3	96.2	7.0	84.6	15.4	0	100
4	96.2	3.7	92.3	8	0	100
5	92.5	11.1	92	8	50	50
6	96.2	3.7	92.3	8	0	100
7	85.1	14.8	82.3	17.7	25	75
8	100	0	96.2	3.8	0	100
9	96.2	3.7	92.3	8	0	100
10	96.2	3.7	92.3	8	0	100
11	96.2	3.7	92.3	8	0	100
12	100	0	96.2	3.8	0	100
13	85.1	14.8	78.2	21.3	25	75
14	85.1	14.8	82.6	17.4	0	100
15	96.2	3.7	92.3	8	0	100
16	88.8	11.1	83.3	16.7	0	100
17	81.4	18.5	81.8	18.2	40	60
18	85.1	14.8	82.6	17.4	25	75

19	85.1	14.8	78.2	21.8	0	100
20	81.4	18.5	77.2	22.3	20	80
21	77.7	22.2	76.1	23.9	16	84
22	66.6	33.3	72.2	27.8	44	56
23	59.2	40.7	69.5	30.5	36	64
24	33.3	66.6	55.5	44.5	72	28
25	33.3	66.6	11.1	88.9	77	23
26	22.2	77.7	16.6	83.4	76	24
27	11.1	88.8	0	100	83	17
28	22.2	77.7	33.3	66.7	90	10
29	11.1	88.8	0	100	83	17
30	14.8	85.1	0	100	78	22
31	14.8	85.1	0	100	78	22
32	11.1	88.8	0	100	83	17
33	25.9	74	14.2	85.8	65	35
34	22.2	77.7	16.6	83.4	80	20
35	14.8	85.1	25	75	86	14
36	22.2	77.7	0	100	71	29
37	18.5	81.4	0	100	72	28
38	22.2	77.7	0	100	71	29
39	37	62.9	20	80	64	36
40	55.5	44.4	46.6	53.4	41	59
41	59.2	33.3	75	25	44	56
42	51.8	48.1	42.8	57.2	38	62
43	92.5	74	88	12	0	100
44	88.8	111	87.5	12.5	33	67
45	81.4	185	77.2	22.8	0	100
46	88.8	111	87.5	12.5	33.3	67
47	96.2	3.7	92.3	7.7	0	100
48	100	0	96.2	3.8	0	100
49	96.2	3.7	96.1	3.9	0	100
50	96.2	3.7	92.3	7.7	0	100
51	96.2	3.7	84.6	15.4	0	100
52	100	0	96.2	3.8	0	100

Table.2 Consecutive dry probability and consecutive wet probability of Phulbani block Consecutive dry probability Consecutive wet probability

SMW	2D	3D	2W	3W
1	88.7	85.0	0	0
2	74	70.3	0	0
3	81.3	81.3	0	0
4	88.7	73.9	0	0
5	85.1	77.6	5.55	0
6	88.7	77.6	0	0
7	70.0	58.9	3.7	0
8	96.2	88.7	0	0
9	88.7	70.2	0	0
10	88.7	85.0	0	0
11	88.7	85.0	0	0
12	96.2	92.4	0	0
13	66.5	55.4	3.7	0
14	70.2	59.1	0	0
15	88.7	81.3	0	0
16	73.9	59.1	0	0
17	66.5	48.0	7.4	3.7
18	70.2	51.7	3.7	0
19	66.5	48.0	0	0
20	62.8	48.0	3.7	0
21	59.1	40.6	3.552	0
22	48.0	25.8	14.652	7.3
23	41.1	30.8	14.652	3.6
24	18.4	0	47.952	33.1
25	3.6	0	51.282	36.6
26	3.6	0	59.052	47.9
27	0	0	73.704	58.9
28	7.3	0	69.93	51.4
29	0	0	73.704	70.0
30	0	0	66.378	58.9
31	0	0	66.378	51.5
32	0	0	73.704	58.9
33	3.6	0	48.1	33.2
34	3.6	0	62.16	36.5
35	3.7	0	73.186	62.2
36	0	0	55.167	40.4
37	0	0	58.608	32.9
38	0	0	55.167	40.4
39	7.4	0	40.256	21.9
40	25.8	7.3	18.204	3.6
41	44.4	29.5	14.652	7.3
42	22.1	22.1	18.278	10.9
43	81.4	70.2	0	0
44	77.7	59.1	3.663	0
45	62.8	36.9	0	0
46	77.7	59.1	3.6963	0
47	88.7	73.9	0	0
48	96.2	85.0	0	0
49	92.4	85.0	0	0
50	88.7	81.3	0	0
51	81.3	70.2	0	0
52	96.2	92.4	0	0

Table 3 Weekly rainfall pattern at Kandhamal district of Odisha

SMW	Mean	Max	Min	SD	CV
1	1.2	30.3	0	5.8	458.5
2	4.6	78	0	15.5	0.77
3	20.1	59	0	11.7	58.1
4	39.2	61.8	0	12.3	31.3
5	11.4	38	0	11.9	72.5
6	16.7	35	0	12.5	42.0
7	10.3	66.9	0	8.4	147.5
8	9.2	13	0	7.1	31.6
9	13.8	44	0	15.5	69.6
10	8.3	23	0	2.9	63.3
11	10.4	29	0	9.8	57.5
12	9.1	15	0	5.4	63.1
13	9.0	56	0	6.0	168.8
14	9.9	70	0	5.8	185.0
15	11.8	27	0	15.5	51.5
16	15.8	33	0	18.6	56.1
17	9.8	38	0	6.2	145.9
18	11.6	64	0	9.0	156.2
19	12.8	146	0	14.5	290.4
20	17.8	101	0	18.5	166.7
21	20.3	100.2	0	38.1	128.1
22	19.2	122	0	30.2	127.1
23	16.9	137.6	0	20.3	214.0
24	45.7	235	0	33.4	165.7
25	32.2	116	0	46.1	218.8
26	55.1	359.6	0	65.6	127.4
27	48.2	429	0	54.8	193.4
28	79.7	401	0	70.6	117.4
29	69.7	348.8	0	94.7	122.2
30	59.2	344	0	94.8	121.9
31	73.8	329.8	0	85.7	112.6
32	71.7	342	0	72.9	117.2
33	88.0	280	0	84.7	98.9
34	104.8	222	0	85.5	57.5
35	69.4	361.6	0	88.7	125.4
36	62.3	155	0	60.6	66.2
37	84.7	346.2	0	87.3	99.1
38	60.3	308.1	0	41.8	108.5
39	64.0	133	0	85.6	55.4
40	100.1	153	0	66.7	40.4
41	49.9	238	0	35.4	71.3
42	38.5	129	0	40.91	144.9
43	32.4	103.8	0	36.16	63.2
44	39.5	97	0	56.9	51.6
45	22.1	98	0	20.9	88.9
46	24.5	41.11	0	20.7	75.6
47	21.9	67	0	19.3	58.7
48	23.7	5	0	18.8	4.0
49	20.9	33	0	13.1	30.2
50	19.9	54	0	0.980	53.5
51	20.2	62	0	0.392	68.7
52	0.1	3	0	0.577	519.8

Weekly rainfall Data of 27 years (1984– 2010) indicated that the monsoon starts effectively from 24th SMW (11 – 17th June) and remains active up to 39th SMW (30th November). Therefore, mean length of rainy season was found to be 15 weeks (105days). It is seen from the above table 3 that among all the 52 weeks contributes an average rainfall of 28.57mm with minimum and maximum rainfall of 0 mm and 429mm. The coefficient of variance (CV) 5.1. It was also observed that even at probability level of 0.55, there was no rainfall from 30th to 52nd week. There is only 19 % probability of receiving more than 10mm rainfall from 11th to 21st week. At 0.80 probability levels, no rainfall was assured during 43rd to 52nd weeks. The winter seasons weeks (between 39th and 52nd) weeks received no rainfall. It was also observed that within a normal month there were weekly rainfall variations causing temporary dry spells. When these dry spells coincide with the critical stage of crop growth, there will be considerable reduction in the yield of standing field crops. Therefore, appropriate moisture conservation measures such as mulching and water harvesting should be adopted to save crops from damaging action of drought. Table 1 shows that the probability of occurrence of dry week is high untill end of 23rd week. The range of probability of occurrence of dry week from 1st to 23rd week is between 59.2% to 100 %. The probability of occurrence of dry week preceded by another dry week and that of dry week preceded by another wet week vary from 0% to 96.2% and 50% to 100% respectively during these periods. The probability of occurrence of wet week preceded by wet week and that of wet week preceded by dry week vary from 0% to 44% and 3.8% to 30.5%. From 24th to 41st week the probability of dry week and that of dry week preceded by another dry week varies from 11.1% to 59.2% and 0% to 75%. The probability that these weeks remain wet varies between 33.3% and 88.8%. The transitional probability of wet week preceded by another wet week varies from 14.65% to 73.7%. The chances of occurrence of dry spells are again high from 44th week to the end of the year. Probability of occurrence of wet week preceded by another wet week during these periods is between 0.00% and 86%.

The results pertaining to initial and conditional probabilities of dry and wet weeks and consecutive dry and wet weeks are presented in table 1 and 2 respectively for all the 52 standard meteorological weeks but, the results are discussed in relevance with rainy season (24th SMW –39th SMW) only. The probability of occurrence of 2 consecutive wet weeks are more than 35% during 24th –39th SMW and the probability of occurrence of 3 consecutive wet weeks are more than 25% during 24th –38th SMW (Table 2). 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 are total of 48 weeks (1st –7th, 9th –11th SMW) where rainfall exceeds more than 20 mm. So harvesting excess runoff water for future supplemental irrigations and also drives attention towards soil erosion measures to be taken up for soil erosion control. During rainy season the mean weekly rainfall is found to be more than the weekly contribution of rainfall towards annual average rainfall is found to be highest during 25th –38th SMW.

Crop planning for kharif (monsoon) season:

During the kharif season, a good weekly rainfall (above 10mm) was received during 11th to 21st at 0.20-0.30 probability level, which was expected to take care of dry spells during the season. It indicates that seedbed preparation and sowing of kharif crops can be initiated in the 11th week. The reliability of getting rainfall at least equal to the mean rainfall is between 0.20 and 0.50 probability levels. Thus, it seems difficult to plan agricultural operations based on mean weekly rainfall alone. At above 0.55 probability level, there was no rainfall after 30th week and it may not be possible to replenish soil moisture in the soils with low water holding capacity. If green manuring crop is harvested early and spread on the surface, it may function as mulch and may reduce evaporation losses from the soil to some extent.

Crop planning for Rabi (winter) season:

During the winter season (31st week onwards), negligible rainfall is recorded at 0.55 probability level. So the surface soil would become dry with rare chances of getting adequate soil-moisture in the seeding zone. Hence, surface moisture conservation would be essential for germination of seed and plant establishment and, if possible, water harvesting should be done to ensure a pre-sowing irrigation. It was also revealed that the rabi crops have to be raised under moisture stress conditions. The crops should be able to use residual soil profile moisture more judiciously as reliability of getting adequate weekly rainfall is low. If irrigation facilities are available, then early sown varieties may be grown with the application of pre- sowing irrigation.

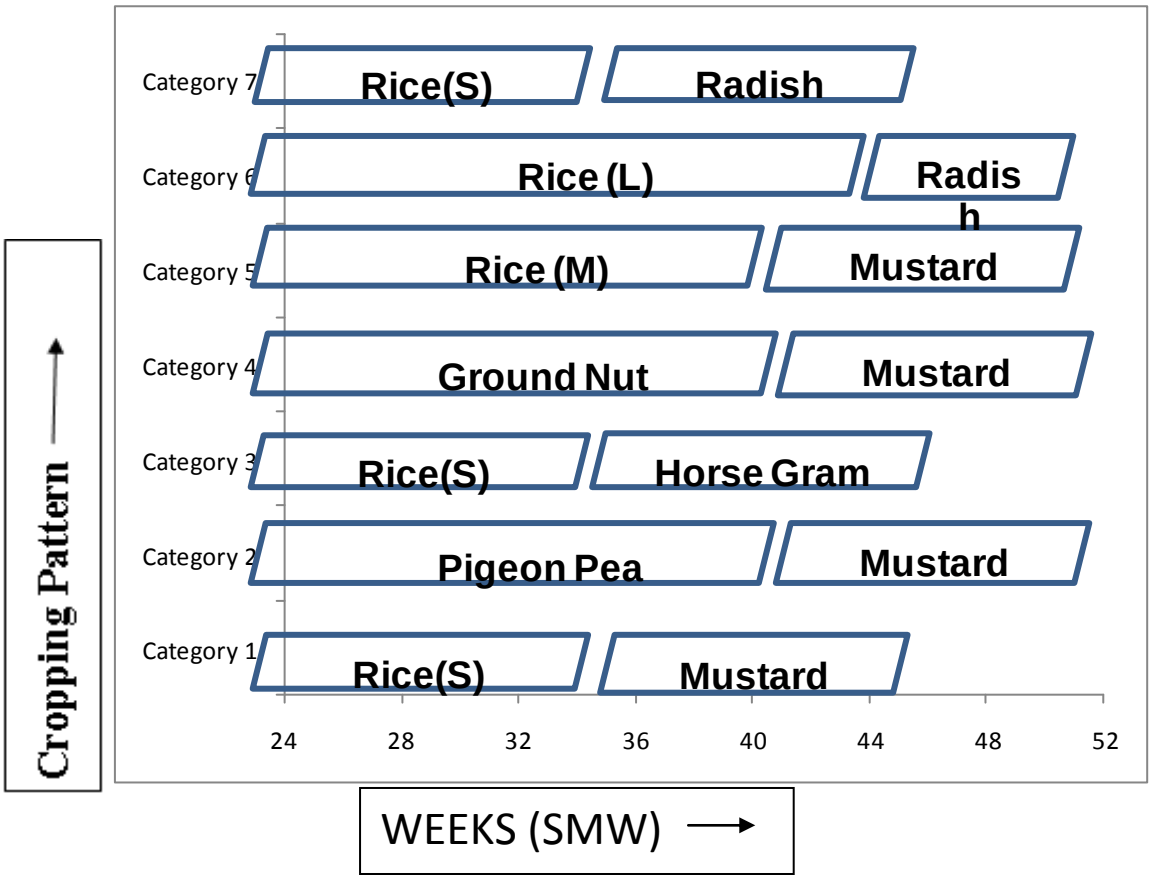

Fig I Different cropping patterns for Kandhamal district

Table 4 shows results obtained from Markov chain analysis

Month	n_d	$\mathbf{n_{dd}}$	$\mathbf{P_d}$	$\mathbf{P_{dd}}$	$\mathbf{P_{d2}}$	$\mathbf{P_{d3}}$	$\mathbf{n_w}$	$\mathbf{n_{ww}}$	$\mathbf{P_w}$	$\mathbf{P_{ww}}$	$\mathbf{P_{w2}}$	P_{w3}
Jan	41	39	98	95	93	86	1	0	2.4	0	0.0	0.0
Feb	41	39	98	95	90	84	1	0	2.4	0	0.0	0.0
March	40	37	95	93	88	67	2	0	4.8	0	0.0	0.0
April	40	37	95	93	72	0	2	0	4.8	0	0.5	0.4
May	33	25	79	76	0	0	9	1	21.4	11	17.3	9.1
June	6	0	14	0	0	0	36	29	85.7	81	83.7	72.7
July	0	0	0	0	0	0	42	41	100.0	98	97.6	38.7
Aug	0	0	0	0	0	0	42	41	100.0	98	92.5	41.6
Sept	2	0	5	0	2	0	40	37	95.2	93	42.9	6.1
Oct	22	11	52	50	42	0	20	9	47.6	45	42.9	0.0
Nov	35	28	83	80	81		7	1	16.7	14	0.0	
Dec	42	41	100	98			0	0	0.0	0		

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