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Research Article

Rainfall Probability and Variability Analysis for Crop Planning in Scarcity Zone of Western Maharashtra

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ABSTRACT

A detailed statistical analysis of rainfall data of Baramati, located in the scarcity zone of western Maharashtra was carried out using 33 years (1986 to 2018) of daily data for crop planning. Incomplete gamma distribution was used to calculate the assured rainfall at 25, 50, 75 and 90% probability levels. Markov chain probability model was used to calculate the initial, conditional and consecutive probabilities of dry and wet spells considering a threshold of 20 mm for weekly rainfall. The average annual rainfall of Baramati was found to be 571.2 mm with a coefficient of variation of 25.4%. The average onset week of the rainy season is 26th standard meteorological week (SMW), which makes 25th SMW an optimum time for sowing *kharif* crops in the region. During the rainy season (26 - 41st SMWs), the expected weekly and total assured rainfalls were 2.5 and 15 mm at 90% probability level. The probability of getting dry and consecutive dry spells at the early and middle stages of the rainy season was high, indicating the need for *in-situ* moisture conservation and supplemental irrigations. During 36 - 40th SMWs the probability of getting wet and consecutive wet spells was high, coinciding with the grand growth period of the major *kharif* crops grown in the region. The crop water requirement can be met by rainfall during this period and excess water needs to be harvested. Findings of this study can be helpful in crop planning, agro advisories and efficient water management in the region.

Key words: Markov Chain Model, Gamma distribution, Rainfall, Probability

Introduction

Rainfall is one of the most important climatic factors in crop production, particularly in rainfed agriculture. Weather variability due to changing climate is increasing and will continue to increase in the near future (IPCC, 2022). The occurrence of frequent dry spells or breaks in monsoon rainfall is a common phenomenon resulting in early, mid and late-season agricultural droughts. In the cropping calendar of plants, the timing of breaks in rainfall (dry spells) is more critical for crop viability than total seasonal rainfall. The dry spells within crop season, play vital role in determining productivity of rainfed crops (Bal *et al*., 2022). Bedane (2022) reported that the amount of rainfall and its distribution in a rainy season is critical for crop production. In agricultural planning, rainfall variability analysis aids to take farm decisions on time of sowing, inter culture operations, fertilizer application and other agricultural operations. The rainfall probability analysis assists in estimating the probability of intra-seasonal dry and wet spell. Sequence of dry and wet periods are utmost important for crop planning and agricultural operation (Singh *et al.*, 2016). The probability analysis of the occurrence of initial, conditional and consecutive probabilities may be utilized to minimize

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risk factors due to weather aberrations in crop cultivation and planning irrigation management. The Markov chain model has been extensively used to study the probabilities of rainfall occurrence (Swetha *et al.*, 2015; Dabral *et al.,* 2019; Dash *et al*., 2020). In studies, different researchers have suggested crop planning considering rainfall at different probability levels (Mandal *et al.*, 2015; Hirapara *et al.*, 2020).

The effect of changing climate is significantly seen in the long-term climate data of Maharashtra (Singh *et al.,* 2021a, b). The LPA of average annual rainfall in the western scarcity zone of Maharashtra is around 575 mm, which is restricted mainly to the southwest and retreating monsoon (Singh *et al.,* 2021c). Because of low rainfall, the soils in the area are shallow and poorly developed. Major agricultural lands are rainfed except for a small portion which is canal irrigated and mainly supports sugarcane. Agricultural drought is a common phenomenon in the area. In this scenario, rainfall probability and variability analysis become essential to ensure crop planning and water management in canals. With the above background, the present study aims to investigate the initial, conditional and consecutive probabilities of dry and wet spells along with variability analysis of long-term rainfall in the scarcity zone of western Maharashtra in crop planning.

Materials and Methods

Data used and basic statistics

The daily rainfall data of 33 years (1986-2018) was used for the analysis. The data was recorded in meteorological stations located in Baramati, Pune. Climate of Baramati is arid to semi-arid and it comes under the scarcity zone of western Maharashtra. The above daily rainfall data for 1986-2010 was collected from Meteorological station of Maharashtra State Irrigation Department Office, Malegaon Colony, Baramati located at 18°13′ N latitude and 74°54′ E longitude while the data for 2011-2018 was collected from ICAR-National Institute of Abiotic Stress Management, Malegaon, Baramati located at 18°09′ N latitude and 74°30′ E longitude. The daily rainfall data was converted and analysed on weekly, monthly, seasonal and annual scales. Basic statistical parameters like, mean, standard deviation (SD), skewness (CS) and kurtosis (CK) of rainfall were determined. Whisker’s-box plot was used for visualizing the median, interquartile range and outliers in the rainfall data. The rainfall variability was studied using the coefficient of variation (CV). Rainfall events with CV > 30 are classified as events with high rainfall variability (Asfaw *et al*., 2018).

Onset and withdrawal of rainy season

The onset and withdrawal of rainy season was computed from weekly rainfall data using forward and backward accumulation methods, respectively (Joseph *et al.*, 2017; Singh *et al*., 2019). In this method, weekly rainfall was summed by forward accumulation (20+21+…+52 weeks) until a certain amount of rainfall was accumulated. 75 mm of rainfall accumulation has been considered as the onset time for the land preparation and growing of dry seeded crops season in rainy season (Mandal *et al.,* 2015). The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+…+30 weeks) data. 20 mm of accumulation of rainfall was chosen for the end of rainy season (Mandal *et al.*, 2015), which may be sufficient for ploughing of fields after harvesting of crops.

Assured rainfall

Assured rainfall is the amount of rainfall received at different probability levels. In this study, it was computed in accordance with that of Kumar *et al.* (2015) and Ganchaudhuri *et al.* (2022) with the general formula for the probability density function as,

$$f(x) = \frac{\left(\frac{x-u}{\beta}\right)^{\gamma-1} exp\left(\frac{x-u}{\beta}\right)}{\beta\Gamma(\gamma)} \quad x \geq \mu; \gamma, \beta > 0$$

where, γ is the shape parameter, μ is the location parameter, β is the scale parameter and Γ is the Gamma function which is given by the formula:

$$\Gamma(a) = \int_0^\infty t^{a-1} e^{-t} dt$$

The case where, μ = 0 and β = 1 is called the standard Gamma distribution and the equation for the same reduces to:

$$f(x) = \frac{x^{\gamma-1}e^{-t}}{\Gamma(\gamma)} \quad x \geq 0;\ \gamma > 0$$

Using the above standard formulas, the assured rainfall at 25, 50, 75 and 90% probabilities were calculated for the rainfall data of 1986-2018.

Initial and conditional probabilities of rainfall

Initial probability indicates the minimum amount of rainfall to be expected for particular time series of data. Initial probability analysis was carried out using first order Markov-chain model as suggested by Dabral *et al.* (2014). In the study, weekly rainfall data of 33 years were considered at the threshold limit of 20 mm of weekly rainfall. A week is considered as a dry week when rainfall is less than 20 mm in a week and when rainfall is more than 20 mm it is a wet week (Joseph *et al.*, 2017; Manikandan *et al.*, 2017). Rainfall probability for a week is termed as initial probability and the probability of a given week either wet P (W) or dry P (D) were calculated by the following formulae (Kumar *et al.*, 2015; Hirapara *et al.*, 2020):

$$P(D_x) = \left[\frac{F(D_x)}{N}\right]$$

$$P(W_x) = \left[\frac{F(W_x)}{N}\right]$$

where,

$F(D_x)$: Number of years with rainfall < 20 mm during 'xth' week

$F(W_x)$: Number of years with rainfall >20 mm during 'xth' week

N: Number of years of data

Conditional probability indicates the probability level at which a particular amount of rainfall is expected for a particular place over a specific time-series data. Considering the previous period, rainfall probability for a week is defined as conditional probability. The conditional probability of a wet week (W) preceded by a wet (W) or dry (D) week is abbreviated as P(WW) and P(WD), respectively while the conditional probability of a dry week preceded by a wet or dry week as P(DW) and P(DD), respectively were determined by the following formulae (Rai *et al.*, 2014):

$$P(WW_x) = \left[\frac{F(WW_x)}{F(W_x)}\right]$$

$$P(DD_x) = \left[\frac{F(DD_x)}{F\ (D_x)}\right]$$

$$P(WD_x) = 1 - P(DD_x)$$

$P(DW_x) = 1 - P(WW_x)$; where,

$F(WW_x)$: No. of years getting rainfall > 20 mm in 'xth' and the next week

$F(DD_x)$: No. of years getting rainfall < 20 mm in 'xth' and the next week

$P(DD_x)$: Conditional probability of getting rainfall < 20 mm durin 'xth' and the next week

$P(WW_x)$: Conditional probability of getting rainfall > 20 mm in 'xth' and the next week

$F(D_x)$: Number of years with rainfall < 20 mm during 'xth' week

$F(W_x)$: Number of years with rainfall > 20 mm during 'xth' week

Consecutive probabilities of rainfall

The probabilities of occurrence of two or three consecutive dry weeks is abbreviated as P (2D) or P (3D), respectively while the probabilities of occurrence of two or three consecutive wet weeks is abbreviated as P (2W) or P (3W) , respectively were calculated using the formula (Rai *et al.*, 2014; Hirapara *et al.*, 2020):

$$P(2D) = P(Dw_1)\ \times\ P(DDw_2)$$

$$P(3D) = P(Dw_1)\ \times\ P(DDw_2) \times\ P(DDw_3)$$

$$P(2W) = P(Ww_1)\ \times\ P(WWw_2)$$

$$P(3W) = P(Ww_1)\ \times\ P(WWw_2)\ \times\ P(WWw_3);$$

where,

$P(Dw_1)$: Probability of week being dry i.e. rainfall < 20 mm (first week)

$P(Ww_1)$: Probability of week being wet i.e. rainfall > 20 mm (first week)

$P(DDw_2)$: Probability of second consecutive week being dry given the preceding week dry

$P(DDw_3)$: Probability of third consecutive week being dry given the preceding week dry

$P(WWw_2)$: Probability of second consecutive week being wet given the preceding week wet

$P(WWw_3)$: Probability of third consecutive week being wet given the preceding week wet

Results and Discussion

Rainfall characteristics

Preliminary analysis and rainfall variability

Descriptive statistical parameters including mean, standard deviation (SD), coefficients of variation (CV), skewness (CS), and kurtosis (CK) of monthly, seasonal and annual rainfall of Baramati over the period of 1986-2018 are summarized in Table 1. The mean monthly rainfall was maximum in September. The long period average (LPA) of annual rainfall was 571.2 mm. Out of this, 0.3%, 9%, 71%, and 19% of rainfall were obtained in winter, pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 1). The long-term seasonal and annual rainfall variations are depicted in Fig. 1. The LPA of rainfall variability was very high (>30) in all months, seasons and annual rainfall. Notched box plots were applied to get an overall picture of the monthly, seasonal and annual rainfall variations. Notched boxplots showing the median, 1st and 3rd quartiles, possible outliers, the minimum and the maximum data points are shown in Fig. 2. Highest interquartile range (IQR) values in monthly rainfall were recorded in September (170.8 mm). The highest seasonal IQR was recorded in monsoon with values of 217 mm. The IQR of annual rainfall was 215.6 mm. Also, the boxplots show a relative comparison of rainfall intensity. Box plots and CS values (Table 1) indicate that the rainfall data was positively (right) skewed. Another important finding from boxplots is the presence of several outliers in the rainfall time series. It can be inferred that extreme rainfall events occurred from 1986–2018.

Onset and end of rainy season

The data on onset, withdrawal and duration of the rainy season (difference between onset and withdrawal time) and its variability in Baramati are

Table 1. Rainfall characteristics of monthly, seasonal and annual rainfall at Baramati during 1986-2018.

Month/Season	Mean (mm)	SD	CV	CS	CK
Jan	0.7	2.6	392.7	4.0	17.9
Feb	1.3	4.5	359.0	4.2	21.0
Mar	5.8	14.8	256.2	4.1	20.7
Apr	7.5	13.3	176.4	2.7	9.9
May	39.4	46.2	117.2	1.7	6.1
Jun	109.1	74.4	68.2	1.1	4.0
Jul	65.0	43.7	67.1	0.8	2.7
Aug	70.3	63.1	89.8	1.4	4.9
Sep	161.4	106.3	65.9	0.5	2.1
Oct	92.0	81.5	88.6	1.1	3.6
Nov	12.9	21.4	165.9	2.6	9.5
Dec	5.8	16.5	285.7	3.4	13.2
Winter	1.9	5.1	262.6	3.1	12.7
Pre-monsoon	52.8	57.6	109.1	1.7	5.7
Monsoon	405.8	158.8	39.1	0.4	2.5
Post-monsoon	110.7	98.4	88.9	1.4	4.5
Annual	571.2	209.9	36.7	0.6	3.5

SD: Standard Deviation, CV: Coefficient of variation, CS: Coefficient of Skewness, CK: Coefficient of Kurtosis.

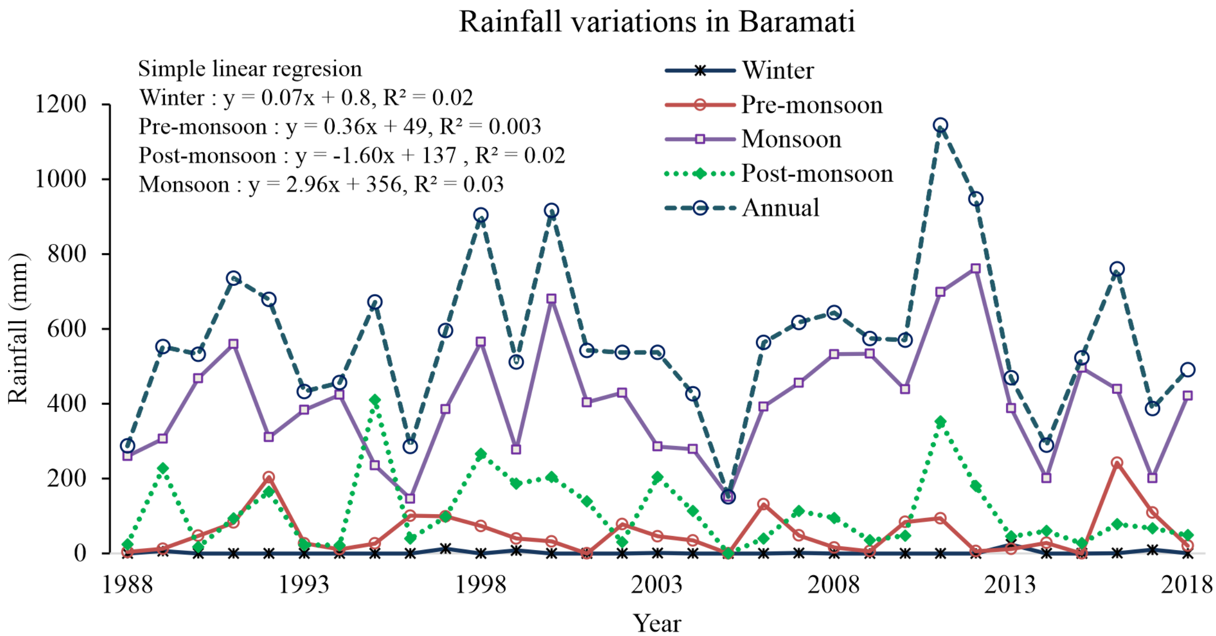

Fig. 1. Mean distribution of a) winter b) pre-monsoon c) monsoon d) post-monsoon and e) annual rainfall at Baramati

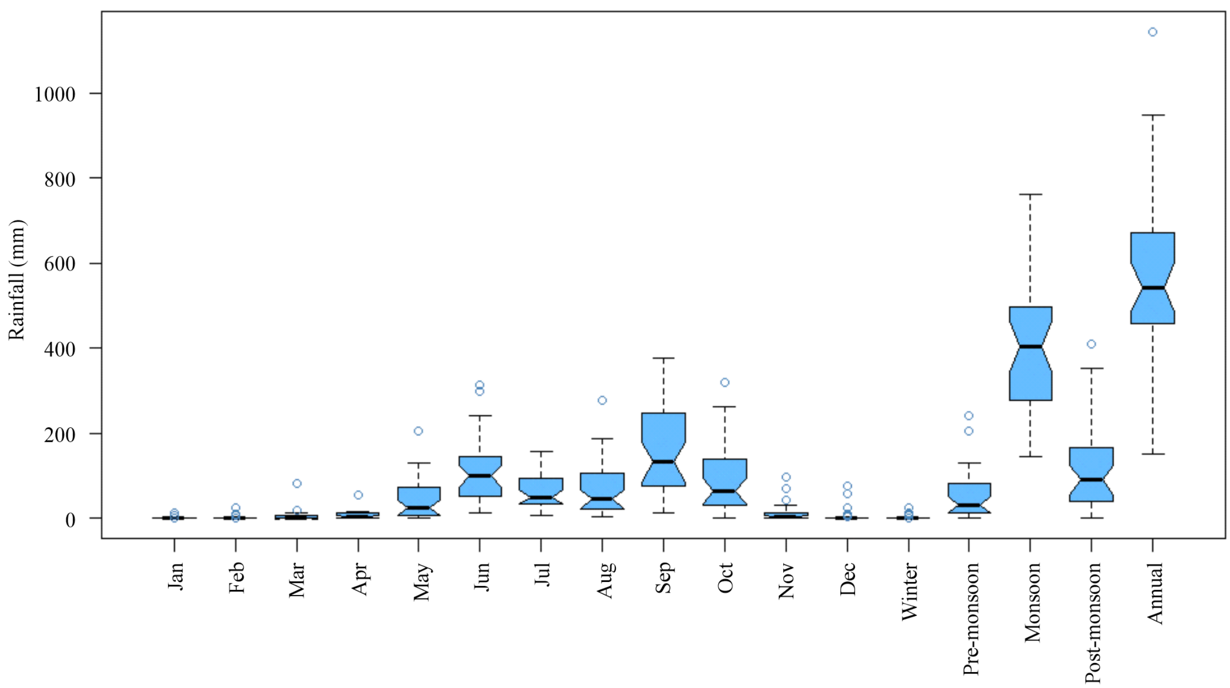

Fig. 2. Temporal variations of monthly, seasonal and annual rainfall at Baramati

presented in Table 2. The earliest start of rainy season occurred during 23rd SMW (4 - 10 Jun) and the latest by 32nd SMW (6 - 12 Aug.). The normal start of the rainy season was found to be in 26th SMW (25 June - 1 July). The probability of onset of rainy season by 24th SMW was 52%, which indicates that by this week the rainy season can be expected to start in every alternate year. The normal withdrawal of rainy season was by 41st SMW (8 - 15 Oct). Therefore, the mean length of the rainy season was found to be 16

Table 2. Rainy season onset, withdrawal, quantum and duration of rainfall at Baramati during 1986-2018

Year	Onset (SMW)	Withdrawal (SMW)	Monsoon Rainfall (mm)	Duration (Weeks)
1986	25	39	261.4	14
1987	29	42	306.3	13
1988	30	39	468.0	9
1989	23	40	559.5	17
1990	24	43	223.9	19
1991	23	40	380.4	17
1992	24	39	425.7	15
1993	27	42	235.2	15
1994	29	40	193.1	11
1995	26	41	378.0	15
1996	24	43	565.4	19
1997	24	43	277.2	19
1998	23	42	680.8	19
1999	26	41	399.8	15
2000	23	41	429.2	18
2001	31	41	285.8	10
2002	24	42	278.7	18
2003	24	34	151.4	10
2004	24	40	392.4	16
2005	26	42	455.4	16
2006	25	40	534.4	15
2007	24	38	533.5	14
2008	32	41	438.6	9
2009	23	41	678.2	18
2010	24	43	761.5	19
2011	24	41	334.0	17
2012	30	40	137.0	10
2013	24	40	471.2	16
2014	30	41	439.4	11
2015	25	40	201.1	15
2016	23	40	421.4	17
2017	26	41	645.8	15
2018	25	38	233.1	13
Avg.	26	41	399.3	15

weeks (112 days) in the study area. The probability of withdrawal of rainy season on 40th or beyond was was 82%. The shortest and longest duration of the rainy season were 9 and 19 weeks, respectively.

Weekly mean and assured rainfall

Weekly mean rainfalls were computed along with assured rainfall. Assured rainfall was calculated using incomplete gamma distribution at various probability levels (25, 50, 75 and 90%) and the results are depicted in Fig. 4. Weekly mean rainfall was more than 20 mm in 11 SMWs and the highest value of 48.1 mm was observed in 37th SMW. During 37 - 40th SMWs weekly mean rainfall remained higher than 40 mm. At 90% and 75% probabilities, the expected weekly rainfall during the rainy season (26

- 41st SMWs) was less than 2.5 and 10 mm, respectively. Assured rainfall, at 90% and 75% probabilities in the rainy season are only 15 and 62.6 mm, respectively, which added uncertainty factor in the production of rainfed crops. The highest rainfall amount expected at 75 percent probability is 8 mm which occurs in 38th SMW. During 22 - 25th, 28 - 31st and 35 - 40th SWMs at least 3 mm per week can be expected at 75% probability, indicating the potentiality for crop growth in dryland areas. However, at 50% probability, which means on every alternate year basis, there was definite rainfall receipt of more than 10 mm per week during 22nd - 25th SMWs, while during 37 - 40th SMWs more than 20 mm rainfall per week can be expected (Fig.4). This analysis will be helpful for planning farming operations and agro-advisories.

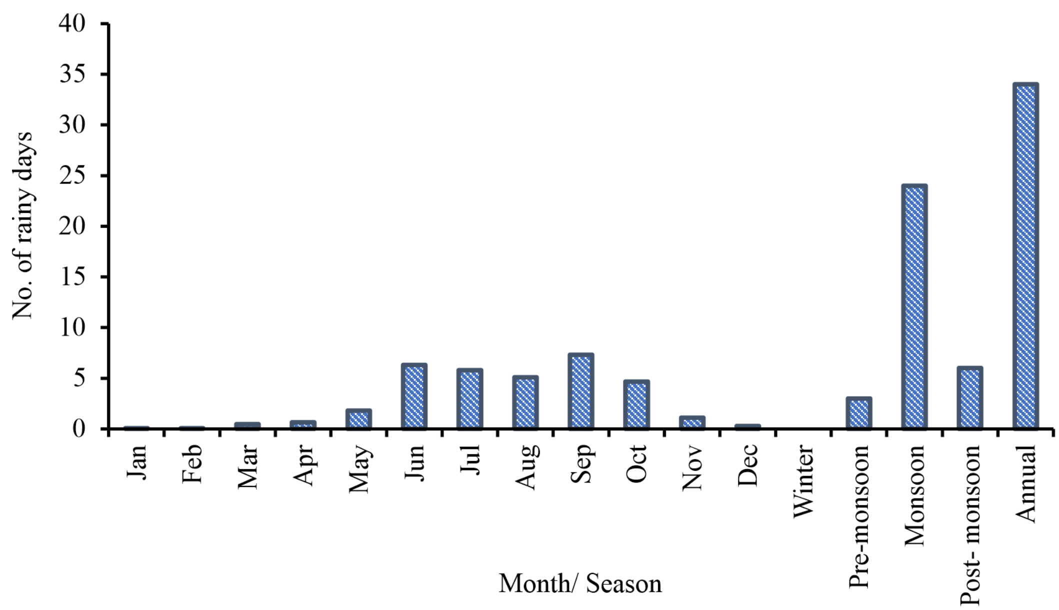

Fig. 3. Temporal variations in monthly, seasonal and annual rainy days at Baramati

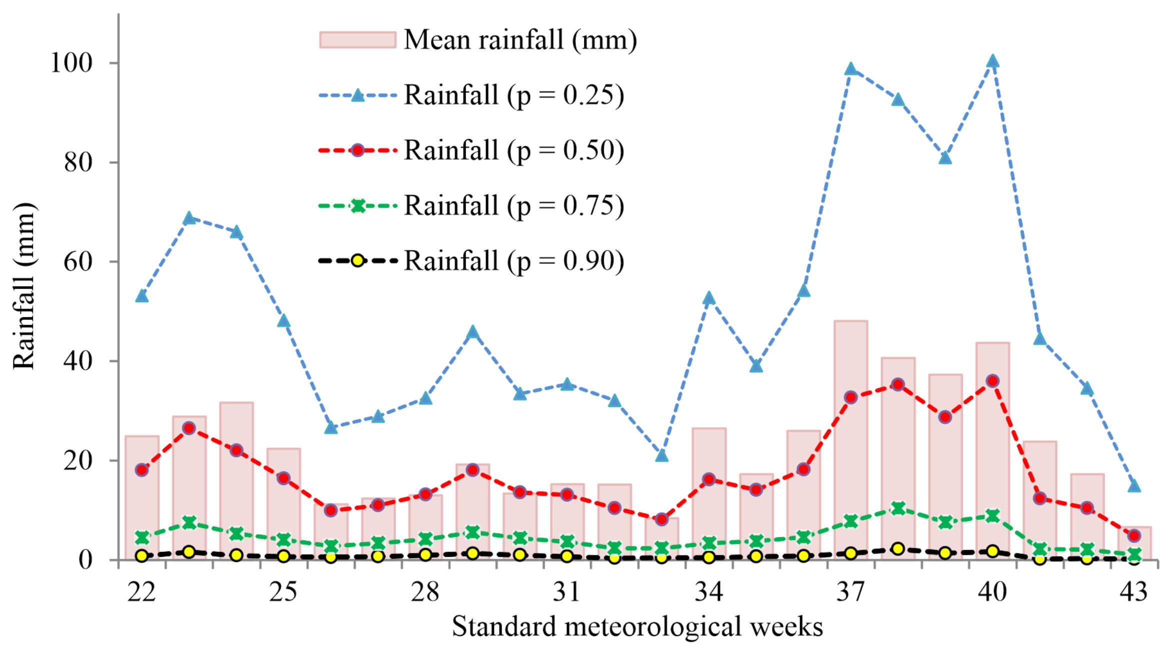

Fig. 4. Weekly mean and assured rainfall (at p = 0.25, 0.50, 0.75 and 0.90) at Baramati

Initial and conditional weekly rainfall probabilities

Initial and conditional probabilities of dry and wet week calculated for Baramati and the results in relevant only to the rainy season are discussed (22 - 43rd SMWs). During 36 - 40th SMWs the probability of getting wet spells (P(W)) were high due to heavy downpour during retreating monsoon. Only three SMWs (38, 39 and 40th) showed a probability higher than 50% for 20 mm rainfall. Similar patterns were also observed for conditional probabilities of wet week proceeded by wet (P(WW)) or dry week (P(WD)) (Fig.5a). The probabilities of occurrence initial dry weeks (P(D)) were high during 28 – 33rd SMWs. Similar patterns were also observed for conditional probabilities of dry week proceeded by dry (P(DD)) while for conditional probabilities of dry week proceeded by wet (P(DW)) were higher than 50% during 30-34th SMWs (Fig.5b).

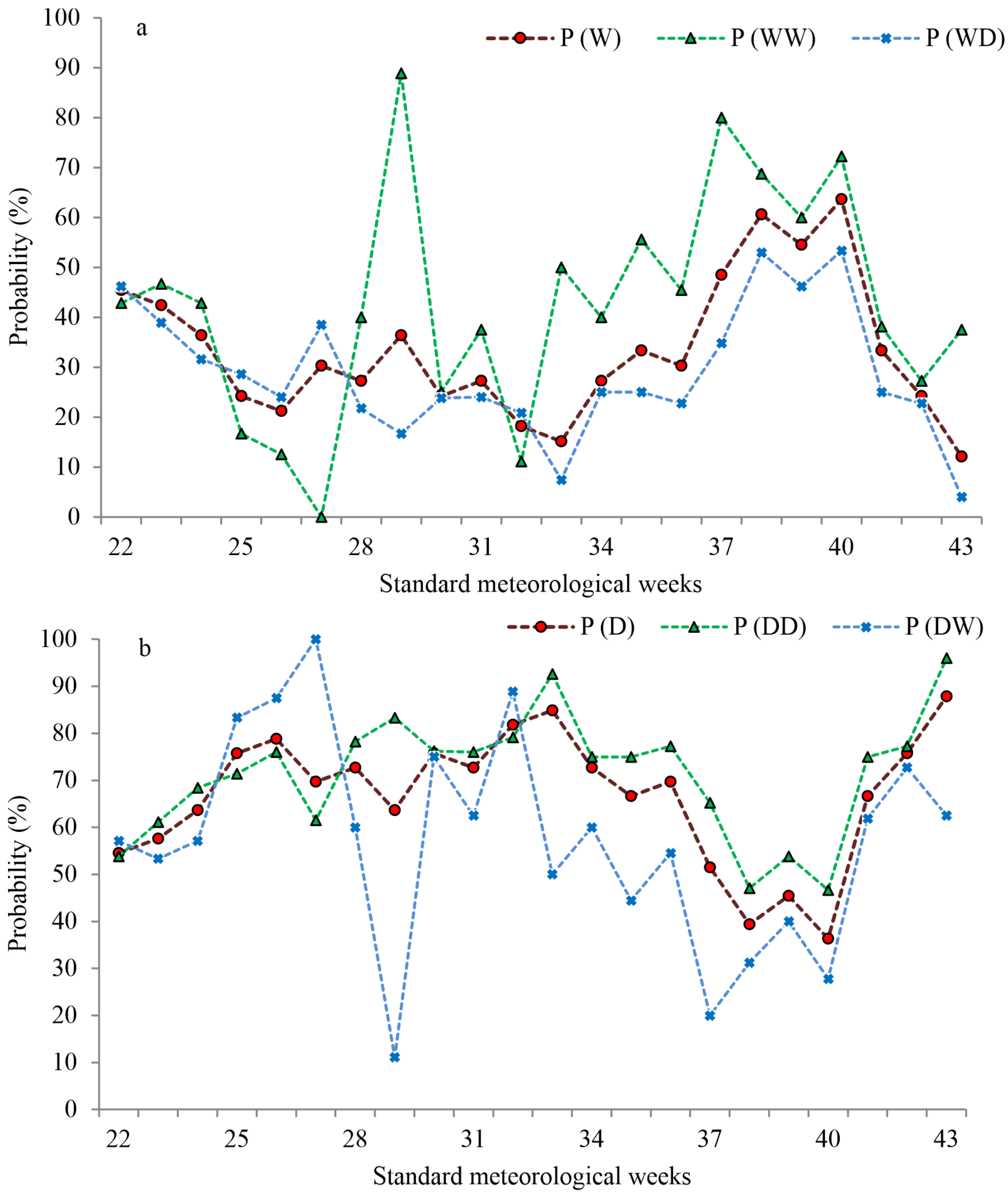

Fig. 5. Initial and conditional probabilities of rainfall for different combinations of wet and dry weeks at Baramati

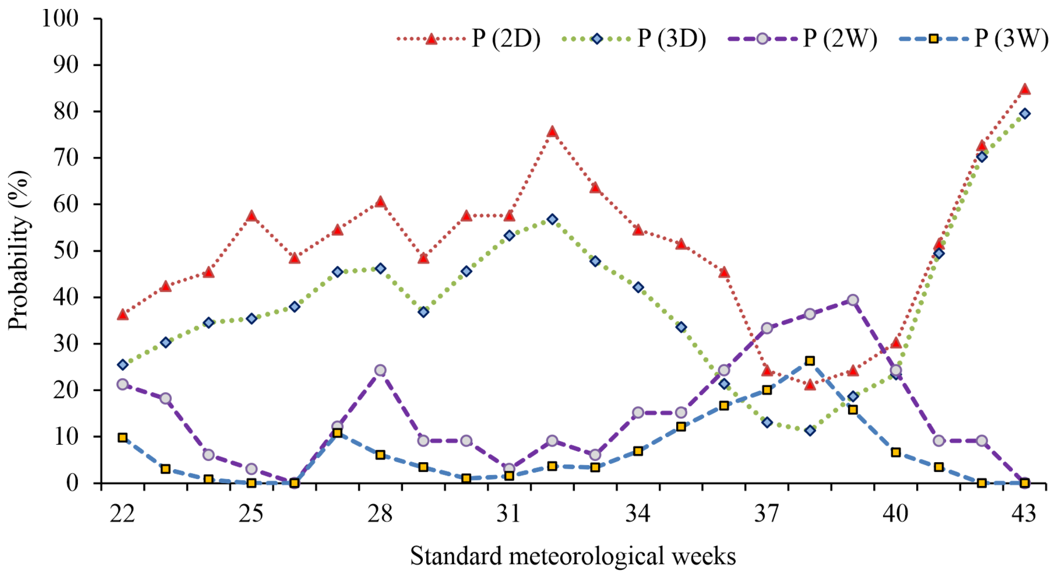

Fig. 6. Consecutive dry and wet week probabilities of rainfall at Baramati

Consecutive dry and wet week probabilities

The probabilities of occurrence of two and three consecutive wet and dry weeks for 20 mm of rainfall limit are given in Fig. 6. Probability of two consecutive weeks being wet (P (2W)) was higher during 37-39th SMWs in the ranges from 33 -39%. The probability of three consecutive wet weeks (P(3W)) was less than 15% during 29-35th SMW. The probabilities of occurrence of two consecutive dry weeks (P(2D)) were higher since the start of rainy season from 23 - 36th SMWs and ranges between 40-75%, while the probabilities of occurrence of three consecutive dry weeks (P(3D)) were higher than 50% during 31-32nd SMWs which means during this period almost in every alternate year, there is definite dry spell receiving less than 20 mm of rainfall per week. If the rainfall is less than 20 mm/week for two or more consecutive weeks, the crops are likely to be subjected to moisture stress in the absence of adequate stored soil moisture. In-situ soil-moisture conservation is a vital component of crop management during dry spell. In case of long dry spells, specific contingency plans are needed for a crop-based production system.

Crop planning

The analysis of rainfall data and the chances of occurrence of wet and dry spells during the rainy season provide useful information for proper planning of agricultural crops and water management in the scarcity zone of western Maharashtra. The average weekly rainfall received prior to the onset of the rainy season (26th SMW) period of the region (22 -25 SMWs, 28 May – 24 June) ranged from 22 to 32 mm and chances of occurrence of wet week were 24 to 45%, summer ploughing and initial seed bed preparations shall be taken up by utilizing rain during this period. The sowing operations of *kharif* season crops like sorghum, pearl millet, sunflower, soybean, pigeon pea and vegetables like cowpea and cluster bean can be taken after 25th SMW as the mean onset of rainy season is found to be 26th SMW (25 June –1 July). Major crop of region, sugarcane can be planted during 25 - 27th SMWs with supplemental irrigations to get better germination utilizing the available soil moisture. The higher probabilities of occurrence of two and three consecutive dry weeks are higher during 28 – 33rd SMWs which come in mid-season of crop growth. Hence during this mid-season dry spell, supplementary irrigations and moisture conservation practices like mulching need to be taken up in sugarcane, while plant protection, top-dressing of fertilizers, intercultural operations and supplemental irrigation can be given in sorghum, pearl millet, sunflower and soybean. During 36-40th SMWs the probability of getting wet and consecutive wet spells were high and 13-25 mm weekly rainfall can be expected at 50% probability which coincides with the grand growth period of the sorghum, pearl millet, sunflower, and soybean. The crop water demand can be met by rainfall itself during this period. During this period, the weekly mean rainfall in the region is more than 40 mm/week, which indicates the potential scope of harvesting excess runoff water for future supplemental irrigations. Also, continuous high rainfall in a short span during this period may lead to water logging in the crop fields. Therefore, contingency measures like providing surface drainage, application of hormones/ nutrient sprays to prevent flower drop or promote quick flowering at crop maturity stage, harvesting of produce at the physiological maturity stage should be followed to avoid economic losses. The findings of this study can be helpful for efficient water management and irrigation planning in the region.

Conclusions

This study analysed 33 years of daily rainfall data of scarcity zone of western Maharashtra using incomplete gamma distribution and Markov chain probability model for crop planning. The result of analyses showed that the normal onset and cessation of the rainy season at Baramati located in scarcity zone of western Maharashtra was 26th SMW and 41st SMW, respectively making a growing season of 110 days or 16 weeks. So the *kharif* season crops like sorghum, pearl millet, sunflower, soybean, pigeon pea and vegetables like cowpea and cluster bean can be taken, and the sowing operations can be taken up from 25th SMW (18 June – 24 June). It was observed that the probability of getting dry and consecutive dry spells at the early and middle stages of the rainy season was high, indicating the need for in-situ moisture conservation measures and the need for life-saving irrigation. During 36-40th SMWs the probability of getting wet and consecutive wet spells was high, indicating that there is less probability of application of irrigation water for a short duration period. Harvesting runoff water and soil erosion measures need to be practiced for better water management.

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