Analysis of rainfall variability and Probability in Parbhani district (Maharashtra), India

ABSTRACT

Daily data of 30 years (1987-2016) was used to find rainfall variability & probability distribution, wet & dry weeks and incomplete gamma distribution analysis at Parbhani. The annual and seasonal rainfall data has analyzed statistically and different statistical parameters like mean, median, standard deviation, coefficient of variation, coefficient of skewness and kurtosis. Weekly initial and conditional probabilities of dry and wet spell for *monsoon* and *post-monsoon* rainy season for 20 mm, 40 mm, 60 mm and 80 mm for the 22nd to 48th SMW were determined, to obtain specific information needed for crop planning and for carrying out agricultural operations. The probability of occurrence of wet week preceded by another wet week is higher from 23rd to 39th SMW. Incomplete gamma probability distribution for weekly rainfall shows that there was 90% probability of getting an assured rainfall of at least 641.6 mm and more than 20 mm of rainfall could be expected during 24th to 36th and 38th SMW with 50 % probability, which shows thepotentiality for rain water harvesting. Therefore, it is required to create the means for the storage of rainfall that can be utilized in the hard time to meet the shortage of water.

Keywords: *Rainfall variability,Markov chain model, Initial and conditional probability, Incomplete gamma distribution.*

1. INTRODUCTION

The spatial and temporal variability of rainfall and its uneven and inadequate distribution determines the failure of crops especially in drought prone areas. The annual and seasonal analysis of rainfall will give general idea about the rainfall pattern of the region, whereas the monthly analysis of rainfall will be much use for agricultural planning is concerned. Probability analysis is great use in crop management practices. Markov chain probability model has been used extensively to find the long-term frequency behavior of wet and dry weather spells. Knowledge of the distribution of dry spells during the monsoon period is essential for successful rain fed farming. It is also important to know the chances of occurrence of dry spells during the critical stages of the crops for deciding the sowing date, cropping pattern and planning for protective irrigation and intercultural operations. The cropping pattern basically dependent on onset, withdrawal, probability of dry and wet periods and the moisture availability periods of monsoon area in region. (Khusre and Sing, 2012). Senthilvelanand *et.al*. (2012) used Markov Chain Model has been extensively to study dry wet spell distribution in Orathanadu region of Tamilnadu. For purpose of week period was considered as the optimum length of time. Vaidya V.B. *et. al.*(2008) analyzed the daily rainfall of different district of Gujarat to study the rainfall characteristics, onset and withdrawal of monsoon rain also the duration of getting assured rainfall. The contribution of south-west monsoon rainfall (June to September) was more than 90% in all regions of Gujarat state. The frequency analysis (at 50% probability) of weeks getting assured rainfall of either 10 mm or 20 mm rainfall revealed that in Kutch district there was not a single week while, it was maximum (16 weeks) in Valsad and Dangs districts. Rainfall of 20 mm per week is adequate for all the growth stages of all the crops grown. Thus, if in a given week the rainfall received is less than 20 mm that week can be designated as a dry week and vice versa (Pandharinath,1991).

Mandal K. G*et. al.* (2014) states that chances of occurrence of dry spells are high from the 1st –22nd SMW and again the 42nd SMW to the end of the year. The probability of 23rd–40th SMW varies between 62 and 100 % for the region. Results obtained through this analysis would be utilized for agricultural planning and mitigation of dry spells at the Daspalla region in Odisha, India. In order to stabilize crop production at a specific level, it is important to design an agriculture system on a scientific basis that makes the best use of a region's rainfall frequency analysis (Shetty *et al.,* 2000) This entails determining the order of a region's dry and wet spells in order to take the necessary steps to prepare a crop plan in rainfed areas (Srinivasa Reddy *et al.*, 2008). Farmers can be benefited from forecasting the dry and wet spells rainfall frequency analysis during SMW season for advanced crop planning models in future (Halder et al., 2016). Several researchers used this model to understand the possibility of rainfall pattern in dry and wet weeks Barron *et al.,* 2003; Deni *et al.,* 2010; Punitha *et al.,* 2017.

2. MATERIAL AND METHODS

2.1 Study area

Parbhani district comes under assured and moderate rainfall zone. Maximum amount of rainfall is received from South-West *monsoon*. Climatologically it comes under semi-arid, sub-tropical region and agro-climatologically identified as plain zone of Maharashtra. The geographic location is 19°16' N latitude and 76°46' E longitude with altitude 423.50 meters above mean sea level (MSL). It has an average rainfall of 963 mm, which is concentrated mostly during months from June to September i.e. from south-west *monsoon*. The remaining rainfall received during *post-monsoon* period from October to December (North-East *monsoon*).

2.2 Collection of Meteorological Data

Daily rainfall data collected from Department of Agricultural Meteorology, Vasantrao Naik Marathwada Agricultural University (VNMAU), Parbhani, for a period of 30 years (1987-2016) were used for the present study. Weekly rainfall values have been computed from daily values and were used for the present analysis.

2.3 Annual, Seasonal and Weekly Rainfall Analysis

The annual and seasonal rainfall data has analyzed statistically with different statistical parameters like mean, median, standard deviation, coefficient of variation, coefficient of skewness and kurtosis. Weekly rainfall analysis has been found to be more useful for better crop planning.

Mean for the series $\bar{X}$, $\frac{1}{N}\sum_{i=0}^{n} X\,i$

Variance of the series, $\sigma^2 \frac{1}{N-1}\sum_{i=1}^{N}(Xi - \bar{X})^2$

Standard deviation, $\sigma\sigma = \sqrt{\sigma^2}$

Coefficient of variation, $C_V = \frac{\sigma}{\bar{X}}100$

Skewness, $C_s \frac{N(N-2)}{N-1}\sum_{i=1}^{N}\left(\frac{Xi-\bar{X}}{\sigma}\right)^3$

Kurtosis, $C_k \left\{ \frac{N(N+1)}{(N-1)(N-2)(N-3)} \sum_{i=1}^{N} \left(\frac{Xi - \bar{X}}{C_s} \right)^4 \right\} - \frac{3(N-1)^2}{(N-2)(N-3)}$

2.4 Markov-Chain Probability model for Dry and Wet week analysis

It is useful to ascertain the probability of sequential events like a wet week following another wet week or a dry week following a wet or dry week during the crop growing season. In this process, weeks receiving 20 mm or more of rainfall are considered as wet and the remaining weeks as dry. On the basis of said criterion each week was categorized as a dry week and wet week with respective probabilities were calculated as follows:

(I) Initial Probability: $P(W_j) = \frac{F(W_j)}{N}$ and $P(D_j) = \frac{F(D_j)}{N}$

Where, $P(W_j)$ = Initial probability of j^{th} week being wet

$P(D_j)$ = Initial probability of j^{th} week being dry

$F(W_j)$ = Frequency of occurrence of j^{th} week being wet

$F(D_j)$ = Frequency of occurrence of j^{th} week being dry

N = Number of years of data used

(II) Conditional Probability:

$$P(WW_j) = \frac{F(WW_j)}{F(W_j)} \text{ And } P(DD_j) = \frac{F(DD_j)}{F(D_j)}$$

Where, $P(WW_j)$ = Probability of wet weeks preceded by another wet week in j^{th} week

$P(DD_j)$ = Probability of dry weeks preceded by another dry week in j^{th} week

$F(WW_j)$ = Frequency of wet weeks preceded by another wet week in j^{th} week

$F(DD_j)$ = Frequency of dry weeks preceded by another dry week in j^{th} week

Incomplete Gamma Probability Distribution

The incomplete gamma distribution probability analysis was done in accordance with that of (Kar S. K. *et. al.* 2015). The general formula for probability density function the gamma distribution is,

$$F(x) = \frac{\left(\frac{x-\mu}{\beta}\right)^{\gamma-1} \exp\left(-\frac{x-\mu}{\beta}\right)}{\beta\Gamma(\gamma)}$$

Where, š is the shape parameter, μ is the location parameter, β is the scale parameter and Γ is the gamma function which has the formula $\Gamma(a) = \int_0^\infty t^{a-1} e^{-t}\, dt$

The case where, μ=0 and $\beta = 1$ is called the standard gamma distribution and the equation for the same reduces to $\int(x) = \frac{x^{\gamma-1} e^{-x}}{\Gamma(\gamma)}$ $x \geq 0;\ \gamma > 0$

Since, the general form of probability functions can be expressed in terms of the standard distribution, all subsequent formulae in this section are given for the standard form of the function.

3. RESULTS AND DISCUSSION

3.1 Annual and Seasonal Rainfall

Total annual rainfall in the Parbhani district ranged between 569.7 (2014) and 1711 mm (1990) with an average of 949.8 mm. If rainfall received in a year was equal to or more than the average rainfall plus 1 standard deviation for 16 years of rainfall (i.e. 949.8+284.6=1234.4 mm), it was considered as excess rainfall year (Sharma and Kumar 2003). Only four years (1988, 1989, 1990 and 1998), had received rainfall of more than 1234.4 mm; these years were considered as excess rainfall years and remaining 26 years were considered as deficit rainfall years. It was also observed that 53.3 % (16 years) of the total years of rainfall were received below average (949.8 mm). Table 2, shows standard deviation is 284.6 mm with coefficient of variation 30 %. Median value was found 859.2 mm, which is close to average value of skewness is 1.11, which shows more variation in annual rainfall. Kurtosis value is found 0.85. Average seasonal rainfall i.e. (June to September) for Parbhani recorded 793.6 mm with standard deviation 285.2 mm.

Table 1: Annual and seasonal rainfall at Parbhani district (1987-2016)

Year	Annual rain (mm)	Monsoon Season rain (mm)	Contribution of seasonal rain to annual rain (%)
1987	819.0	614.1	75.0
1988	1564.9	1533.1	98.0
1989	1344.4	1269	94.4
1990	1711.0	1268.3	74.1
1991	742.6	700.7	94.4
1992	822.7	684.7	83.2
1993	792.7	681.1	85.9
1994	790.3	706.3	89.4
1995	848.7	621.4	73.2
1996	995.9	785.9	78.9
1997	970.3	527.2	54.3
1998	1463.0	1188.2	81.2
1999	952.8	854.8	89.7
2000	954.4	853	89.4
2001	1121.7	648.1	57.8
2002	864.6	746.4	86.3
2003	767.4	678	88.4
2004	680.6	400.8	58.9
2005	1155.5	1154.7	99.9

2006	994.6	837.2	84.2
2007	853.8	821.9	96.3
2008	711.1	572.4	80.5
2009	742.6	492.9	66.4
2010	1135.1	954.6	84
2011	677.5	616.8	91.0
2012	688.2	629	91.4
2013	1207.3	1017.1	84.2
2014	569.7	398.1	69.9
2015	574.8	406.3	70.7
2016	1159.5	963.7	83.1

Table 2:Statistical analysis of an annual and seasonal rainfall at Parbhani district (1987-2016)

1987-2016	Annual rainfall (mm)	Seasonal rainfall (mm)
Average (mm)	949.8	793.6
Median	859.2	703.5
SD	284.6	285.2
CV (%)	30.0	35.9
Skewness	1.11	0.82
Kurtosis	0.85	0.19

3.2 Weekly Rainfall analysis

Weekly average rainfall and its statistical characteristics were shown in Table 3, It is observed that maximum weekly average rainfall was received 80.2 mm in 30th SMW and minimum average weekly rainfall received 0.3 mm in 50th SMW. Variation found to be low in monsoon season. The rainy season spans between 22 to 43 SMW. During the rainy season, there are 20 weeks with the average rainfall of more than 20 mm. The CV varies from 302.63% during 22nd week to 290.54% during 43rd week. As we know, the CV of weekly rainfall should not exceed 150% (Senthilvelan et al., 2012) which shows erratic nature of rainfall in time. Whereas, CV of 24th to 39th week is less than 150 per cent. This showed that the successful crop production can be done during these weeks with an assured moisture regime. Highest value of skewness is found to be 5.48 in 51th SMW and lowest is 0.60 in 38th SMW, which shows more variation resulted in weekly rainfall. The highest kurtosis value is found to be 30 and lowest is -0.86 in 38th SMW.

Table 3. Average weekly rainfall at Parbhani (1987-2016)

Week	Average rainfall (mm)	SD	CV (%)	Skewness	Kurtosis
1	0.6	1.83	282.61	3.94	17.36
2	4.3	10.82	253.21	2.72	6.37
3	0.6	2.14	344.98	3.62	12.52
4	1.1	4.69	413.69	4.52	21.21
5	0.5	2.18	407.02	4.38	19.81
6	1.5	5.60	372.80	4.73	23.60
7	0.8	3.39	452.07	5.29	28.53
8	0.7	2.74	369.91	4.50	21.64
9	2.2	6.41	290.76	2.92	7.36
10	4.7	12.14	258.78	3.09	9.87
11	3.8	11.78	308.30	3.61	13.91
12	0.8	1.91	245.32	2.49	5.09
13	0.9	3.55	392.50	4.93	25.49
14	1.4	3.38	239.57	2.37	4.26
15	3.5	7.80	221.68	2.10	2.99
16	3.2	12.31	382.02	5.17	27.58
17	0.4	1.04	233.61	2.37	4.68
18	2.8	6.43	231.20	2.37	4.45
19	1.1	2.39	212.01	2.14	3.36
20	4.7	16.94	358.16	5.04	26.55
21	7.1	16.83	237.64	3.84	16.67
22	6.6	20.05	302.63	4.21	18.53
23	29.8	49.92	167.63	2.32	5.02
24	45.7	38.47	84.25	1.69	4.22
25	40.5	46.66	115.31	2.39	7.31
26	47.1	57.92	122.95	1.93	3.61
27	46.2	50.11	108.50	1.26	1.20
28	46.4	53.76	115.98	1.64	2.50
29	42.9	55.06	128.45	1.57	1.21
30	80.2	100.64	125.44	2.94	10.40
31	53.9	58.44	108.35	1.12	0.09
32	56.9	69.72	122.62	1.46	1.52
33	46.3	51.20	110.67	1.47	1.78

34	60.0	55.40	92.38	1.13	0.83
35	61.1	58.75	96.10	0.85	-0.25
36	48.5	42.16	86.94	0.79	-0.57
37	35.3	41.33	117.07	1.48	2.16
38	50.4	46.81	92.86	0.60	-0.86
39	26.5	36.33	137.33	2.01	4.08
40	34.4	64.30	186.73	3.44	14.11
41	21.9	36.26	165.83	1.79	2.54
42	17.1	33.83	198.17	2.60	6.84
43	10.4	30.22	290.54	3.12	8.97
44	4.5	10.03	222.14	2.50	5.57
45	6.2	14.08	228.75	2.40	4.85
46	3.6	8.48	234.66	2.54	5.56
47	9.7	19.60	202.30	2.36	5.42
48	3.9	19.73	506.71	5.42	29.56
49	4.0	12.63	318.77	3.24	10.04
50	0.3	0.96	336.56	3.58	11.88
51	0.8	4.38	547.72	5.48	30.00
52	0.5	1.79	392.21	4.01	16.01

3.3 Weekly Probability Analysis for 20-, 40-, 60- and 80-mmrainfall in Parbhani district

Maximum weekly initial rainfall probability (Wx) of getting 20 mm rainfall in *monsoon* season (22nd to 39th SMW) was 76.7% in 24th SMW and minimum probability was 6.7% in 22nd SMW. It may be noted from (figure 1) that the probability of occurrence of wet week (Wx) during *monsoon* season was high during 30th to 36th SMW at 20 mm rainfall probability level. Conditional probability for wet week followed by wet week (W/Wx) was more than 50% during 23rd to 38th SMW. In case of *post-monsoon* season (40th to 48th SMW) maximum initial rainfall probability of wet week (Wx) was 40% in 40th SMW Maximum conditional rainfall probability of wet week followed by wet week (W/Wx) was 58.3% in 40th SMW and minimum probability 0.0% during 45th to 47th SMW. Thus, farmers advised to provide irrigation to kharif crops as per the requirement. shown in (Fig. 1).

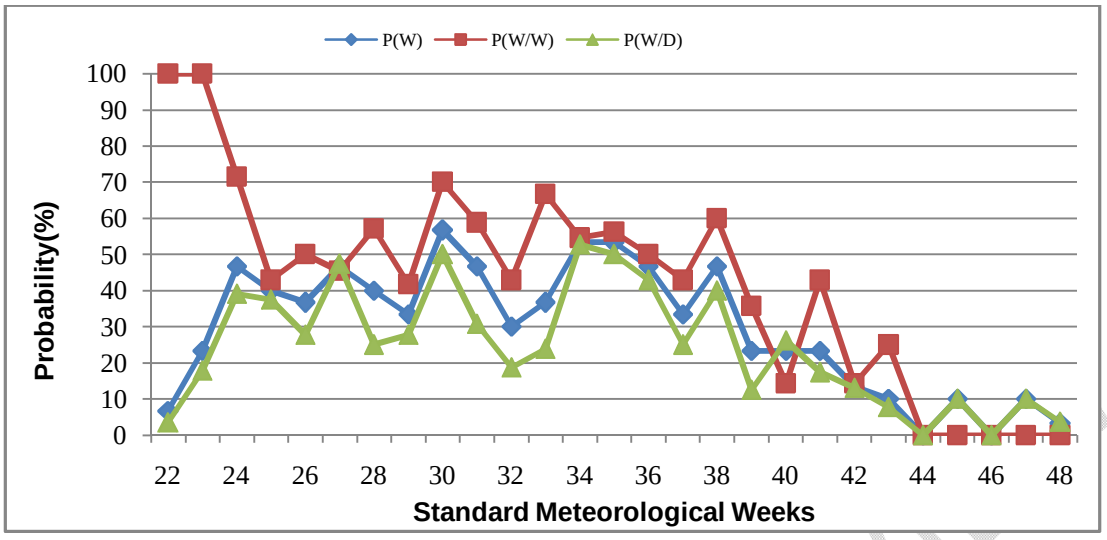

Fig. 1: Weekly probability (%) analysis for 20 mm rainfall in Parbhani during *monsoon* season (22nd to 39th SMW) and *post-monsoon* season (40th to 48th SMW)

The probability of occurrence of 40 mm rainfall was more than 50% during 30th, 34th and 35thSMW. Maximum conditional probability (W/Wx) was 100.0% in 22nd and 23rd SMW and minimum was 35.7% in 39th SMW. It indicates that kharif crops found to be good vegetative growth during 22nd and 23rd SMW. In case of *post-monsoon* season maximum probability for (Wx) was 23.3% in 40th and 41st SMW & Maximum conditional rainfall probability for (W/Wx) was 42.9% in 41st SMW (Fig. 2). Initial and Conditional probability Wx, W/Wx, W/Dx was less than 50% for getting 40mm rainfall during 40th to 48th SMW so farmers can grow short-season crops such as pulses, sorghum, maize, and millets during the Rabi season to produce a high yield while using less water and surviving drought conditions.

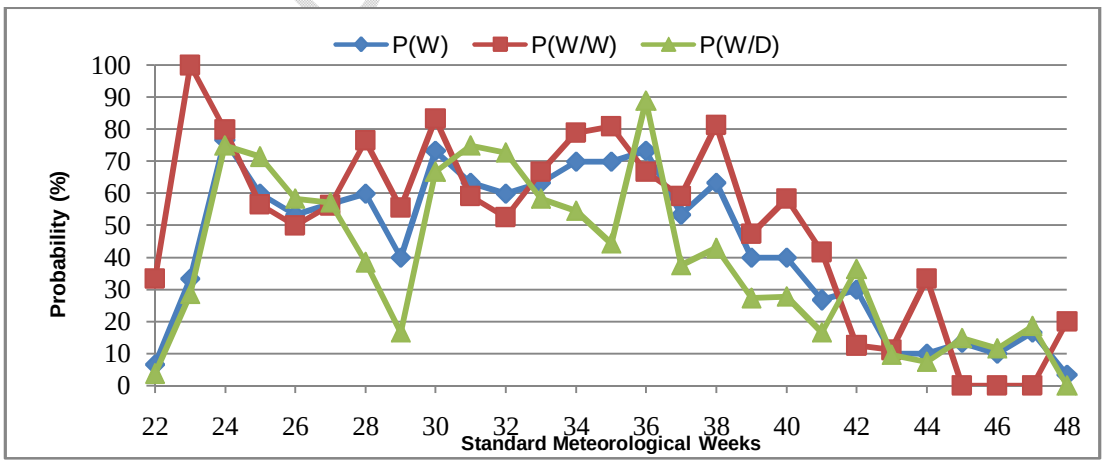

Fig. 2: Weekly probability analysis for 40 mm rainfall in Parbhani during *monsoon* season (22nd to 39th SMW) and *post-monsoon* season (40th to 48th SMW)

Maximum initial rainfall probability of wet week (Wx) of getting 60 mm rainfall was 53.3% in 30th SMW and minimum of 3.3% in 22nd SMW. Maximum conditional probability (W/Wx) for wet week was 100% in 23rd SMW and minimum 0.0% in 22nd SMW. Maximum probability of (W/Dx) was

52.2% during 30th SMW and minimum of 3.5% in 22nd SMW. In case of *post-monsoon* season, maximum probability for wet week (Wx) was16.7% during 40th and 41st SMW. Maximum conditional rainfall probability for (W/Wx) was 25% in 40th SMW and minimum of 0.0% during 41st and 43rd to 48th SMW. Fig. 3.

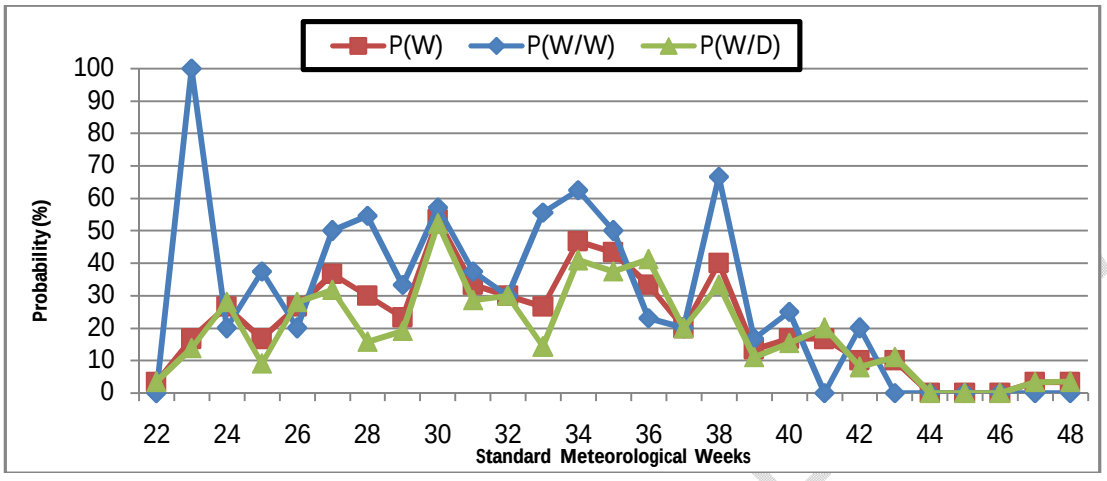

Fig. 3: Weekly probability analysis for 60 mm rainfall in Parbhani during *monsoon* season (22nd to 39th SMW) and *post-monsoon* season (40thto 48th SMW)

Maximum percentage of initial rainfall probability (Wx) of 80 mm rainfall in *monsoon* season was 36.7% in 30th SMW and minimum 3.3% in 22nd SMW. Maximum probability of (W/Wx) was found 10% in 23rd SMW and minimum 0.0% in 22nd SMW. Maximum probability percentage of (W/Dx) was 36.0% (30th SMW) and minimum of 3.5% in 22nd SMW. In case of post-*monsoon* season, maximum initial rainfall probability for wet week (Wx) was 16.7% in (40th SMW) and minimum of 0.0% during 44th to 46th SMW) and Maximum conditional rainfall probability for (W/Wx) was 3.3% during 40th and 42nd SMW) and minimum of 0.0% during 41st to 48th SMW except 42nd SMW and maximum probability of (W/Dx) was 14.8% in 40th SMW and minimum 0.0% during 44th to 48th SMW shown in (Fig. 4).

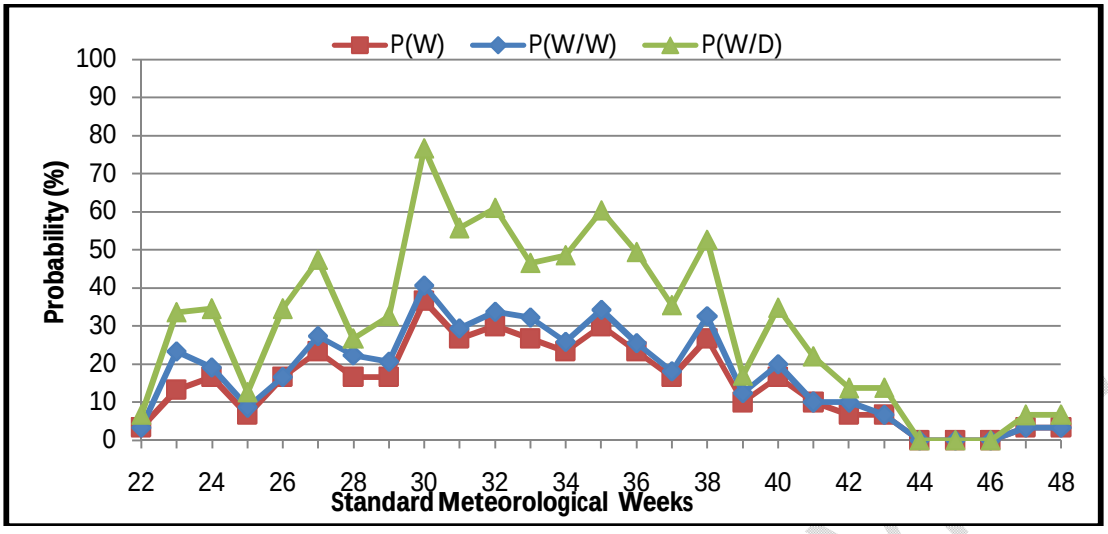

Fig. 4: Weekly probability analysis for 80mm rainfall in Parbhani during *monsoon* season (22nd to 39th SMW) and *post-monsoon* season (40th to 48th SMW)

3.4 Incomplete Gamma Probability Distribution for Weekly Rainfall in Parbhani district

The incomplete gamma probability distribution for weekly rainfall at Parbhani indicated that, more than 20 mm of rainfall could be expected during 24th to 36th and 38th SMW with 50 % probability, which shows the potentiality for rain water harvesting. At 75 percent probability at least 3 mm per week was expected during 23th to 40th SMW which indicates potentiality for crop growing in dry land areas. Whereas, with 25 per cent probability, the expected rainfall of more than 20 mm was observed from 23th to 42th SMW (Table- 4).

Table 4: Incomplete gamma probability distribution for weekly rainfall at Parbhani district (1987-2016)

Week	90%	75%	50%	25%	10%
1	0.5	0.8	1.4	2.2	3.1
2	0.2	0.8	2.8	7.2	13.7
3	0.4	0.7	1.3	2.2	3.2
4	0.2	0.6	1.5	3	4.9
5	0.4	0.7	1.3	2.1	3
6	0	0	1.5	6.3	9.8
7	0	0	0.8	4.1	6.3
8	0	0	0.7	3.7	5.5
9	0.2	0.7	2	4.4	7.9
10	0.1	0.7	2.9	7.7	15

11	0.1	0.6	2.4	6.5	12.7
12	0.4	0.8	1.5	2.4	3.5
13	0.3	0.7	1.5	2.6	4.1
14	0.3	0.8	1.8	3.3	5.3
15	0.2	0.8	2.6	6.2	11.4
16	0.2	0.7	2.4	5.8	10.8
17	0.6	0.9	1.3	1.9	2.5
18	0.2	0.8	2.4	5.3	9.5
19	0.4	0.9	1.7	2.9	4.4
20	0.1	0.7	2.9	7.7	15.1
21	0.2	1.2	4.2	11	21
22	0.2	0.9	3.7	10.2	20.3
23	0.6	3.4	14.6	41	82.5
24	7	16.3	34.8	64.4	102
25	3.6	10.7	27.5	57.5	98
26	3.2	10.7	30.1	66.5	117
27	2.3	8.9	27.7	64.9	118.1
28	2.2	8.7	27.4	65	119.1
29	2.4	8.7	26.3	60.4	108.9
30	7.1	21	54	112.6	191.7
31	2.7	10.4	32.3	75.5	137.4
32	3.2	11.6	34.8	79.7	143.3
33	3.6	11.3	30.5	65.4	113.3
34	5.9	16.7	41.5	84.5	141.9
35	2.9	11.4	36	85.3	156.2
36	5.4	14.5	34.6	68.6	113.4
37	1.2	5.6	19.6	49.4	93.7
38	3	10.6	31.3	70.9	126.7
39	0.8	4	14.5	37.3	71.3
40	0.5	3.6	16	46.8	96
41	0.3	1.9	9.6	29.8	63
42	0.2	1.3	7.2	23.3	50.2
43	0.1	0.7	4.2	14.4	32.1
44	0.2	0.9	3	7.5	14.2
45	0.1	0.8	3.4	9.6	19.1
46	0.2	0.8	2.6	6.3	11.7

47	0.2	1	4.8	14.1	29
48	0.1	0.5	2.2	6.5	13.3
49	0.1	0.6	2.4	6.6	13.3
50	0.6	0.8	1.2	1.6	2.1
51	0.3	0.6	1.3	2.5	4
52	0.4	0.7	1.2	1.9	2.8
Annual	**641.6**	**782.1**	**961.2**	**1165.9**	**1372.9**

4. CONCLUSION

The Markov chain model concludes that the probability of occurrence of wet week preceded by another wet week is higher during 23rd to 38th SMW because of the *monsoon* season. Whereas, in *post-monsoon* season the probability of occurrence of dry week preceded by another dry week is higher as there is less rainfall or no rainfall recorded. Due to the long dry spells, drought has found which shows serious impact on crop growth and development, water availability, socioeconomic factors and environmental problems. It is required to create the means for the storage of rainfall that can be utilized in the hard time to meet the shortage of water. farmers can grow short-season crops such as pulses, sorghum and millets during the Rabi to produce a high yield while using less water and surviving drought conditions.

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