



Markov Chain Model of weekly rainfall probability and dry and wet spells for agricultural planning in Coimbatore in western zone of Tamil Nadu

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ABSTRACT

The historical rainfall data for the period 1981-2011 of Coimbatore in western zone of Tamil Nadu were analyzed using Markov Chain Probability Model to describe the long-term behavior of wet or dry weather spells. The model considered less than 20 mm rainfall in a week as a dry week and 20 mm or more as a wet week to estimate the dry and wet spell probability. The probability of occurrence of dry week was very high from 1st to 38th Standard Meteorological Week (SMW) ranging from 75-100%. The probability of occurrence of dry week preceded by another dry week was also high up to the 40th standard week and that of dry week preceded by a wet week was high up to 35th week and varied from 75-100%. The conditional probability of wet week preceded by another wet week was comparatively high and varied from 43.8 to 92.3% during 39th to 48th week. The analysis of consecutive dry and wet spells revealed that there are 50 to 100% chances that two consecutive dry weeks will occur within the first 38 weeks of the year. Similarly the probability of occurrence of three consecutive dry weeks was also very high (53 to 100%) in the first 38 weeks of the year. The successive dry weeks indicate the need for supplemental irrigation and suitable moisture conservation practices whereas, occurrence of successive wet weeks gives an idea of excessive runoff water availability for rainwater harvesting and to take up suitable measures to control soil erosion. The analysis also showed the mean, earliest and delayed weeks of onset and withdrawal of rainy season in Coimbatore as 28th, 22nd, 39th and 47th, 44th, 52nd, respectively. Hence, it is suggested that sowing of crops may be started in 27th week. High rainfall, more wet weeks and delayed withdrawal of rainy season with high probability (73.4-95.3%) from 49th to 52nd week could be utilized successfully for *rabi* crops. Since dry probabilities are high during *kharif* (23rd to 39th standard week), short duration crops and other less water requiring crops may be grown which have high return value.

1. INTRODUCTION

Coimbatore region comes under agro-climatic western zone of Tamil Nadu state and lies between 11°N latitude and 77°E longitude with an elevation of 426.72 m above msl covering an area of 323.88 ha. The mean annual rainfall is 723.24 mm, of which 59.9% occurs during North East monsoon. The maximum and minimum temperatures are between 31.5°C in May and 21.4°C in February, respectively. The relative humidity varies from 41 to 91%. Coimbatore has a sub-tropical, semi-arid climate with hot summer.

Indian agriculture is mainly dependent on monsoon rainfall and its distribution. The erratic trend and uneven distribution of rainfall are the characteristics of this region. The situation is further aggravated by extremes of temperatures and associated land degradation. Paddy, cholam, cumbu, ragi, maize, red gram, black gram, green gram, horse gram, groundnut, gingelly, sunflower, soybean, cotton and sugarcane are the major crops of the region. The soils of the region are poor in organic carbon, nitrogen and phosphorus content which also adversely affect the crop yield.

The yield of crops, particularly in rainfed condition depends on the rainfall pattern. The probable behavior of rainfall was studied by many researchers (Chakravorthy and Mandal, 2008; Jat *et al.*, 2010; Chand *et al.*, 2011; Jakhar *et al.*, 2011; Kumar *et al.*, 2007). The wet and dry spell analysis will help in characterization of command area crop, cropping system planning and design of conservation structures. The concept of probability is usually used to study the dry and wet spells for agricultural planning (Shrivastav *et al.*, 2004). The Markov Chain Model has been used extensively to study the spell distributions and other properties of rain occurrence. Markov Chain Probability Model assumes that the probability of rainfall occurring on any day depends on whether the previous day was wet or dry. The model calculates the initial probabilities of getting a dry spell or wet spell in a given SMW. The calculation of conditional probabilities provides the information on the dry spell followed by dry spell or wet spell and vice versa.

Pandharinath (1991); Rath *et al.* (1996); Singh and Bhandari (1998); Panigrahi and Panda (2002); Kar (2003); Srinivasa Reddy (2008); Chand *et al.* (2011) Senthilvelan (2012); Singh *et al.* (2014); Pali and Thakur (2015) applied Markov Chain model for calculating initial and conditional probability of dry and wet spells of different duration for various climatic situations and have evaluated its practical importance in crop planning. Another aspect useful for crop planning is the 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 cropping strategies and hence the success of rainfed agriculture.

The zone having semi-arid climate is characterized by recurrent drought and frequent moisture stress periods due to breaks in monsoon rains or early withdrawal of monsoon. The drought periods at times extend to more than two weeks and often occur during mid and later part of the rainy season in August extending to September and merging with the withdrawal of monsoon from the region. The proper understanding and efficient utilization of the natural resources especially rainfall is of great concern for the improvement and sustainability of agriculture in rain fed areas. 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 as agricultural planning is concerned. There is a need to quantify regional rainfall variability to assess its effect on agricultural productivity. Hence the present study was aimed at investigating the dry and wet spells for suitable agricultural planning in Coimbatore region of Tamil Nadu.

2. MATERIALS AND METHODS

Daily rainfall data for 31 years (1981- 2011) were collected

from Agro-Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. 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 (Dash and Senapati, 1992; Pandharinath, 1991). Generally, dry spells occur due to inadequate rainfall throughout the rainy season. The evaporative demand of the atmosphere varies from 40 mm week⁻¹ during the beginning of the season and decreased to 30 mm week⁻¹ during the active rainy season. A week receiving rainfall of about 20 mm will be able to meet 0.5 to 0.75 times the evaporative demand. Therefore, a week with rainfall less than 20 mm was considered as a dry week. However, during a dry week, the crop may meet its water requirement through the moisture available in the soil. If the rainfall is less than 20 mm week⁻¹ for two or more consecutive weeks, the crops are likely to be subjected to moisture stress in the absence of adequate stored soil moisture.

The different notations followed in the Markov Chain Analysis are given below:

Initial Probability : $P_d = F_d/n$; $P_w = F_w/n$.

Conditional Probabilities : $P_{dd} = F_{dd}/F_d$; $P_{ww} = F_{ww}/F_w$; $P_{wd} = 1 - P_{dd}$; $P_{dw} = 1 - P_{ww}$.

Consecutive Dry and Wet Week Probabilities : $P_{2d} = P_d \times P_{dd}$; $P_{2w} = P_w \times P_{ww}$; $P_{3d} = P_{dd} \times P_{dd} \times P_{dd}$; $P_{3w} = P_w \times P_{ww} \times P_{ww}$.

Where, P_d is the probability of the period considered being dry, P_w is the probability of the period considered being wet, F_d is the number of dry weeks observed, F_w is the number of wet weeks observed, n is the number of years of data used, P_{dd} is the probability of dry week preceded by another dry week (conditional). F_{dd} is the number of dry weeks preceded by another dry week, P_{wd} is the probability of wet week preceded by another dry week, P_{dw} is the probability of dry week preceded by another wet week, P_{2d} is the probability of two consecutive dry weeks, P_{3d} is the probability of three consecutive dry weeks, P_{2w} is the probability of two consecutive wet weeks, P_{3w} is the probability of three consecutive wet weeks, P_{d1} is the probability of the period being dry (1st week), P_{dd2} is the probability of the second consecutive dry week, given that the preceding week being dry, P_{dd3} is the probability of the third consecutive dry week, given that the preceding week being dry, P_{w1} is probability of the period being wet (1st week), P_{ww2} is the probability of the second consecutive wet week, given that the preceding week being wet and P_{ww3} is the probability of the third consecutive wet week, given that the preceding week being 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 mm 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 (52+51+50+49+48+47+46+...+30 weeks) data. Twenty mm 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 probabilities of onset and withdrawal of rainy season were calculated by using Weibull's formula. The percent probability (P) of each rank was calculated by arranging weeks in ascending order and by selecting highest rank allotted for particular week. The Weibull's formula $P=m/N+1$ is used to find the probability, where, m is the rank number and N is the number of years of data used.

3. RESULTS AND DISCUSSION

The mean annual rainfall of Coimbatore in Western zone of Tamil Nadu for the past 31 years (1981-2011) was found to be 724.23 mm with standard deviation 167.91 mm and coefficient of variation 23.2%. The annual rainfall amount ranged from 477.3 mm (the lowest during the year 1995) to 1082.1 mm (the highest during the year 2011) over the years. Out of 31 years, 16 years recorded annual rainfall in excess of average or normal (724.23 mm) while 15 years recorded below normal rainfall (Fig. 1). Weekly rainfall data of 31 years (1981-2011) indicated that there exist very low variability of $CV < 10\%$ (Fig. 2 and Fig. 3). According to the Crop Planning-Climate Atlas (Veeraputhiran, 2003), the threshold limit for coefficient of variation for weekly rainfall should be less than 150%. This indicated higher dependability of rainfall during this period. Hence, the weekly rainfall probability and pattern of deficit and surplus rainfall are very useful for suitable agricultural planning and efficient use of rainwater. The weekly rainfall variability indicated that mean weekly rainfall was < 20 mm up to the 38th week except 18th week and during 37th-47th SMW it varied from 15 to 60 mm (Fig. 2). The mean weekly rainfall showed that 37 to 47 SMW are considered as most stable period and total average length of rainy period is 11 weeks at Coimbatore. The weekly contribution of rainfall towards annual average rainfall is found to be highest during 37-47 SMW accounting to 52.8% of the average annual rainfall.

Onset and Withdrawal of Rainy Season

The results of forward and backward accumulation of rainfall for onset and withdrawal of rainfall and their probabilities are presented in Table 1 and Table 2, respectively.

The results of forward accumulation of rainfall showed that there was 51.6% chance of getting 75 mm cumulative rainfall in the 28th week. Except 32nd week, from 29th to 36th week have

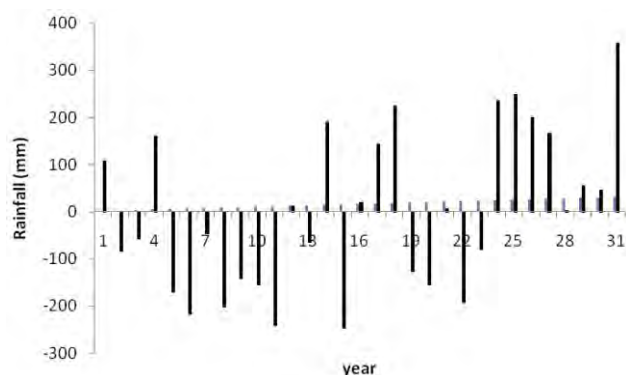


Fig. 1. Annual variability of rainfall over normal in Coimbatore region (1981-2011)

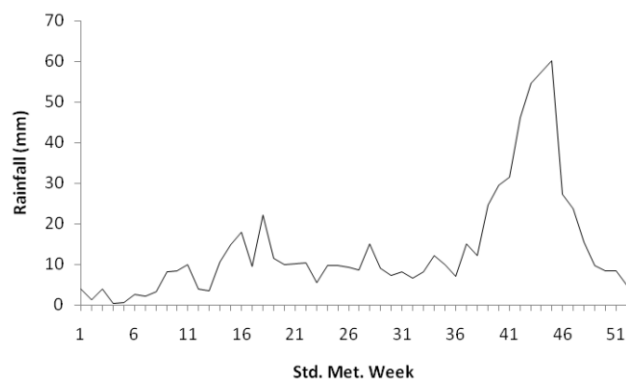


Fig. 2. Weekly rainfall distribution of Coimbatore region (1981-2011)

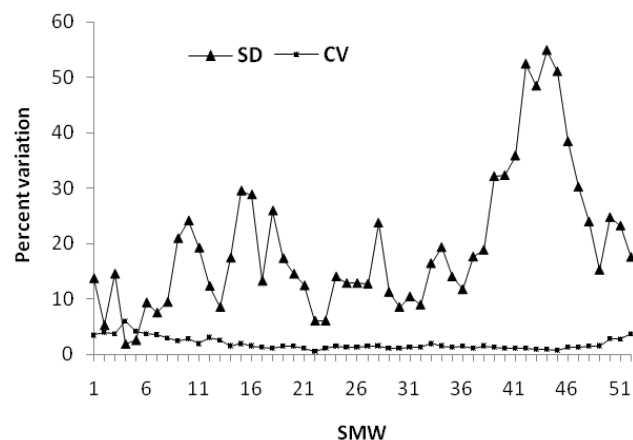


Fig. 3. Weekly rainfall variability of Coimbatore (1981-2011)

Table: 1
Onset and Withdrawal of rainy season in Coimbatore (1981-2011)

Parameter	Onset of rainy season	Withdrawal of Rainy season	Duration of week
Mean week	28	47	19
Earliest week	22	44	22
Latest week (Delayed week)	39	52	13

Table: 2
Probability of onset and withdrawal of rainy season in Coimbatore

a. Onset														
SMW	22	23	24	25	26	27	28	29	30	31	33	34	35	36
P (%)	3.1	6.3	9.4	20.3	32.8	41.6	51.6	62.5	71.9	78.1	81.3	85.9	90.6	93.8
b. Withdrawal														
SMW	44	45	46	47	48	49	50	51	52					
P (%)	3.2	9.7	21.9	37.5	56.3	73.4	83.9	87.5	95.3					

more probability of getting a cumulative rainfall of 75 mm. The probability varies from 62.5 to 93.8%. The results of backward accumulation of rainfall showed that there was 53.6% chance of getting 20 mm cumulative rainfall in the 48th week. The probability of getting a cumulative rainfall of 20 mm increased from 49 to 52 SMW (Table 2). In other words the probability results revealed that there is more than 75% chance that the onset of rainy season and cessation of rainy season will occur during 31st and 50th SMW, respectively. The analysis also showed the mean, earliest and delayed weeks of onset and withdrawal of rainy season in Coimbatore as 28th, 22nd, 39th and 47th, 44th, 52nd, respectively. Hence, sowing of crops may be started in 27th week. Mean duration of rainy season was observed as 19 weeks. The longest and shortest length of rainy season was 22 and 13 weeks, respectively (Table1). Farmers can effectively utilize the rainfall for the three crop seasons. The agricultural operations like weeding, hoeing etc can be carried out successfully. High rainfall and more wet weeks and delayed withdrawal of rainy season with high probability (73.4-95.3 %) from 49th to 52th week, respectively (Table 2) can be utilized successfully for *rabi* crops. Irrigation is required up to 39th week as the dry probabilities are high and only short duration crops can be recommended during this period.

Initial, Conditional, Consecutive Dry and Wet Probability of Weekly Rainfall

The results pertaining to initial and conditional probabilities of dry and wet weeks and consecutive dry and wet weeks are presented in Table 3 for all the 52 standard meteorological weeks. The probability of occurrence of dry week was very high from 1st to 38th week ranging from 75-100%. The probability of occurrence of dry week preceded by another dry week was also high up to the 40th week and that of dry week preceded by another wet week was high up to 35th week and varied from 75-100%. However, from 39th to 48th the probability of dry week and that of dry week preceded by another dry week reduced even to the level of 30% in certain cases. The probability that weeks remain wet varies between 22.6 to 77.4%. The conditional probability of wet week preceded by another wet week was comparatively high and varies from 43.8 to 92.3% during the period (Fig. 4). The intensity of dry spell further increased up to 52nd week. The probability of occurrence of a wet week preceded by another wet week increased from 36th week to 51st week. Also

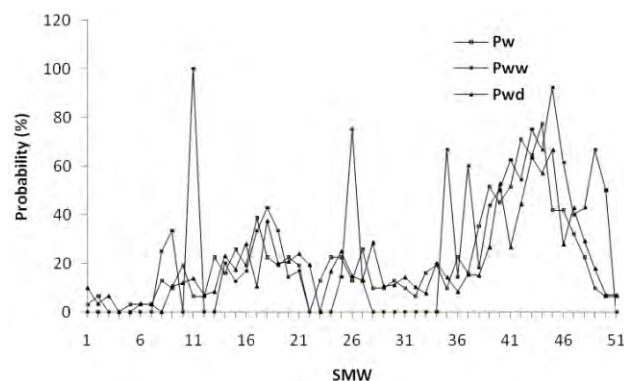


Fig. 4. Initial and conditional probability of rainfall in Coimbatore by Markov chain model

there was 58.1 to 93.5% risk that week from 46th to 52nd remain dry.

The analysis of consecutive dry and wet spells revealed that there are 50 to 100% chances that two consecutive dry weeks will occur within the first 38 weeks of the year. Similarly the probability of occurrence of 3 consecutive dry week is also very high (53 to 100%) in the first 38 weeks of the year. The corresponding values of 2 and 3 consecutive wet weeks from 1st to 39th weeks were very low with figures ranging from 0 to 19.4% and from 0 to 7.8%, respectively. From 40th to 48th week, the chances of occurring 2 and 3 consecutive dry weeks were only within 7.5 to 47.9% and 4.5 to 24%, respectively. In other words, there are 4.9 to 71.4% and 15.3 to 43.9% chances that the weeks 40th to 50th will be getting sufficient rain with 2 and 3 consecutive wet weeks, respectively. The study revealed that the last 2-3 weeks of the year may remain under stress as there is more than 50% probability for 2 and 3 consecutive dry weeks.

Crop Planning Strategies

The erratic rainfall distribution, frequent occurrence of early, intermittent and late season continuous dry spells are the main reasons of low crop productivity in Coimbatore region of Tamil Nadu. The results derived from the above analysis can be used effectively for agricultural planning. The probability of occurrence of wet week is around 20% during 20th to 22th week and average weekly rainfall is 10 mm, this pre-monsoon rain can be utilized for summer ploughing and initial seed bed preparations. Mean duration of rainy season was observed as 19 weeks. Farmers can effectively utilize the rainfall for the three crop seasons.

Table: 3**Initial, conditional and consecutive dry and wet week probabilities of rainfall in Coimbatore region (1981-2011)**

Week	Initial Probability %		Conditional probability %				Consecutive probability %			
	PD	PW	PDD	PWD	PWW	PDW	P2D	P3D	P2W	P3W
W1	90.3	9.7		...			81.3	78.5	0.0	0.0
W2	96.8	3.2	90.0	10.0	0.0	100.0	93.5	87.4	0.0	0.0
W3	93.5	6.5	96.6	3.4	0.0	100.0	87.4	87.4	0.0	0.0
W4	100.0	0.0	93.5	6.5	0.0	100.0	100.0	100.0	0.0	0.0
W5	100.0	0.0	100.0	0.0	0.0	100.0	100.0	96.7	0.0	0.0
W6	96.8	3.2	100.0	0.0	0.0	100.0	93.6	90.5	0.0	0.0
W7	96.8	3.2	96.7	3.3	0.0	100.0	93.6	93.6	0.0	0.0
W8	96.8	3.2	96.7	3.3	0.0	100.0	96.8	86.4	0.8	0.3
W9	87.1	12.9	100.0	0.0	25.0	75.0	77.8	68.4	4.3	0.0
W10	90.3	9.7	89.3	10.7	33.3	66.7	79.5	68.5	0.0	0.0
W11	80.7	19.4	88.0	12.0	0.0	100.0	69.5	64.7	19.4	0.0
W12	93.5	6.5	86.2	13.8	100.0	0.0	87.1	79.8	0.0	0.0
W13	93.5	6.5	93.1	6.9	0.0	100.0	85.7	65.9	0.0	0.0
W14	77.4	22.6	91.7	8.3	0.0	100.0	59.5	49.2	4.5	0.6
W15	83.9	16.1	76.9	23.1	20.0	80.0	69.3	49.9	2.0	0.3
W16	74.2	25.8	82.6	17.4	12.5	87.5	53.4	47.8	4.3	1.4
W17	80.7	19.4	72.0	28.0	16.7	83.3	72.2	45.1	6.4	2.8
W18	61.3	38.7	89.5	10.5	33.3	66.7	38.3	30.6	16.6	5.5
W19	77.4	22.6	62.5	37.5	42.9	57.1	61.9	49.0	7.5	1.1
W20	80.6	19.4	80.0	20.0	33.3	66.7	63.8	48.5	2.8	0.5
W21	77.4	22.6	79.2	20.8	14.3	85.7	58.8	47.4	3.8	0.0
W22	80.7	19.4	76.0	24.0	16.7	83.3	65.0	65.0	0.0	0.0
W23	100.0	0.0	80.6	19.4	0.0	100.0	100.0	83.3	0.0	0.0
W24	87.1	12.9	100.0	0.0	0.0	100.0	72.6	54.4	0.0	0.0
W25	77.4	22.6	83.3	16.7	0.0	100.0	58.1	49.5	3.2	2.4
W26	77.4	22.6	75.0	25.0	14.3	85.7	65.9	57.4	17.0	2.1
W27	87.1	12.9	85.2	14.8	75.0	25.0	75.8	54.1	1.6	0.0
W28	74.2	25.8	87.0	13.0	12.5	87.5	53.0	47.3	0.0	0.0
W29	90.3	9.7	71.4	28.6	0.0	100.0	80.6	71.7	0.0	0.0
W30	90.3	9.7	89.3	10.7	0.0	100.0	80.3	68.8	0.0	0.0
W31	87.1	12.9	88.9	11.1	0.0	100.0	74.6	69.6	0.0	0.0
W32	90.3	9.7	85.7	14.3	0.0	100.0	81.0	74.8	0.0	0.0
W33	93.5	6.5	89.7	10.3	0.0	100.0	86.3	69.0	0.0	0.0
W34	83.9	16.1	92.3	7.7	0.0	100.0	67.1	57.5	0.0	0.0
W35	80.6	19.4	80.0	20.0	0.0	100.0	69.1	63.3	12.9	1.9
W36	90.3	9.7	85.7	14.3	66.7	33.3	82.8	70.1	1.4	0.8
W37	77.4	22.6	91.7	8.3	14.3	85.7	65.5	55.7	13.6	2.5
W38	83.9	16.1	84.6	15.4	60.0	40.0	71.3	52.3	2.9	1.3
W39	64.5	35.5	85.0	15.0	18.2	81.8	47.3	22.3	15.6	7.8
W40	48.4	51.6	73.3	26.7	43.8	56.2	22.8	16.7	25.8	16.1
W41	54.8	45.2	47.1	52.9	50.0	50.0	40.2	22.3	28.3	15.3
W42	48.4	51.6	73.3	26.7	62.5	37.5	26.9	9.8	28.1	21.1
W43	29.0	71.0	55.6	44.4	54.5	45.5	10.6	4.5	53.3	35.5
W44	35.5	64.5	36.4	63.6	75.0	25.0	15.2	5.1	43.0	39.7
W45	22.6	77.4	42.9	57.1	66.7	33.3	7.5	5.4	71.4	43.9
W46	58.1	41.9	33.3	66.7	92.3	7.7	41.9	24.0	25.8	10.3
W47	58.1	41.9	72.2	27.8	61.5	38.5	33.2	23.5	16.8	7.2
W48	67.7	32.3	57.1	42.9	40.0	60.0	47.9	44.1	13.9	9.2
W49	77.4	22.6	70.8	29.2	42.9	57.1	63.5	59.1	15.1	7.5
W50	90.3	9.7	82.1	17.9	66.7	33.3	84.1	78.3	4.9	0.0
W51	93.5	6.5	93.1	6.9	50.0	50.0	87.1	..	0.0	..
W52	93.5	6.5	93.1	6.9	0.0	100.0	..	..	..	..

The agricultural operations like weeding, hoeing *etc.* can be carried out successfully. Since dry probabilities are high during *kharif* (23rd to 39th standard week), short duration crops of groundnut, pigeon pea, pearl millet, maize, sorghum, green gram, soya bean, sunflower, field bean, cowpea and other

less 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 crops can be harvested by the end of September (39th-40th SMW). The successive dry weeks indicate the need for

supplemental irrigation and suitable 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.

Since dry probabilities are high throughout the year, moisture conservation techniques such as mulching, use of anti-transpirants, effective control of weeds, adequate plant stands per square meter etc. helps in better crop production under moisture stress environment or dry spells periods and to mitigate the effect of drought during active growth period. Proper land leveling and grading would help to ensure easy and equal distribution of irrigation in the region. Using micro irrigation higher water application efficiency can be achieved. Contour farming, conservation tillage, trenching, mixed and intercropping and agro forestry techniques and addition of organic matter through residue management or green manures like sanai (*Crotalaria verrucosa*) and dhaincha (*Sesbania aculeate*) can conserve moisture, minimize evaporation losses and increase water holding capacity of soil and also fulfill the food, fuel, fodder and fiber needs of the local people to check migration during drought periods.

High rainfall, more wet weeks and delayed withdrawal of rainy season with high probability (73.4-95.3%) from 49th to 52th week could be utilized successfully for *rabi* crops. Since, North-East rainfall is certain and more even than South West monsoon, growing of high value *rabi* crops such as cotton, rice, sugarcane and vegetables would be highly profitable during 40th to 50th SMW. The significant contribution of weekly rainfall (>40 mm) during 42nd to 45th SMW and high consecutive wet week probability during 41th to 47th SMW hints for potential scope of harvesting excess runoff water for future supplemental irrigations.

4. CONCLUSIONS

Erratic rainfall distributions, frequent occurrence of early, intermittent and late season continuous dry spells are the characteristics of rainfall in Coimbatore region. Since dry probabilities are high during *kharif* (23rd to 39th standard week), *kharif* crop requires supplemental irrigation and hence short duration crops of groundnut, pigeon pea, pearl millet maize, sorghum, green gram, soya bean, sunflower, field bean, cowpea and other less water requiring crops which have high return value can be taken up. But the probability of occurrence of wet week is around 20% during 20th to 22nd week and average weekly rainfall is 10 mm, this pre-monsoon rain can be utilized for summer ploughing and initial seed bed preparations. Probabilities of dry, wet weeks, conditional probabilities of dry week preceded by a dry week, and wet week preceded by a wet week in Coimbatore region showed that the initial probability of getting dry spell is high during early part of the year and

the probability decreased with the progress of rainy season from 37th week onwards. The conditional probability of getting a wet week followed by wet week is also high from 35th week onwards. The possibility of taking summer crop is highly risky in Coimbatore region. The significant contribution of weekly rainfall and high consecutive wet week probability during 41th to 47th SMW indicated good scope for high value *rabi* crops of long duration.

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