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Dry and wet spell probability analysis using Markov chain model for planning jute-based cropping systems in eastern India

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ABSTRACT

Knowledge about the rainfall distribution, frequency of dry and wet spells, and the probable weeks of the onset and termination of monsoon season are the prerequisite for planning agricultural operations particularly for rainfed crops such as jute in eastern India. In this paper, therefore, the marginal, conditional, and consecutive dry and wet week probabilities were analysed using Markov chain model, and the forward and backward accumulation method was used for computing probabilities of onset and withdrawal of monsoon season for planning jute-based cropping systems in eastern India. Both the methods were applied for weekly rainfall data of the four stations situated in jute growing areas of eastern India such as Nagaon (period: 2011-2020), Pundibari (period: 1998-2016), Barrackpore (period: 1983-2020) and Bhubaneswar (period: 2008-2020). In jute season (13-29 weeks), the probability of dry weeks was maximum (3-81%) in Barrackpore and minimum (0-19%) in Nagaon. The probability of dry week preceded by another dry week was maximum in Bhubaneswar and minimum in Nagaon. The probability of two and three consecutive dry weeks was maximum (0-65% and 0-52%, respectively) in Barrackpore and minimum (0-9% and 0-6%, respectively) in Nagaon. The onset and withdrawal of monsoon season were also computed for all the four stations data. This analysis will be helpful for water management and determining or adjusting proper sowing time of jute or any other crops especially rainfed crops so that the critical water-sensitive phenological phases might not coincide any water stress situation and thus ensuring to reach potential yield of that particular crop.

1. INTRODUCTION

The Markov chain (MC) probability model has widely been applied in characterizing dry and wet spells for agricultural crop planning (Sastry *et al.,* 1976; Victor and Sastry, 1979; Pandharinath, 1991; Dabral *et al.,* 2014). Several researchers illustrated its practical usefulness in agricultural crop planning in different regions / states of India such as Maharastra (Khambete and Biswas, 1984), Andhra Pradesh (Pandharinath, 1991), coastal Tamil Nadu (Chattopdhyay and Ganesan, 1995), Bihar (Subash *et al.,* 2009), Kharagpur (Panigrahi and Panda, 2002), red and laterite zone of West Bengal (Kar, 2003), Bathinda (Singh *et al.,* 2004) and Ludhiana (Gill *et al.,* 2015) of Punjab, Coimbatore in western zone of Tamil Nadu (Joseph *et al.,* 2017), Mirzapur district in Vindhya plateau of Indo-Gangetic plain (Singh *et al.,* 2019), and Medak district of Telangana (Shilpashree *et al.,* 2019). Most of the studies were specific either to a few crops or to the study region. However, no such study was done for planning jute-based cropping system (e.g. Jute-rice) for major jute growing states like West Bengal, Assam, and Odisha. Therefore, such analysis is essential for proper jute-based farming system particularly for water management in the early stage of jute growth and for retting of jute after harvesting.

Jute is the most important bast fibre crop mostly grown as rainfed crop in eastern states of India. The major jute producing states are West Bengal, Assam, and Odisha. For variability of climatic conditions in different regions, the sowing time of jute varies from first week of April to first fortnight of May and harvesting time varies between last week of July and first fortnight of Sept. Jute growing season therefore extends between summer (March to May) and monsoon season (June-Sept). Jute requires almost 500-550 mm of water during entire growth period (120 days) for its better growth and development (Patel *et al.,* 1983; Barman *et al.,* 2014). If the pre-monsoon western shower (known as *Kalbaisakhi* in West Bengal) is not sufficient or not in time, the jute crop experience drought in its first half of growing season (about 60 days). Moreover, if the onset of monsoon season delays, the growth and development of jute crop is further hampered due to low available soil moisture, and therefore yield reduces. In West Bengal condition, Barman *et al.* (2020) showed that jute, during the first half of its growth period, experiences water stress in the entire North Bengal (northern part of West Bengal) except Darjeeling, Cooch Behar, and Jalpaiguri districts. As these cases are similar in all the jute growing areas, the lifesaving or multiple irrigations are needed to apply for obtaining good fibre yield for the entire jute growing belt. This warrants the analysis of short term periods (e.g. week) rainfall data, and probabilities of their dry and wet spells in jute growing areas for irrigation management and other intercultural operations.

Rai *et al.* (2014) suggested for agricultural field preparation when the initial rainfall probability of 10 mm in a week is about 70%. He also suggested for sowing of crop and top dressing of urea fertilizer when the initial and conditional probability of wet week followed by wet week of 20 mm rainfall is more than 80% and 90%, respectively. For cultivation of jute, total rainwater requirement is about 495 mm rainwater among which 77 mm is for land preparation and 418 mm for entire crop growth period (Barman *et al.,* 2014). Weekly rainfall analysis for dry and wet spells during jute growth period will help for taking timely water management measures to fulfil the requirement of rainwater/irrigation water from land preparation to harvesting in jute cultivation.

For planning and management of jute-based (e.g. jute-rice) cropping system in eastern India, our present study focuses on the initial probability, conditional probability of wet and dry weeks and also a probability of occurrence of consecutive two and three weeks of wet and dry spells in four jute growing regions of eastern India by taking rainfall data of four stations, *viz.,* Nagaon (Assam), Pundibari (West Bengal), Barrackpore (West Bengal) and Bhubaneswar (Odisha).

2. MATERIALS AND METHODS

Study Area

The study area comprised of the major jute growing belts of the three states of India, *viz.,* Assam, West Bengal, and Odisha. The representative four meteorological stations were selected such as Nagaon (Assam), Pundibari (West Bengal), Barrackpore (West Bengal), and Bhubaneswar (Odisha) (Fig. 1). Some details about the study areas are presented in Table 1.

Data Used

Daily rainfall data were collected from meteorological stations of Nagaon (Assam), Pundibari and Barrackpore (West Bengal), and Bhubaneswar (Odisha) from the years

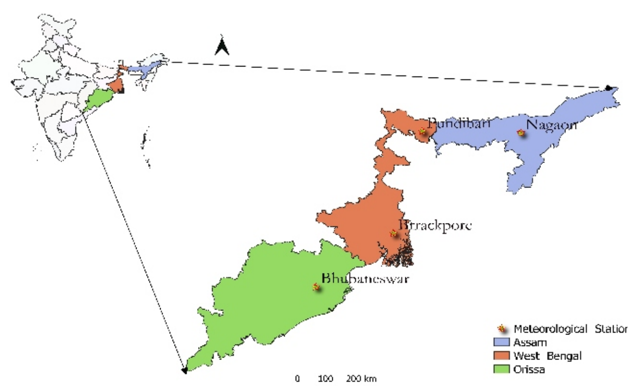

Fig. 1. Study area map of Odisha, West Bengal and Assam

Table: 1
Study regions along with its agro-climatic zones and major jute-based cropping systems

Location	Latitude / Longitude	Annual Avg. Min. Temperature (ºC)	Annual Avg. Max. Temperature (ºC)	Agroclimatic zone	Major Jute based cropping systems
Nagaon (Assam)	24º45´-26º45´N, 91º50´-93º20´E	10.6	35.6	Eastern Himalayan region	Jute-black gram-toria / wheat, jute-rice-toria, jute-toria
Pundibari (West Bengal)	25°57'-26°36'N 88°47' - 89°54' E	9.9	33.8	*Terai* zone	Jute-rice- toria / lentil, jute-black gram, jute-green gram
Barrackpore (West Bengal)	22°45' N 88°25' E	20.8	31.1	New alluvial zone	Jute-rice-potato / wheat / pea / lentil
Bhubaneswar (Odisha)	20°15' N 85°51' E	22.1	32.1	Sub-humid eastern coastal plain	Jute-rice-lentil, Jute-mustard-cowpea

2011-2020, 1998-2016, 1983-2020 and 2008-2020, respectively. The daily rainfall data were converted to weekly total rainfall by simple arithmetic sum for each of the years for every location.

Markov Chain (MC) Model

The MC model is based on the transitional probability describing a situation that changes between two stages that means the current probability of certain state depends on the probability of the immediate preceding state only. In our study, weekly rainfall values computed from daily values were used for initial, conditional, and consecutive dry and wet week analysis based on first order MC probability model. In this model 20 mm or more rainfall in a week is considered as the wet week, and less than 20 mm rainfall in a week is considered as the dry week (Pandharinath, 1991; Dash and Senapati, 1992; Singh and Bhandari, 1998; Kar, 2003).

Determination of Initial Probability

Initial or marginal probability depicts the probability of a week being wet or dry regardless of the weather condition of the preceding week.

$$P(D) = \frac{F(D)}{N} \quad ...(1)$$

$$P(W) = \frac{F(W)}{N} \quad ...(2)$$

Where, $P(D)$ and $P(W)$ = probability of the week being dry or wet respectively, $F(D)$ and $F(W)$ = frequency of dry and wet week respectively and N = total number of years of data being used.

Determination of Conditional Probability

The probability of a dry (wet) week following a dry (wet) week is the conditional probability.

$$P\,(D/D) = \frac{F(D/D)}{F(D)} \quad ...(3)$$

$$P\,(W/W) = \frac{F(W/W)}{F\,(W)} \quad ...(4)$$

$$P(W/D) = 1 - P(D/D) \quad ...(5)$$

$$P(D/W) = 1 - P(W/W) \quad ...(6)$$

Where, $P\ (D/D)$ = probability of occurrence of a dry week preceded by another dry week, $P\ (W/W)$ = probability of occurrence of a wet week preceded by another wet week, $P\ (W/D)$ = probability of a wet week preceded by a dry week, and $P\ (D/W)$ = probability of a dry week preceded by a wet week. $F\ (D/D)$ = frequency of occurrence of a dry week preceded by occurring another dry week, $F\ (W/W)$ = frequency of wet week preceded by another wet week.

Determination of Consecutive Probability

$$P(2D) = P(D_{w1}) \times P\,(DD_{w2}) \quad ...(7)$$

$$P(2W) = P(W_{w1}) \times P\,(WW_{w2}) \quad ...(8)$$

$$P(3D) = P(D_{w1}) \times P\,(DD_{w2}) \times P\,(DD_{w3}) \quad ...(9)$$

$$P(3W) = P(W_{w1}) \times P\,(WW_{w2}) \times P\,(WW_{w3}) \quad ...(10)$$

Where, $P\ (2D)$, $P\ (3D)$ = probability of two and three consecutive dry weeks respectively, $P\ (2W)$, $P\ (3W)$ = probability of two and three consecutive wet weeks, respectively, $P\ (D_{w1})$, $P\ (W_{w1})$ = probability of first week being dry and probability of first week being wet, respectively, $P\ (DD_{w2})$ and $P\ (WW_{w2})$ = probability of second consecutive dry week with preceding week being dry and probability of second consecutive wet week with preceding week being wet, respectively, $P\ (DD_{w3})$ and $P\ (WW_{w3})$ = probability of third week being dry with preceding dry week and probability of third week being wet with preceding wet week, respectively.

Onset and Withdrawal of Rainy Season

The weekly rainfall was used for forward and backward accumulation method in computing the onset and withdrawal of rainy season (Kothari *et al.,* 2009). The forward accumulation (22+23+24....+52 weeks) of 75 mm rainfall has been considered for onset of rainy season, and the backward accumulation (52 + 51+......+36 weeks) of 200 mm rainfall was chosen for the termination of rainy season (WMO, 1982; Panigrahi and Panda, 2002; Dabral *et al.,* 2014). The probability of onset and withdrawal of rainy season was computed by using the Weibull's formula: $P = \{m/(N+1)\} \times 100$ where, P is probability; m is rank number; N is the number of observations.

3. RESULTS AND DISCUSSION

Annual Rainfall

The average annual rainfall of Nagaon (from 2011-2020) was 1658 mm, ranged from 1027 mm (2015) to 2095 mm (2017) with standard deviation (SD) of 291 mm and coefficient of variation (CV) of 18%. The average annual rainfall in Pundibari (1998-2016) was highest among the study locations and it was 3000 mm, ranged from 1529 mm (2010) to 3942 mm (2008) with SD and CV of 971 mm and 32%, respectively. Barrackpore recorded average annual rainfall (1990-2020) of 1616 mm, ranged from 1057 (2009) to 3052 (1997) with 381 mm SD and 24% CV. In Bhubaneswar, the average annual rainfall (2008-2020) was 1533 mm with 266 mm SD and 17% CV and the average annual rainfall ranged from 950 mm (2015) to 2003 mm (2018) (Table 2).

Weekly Rainfall Distribution

The weekly rainfall characteristics of the four study locations were presented in Fig. 2 (a-d). We have divided the year (*i.e.* 52 weeks) in four distinct seasons as per the IMD

Table: 2
Annual rainfall in Nagaon, Pundibari, Barrackpore and Bhubaneswar

	Nagaon (2011-2020)	Pundibari (1998-2016)	Barrackpore (1990-2020)	Bhubaneswar (2008-2020)
Average rainfall (mm)	1658	3000	1616	1533
Standard deviation (mm)	291	971	381	266
Coefficient of variation (%)	18	32	24	17
Max. rainfall (mm) in a year	2095 (2017)	3942 (2008)	3052 (1997)	2003 (2018)
Min. rainfall (mm) in a year	1027 (2015)	1529 (2010)	1057 (2009)	950 (2015)

Figures in parentheses are the corresponding year of observation

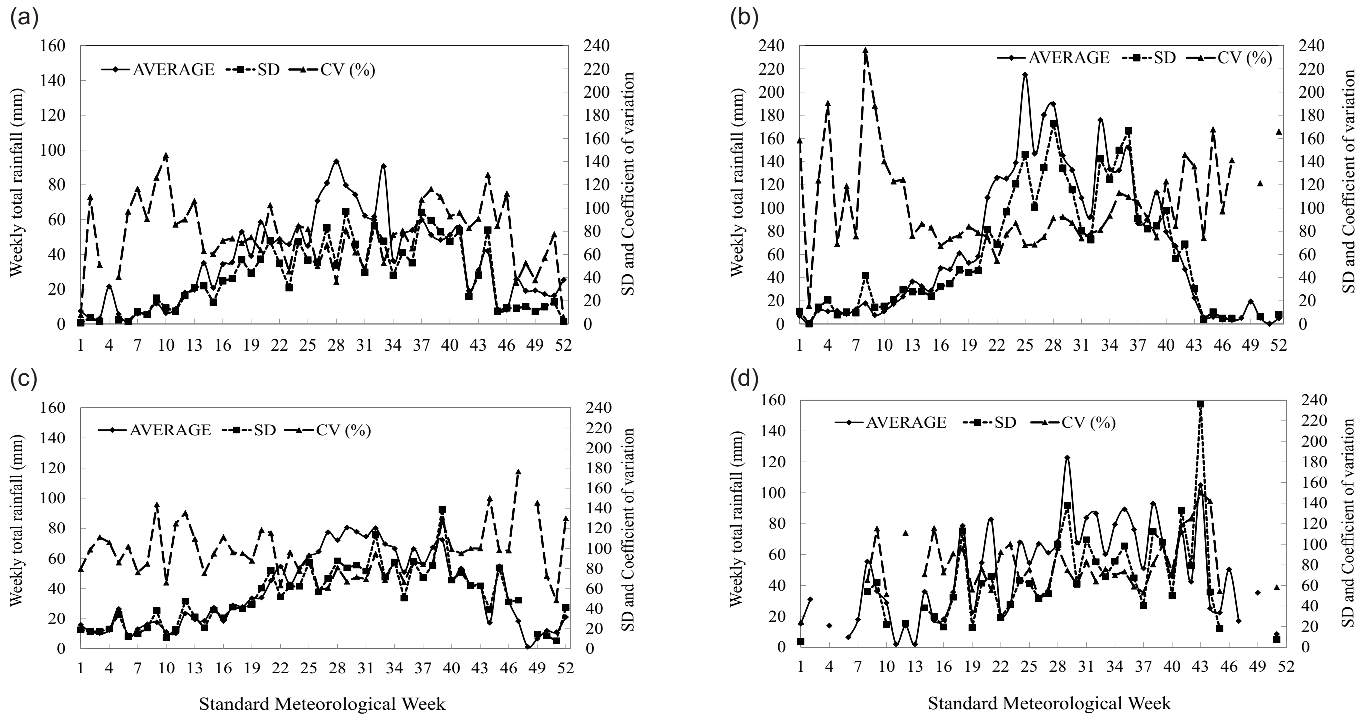

Fig. 2. Weekly rainfall distribution in (a) Nagaon, (b) Pundibari, (c) Barrackpore and (d) Bhubaneswar

classification, *viz.,* winter (1-8 SMW), summer or pre *kharif* (9-22 SMW), monsoon or *kharif* (23-39 SMW) and post monsoon (40-52 SMW) seasons. In Nagaon, weekly rainfall ranged from 1- 22, 7-59, 36-93, 8-56 mm in winter, summer, monsoon, and post monsoon seasons, respectively, and their respective percentages of CVs were 73.2, 86, 73.9, 73.3. In Pundibari, weekly rainfall ranged 0-8, 14-126, 87-215, 0-79 mm in winter, summer, monsoon, and post monsoon seasons, respectively, along with their respective percentages of CVs were 123.5, 95, 86.2, and 125.7. In Barrackpore, weekly rainfall ranged from 8-26, 7-55, 43-101, and 1-55 mm in winter, summer, monsoon, and post-monsoon seasons, respectively, and their respective percentages of CVs were 93, 102.6, 90.4, 109.4. In Bhubaneswar, weekly rainfall ranged from 6-56, 13-83, 27-123, 9-105 mm in winter, summer, monsoon, and post-monsoon seasons, respectively, and their respective percentages of CVs were 44.7, 83.6, 72.6, 103.1. In general, chances of getting weekly rainfall in all the four seasons across the locations were very uncertain which was evident by their high CV values. During jute sowing time (summer season), uncertainty of getting rainfall was highest in Barrackpore (CV, 102.6%) followed by Pundibari (CV, 95%), Nagaon (CV, 86%) and Bhubaneswar (CV, 83%).

Analysis of Initial and Conditional Probability of Dry and Wet Weeks

The initial and conditional probabilities for Nagaon, Pundibari, Barrackpore and Bhubaneswar was presented in Fig. 3.

Nagaon

The probability of occurrence of the dry week [P (D)] is higher from 1-12 and 42-52 SMW (60-100%). During this period probability of a dry week preceded by another dry week [P (D/D)] is also higher (67-100%). There is a 50-100% chance of occurrence of dry week preceded by wet week [P (D/W)] between 14-41 SMW. Probability of wet weeks [P (W)] is higher from 14-38 SMW (50-100%) and

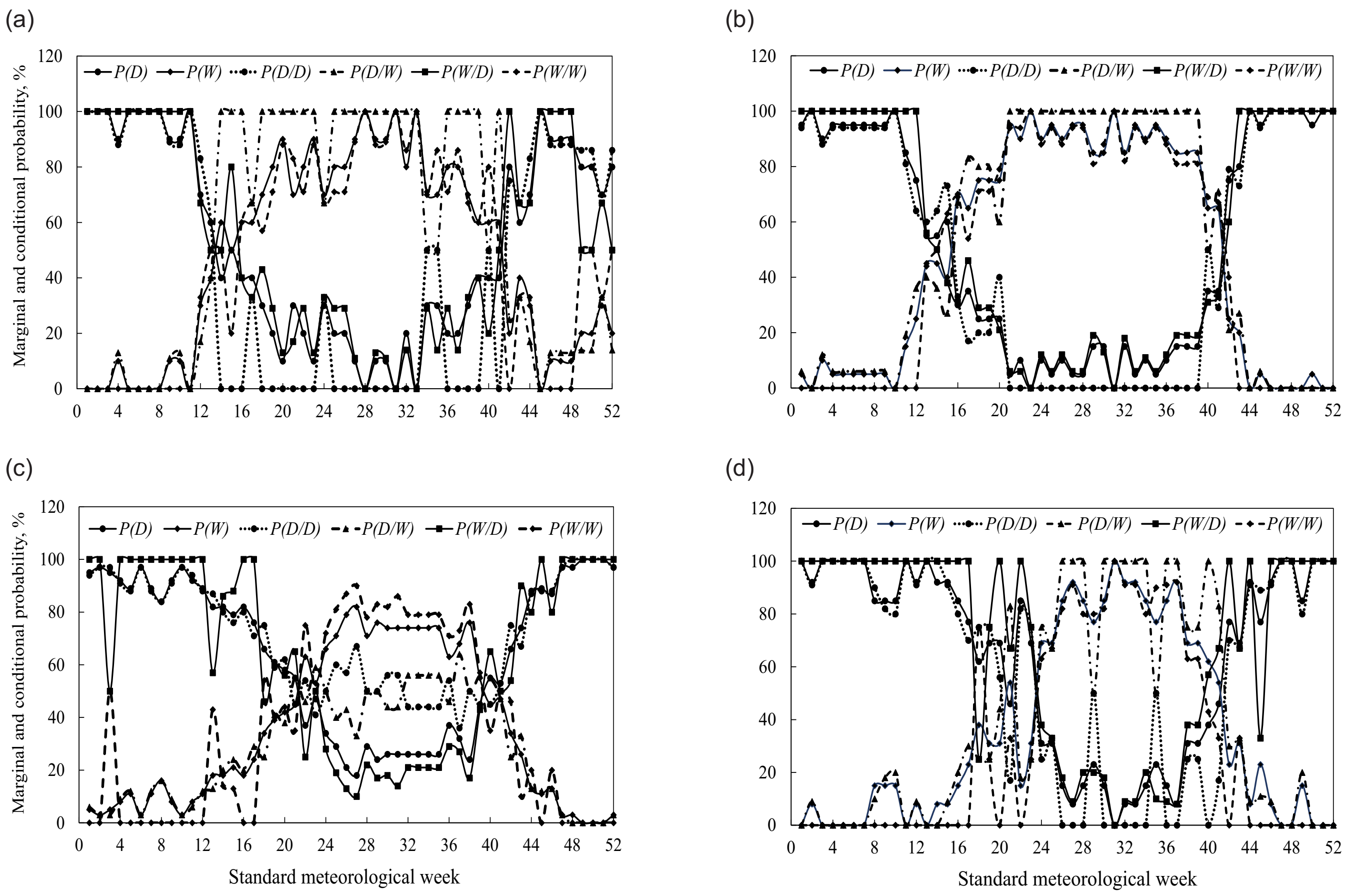

Fig. 3. Initial and conditional probability of dry and wet weeks in (a) Nagaon (b) Pundibari (c) Barrackpore and (d) Bhubaneswar

therefore land preparation and jute sowing operations are recommended on 14th SMW onwards in Nagaon region. Probability of wet week proceeded by a dry week [P (W/D)] and a wet week [P (W/W)] is higher from 1-15 SMW, 41-52 SMW and 13-40 SMW, respectively.

Pundibari

The probability of occurrence of dry week [P (D)] is higher from 1-15 and 42-52 SMW (60-100%). During this period probability of dry week preceded by another dry week [P (D/D)] is also higher (60-100%). There is a 50-100% chance of occurrence of dry week preceded by wet week [P (D/W)] between 17-41 SMW. The probability of wet weeks [P (W)] is higher from 16-39 SMW (65-100%) and, therefore, land preparation and jute sowing operations are recommended from 16th SMW onwards in the Pundibari region. The probability of wet week proceeded by a dry week [P (W/D)] and a wet week [P (W/W)] is higher from 1-12 SMW, 43-52 SMW and 20-39 SMW, respectively.

Barrackpore

The probability of occurrence of the dry week [P (D)] is higher from 1-19 and 43-52 SMW (61-100%). Probability of dry week preceded by another dry week [P (D/D)] is also higher from 1-20 SMW and 44-52 SMW (59-100%). This warrants that one pre-sowing irrigation is highly recommended for land preparation and sowing of jute during 12-20 SMW in Barrackpore region for maintaining optimum soil moisture to ensure good germination and crop establishment without compromising the time of next crop. Chance of occurrence of dry week proceeded by wet week [P (D/W)] is very less. The weeks 32-35 and 37th SMW, 39 SMW recorded [P (D/W)] with more than 55% probability. Probability of wet weeks [P (W)] is higher from 22-39 SMW (55-82%). Probability of wet week proceeded by a dry week [P (W/D)] and a wet week [P (W/W)] is higher from 1-17 SMW, 43-52 SMW and 22-38 SMW, respectively.

Bhubaneswar

Probability of dry week [P(D)] and dry week preceded by another dry week [P(D/D)] during 1-19 SMW and 42-52 SMW is very high (75-100%). Moreover, there is 15-54% probability of a wet week [P(W)] from 16-23 SMW during jute sowing and crop establishment period in Bhubaneswar region and therefore assured irrigation, particularly during this period, is highly recommended for getting better jute yield in this region.

Analysis of Consecutive Dry and Wet Week Probability

The consecutive wet and dry week probability analysis for four jute growing areas have been presented in Fig. 4.

Nagaon

Results revealed that two consecutive dry weeks will occur from 1-12 SMW and 45-52 SMW at 50-90% probability. Chances of three consecutive dry weeks will be from 1-11 SMW at 60-80% probability. Consecutive probability of two wet weeks is varying from 50 to 90 % for 19-37 SMW and consecutive probability of three wet weeks is varying from 50-80% from 25-35 SMW.

Pundibari

Results revealed that two consecutive dry weeks will occur from 1-10 SMW and 44-52 SMW at 75-95% probability. Chances of three consecutive dry weeks will be from 1-10 SMW and 44-52 SMW at 75-90% probability. Consecutive probability of two wet weeks is varying from 75-95% % for 21-36 SMW and consecutive probability of three wet weeks is varying from 65-90% from 21-36 SMW.

Barrackpore

Results revealed that two consecutive dry weeks will occur from 1-17 SMW and 44-52 SMW at 53-97% probability. Chances of three consecutive dry weeks will be from 1-13 SMW and 47-52 SMW at 58-95% probability. Consecutive probability of two and three wet weeks are same for this region ranging from 45-74% distributed over 26-38 SMW.

Bhubaneswar

Results revealed that two consecutive dry weeks will occur from 1-17 SMW and 44-52 SMW at 62-92% probability. Chances of three consecutive dry weeks will be from 1-15 SMW and 46-52 SMW at 54-85% probability. Consecutive probability of two and three wet weeks are same for this region ranging from 62-92% and 54-85% distributed over 26-37 SMW.

This analysis showed that any crop grown during 1-17 SMW and 44-52 SMW, *i.e.* summer and post *kharif* / post monsoon seasons, needs to be irrigated frequently for harvesting good yield as there was very high chance of consecutive two and three dry weeks (*i.e.* very low chances of rainfall) in all the four locations.

Analysis of wet and dry spells in the context of jute-based cropping systems

Jute is mainly sown in 23rd March to 7th April *i.e.,* between 12-14 SMW and accordingly harvested between 28th July to 4th August *i.e.,* 30-31 SMW in the north eastern

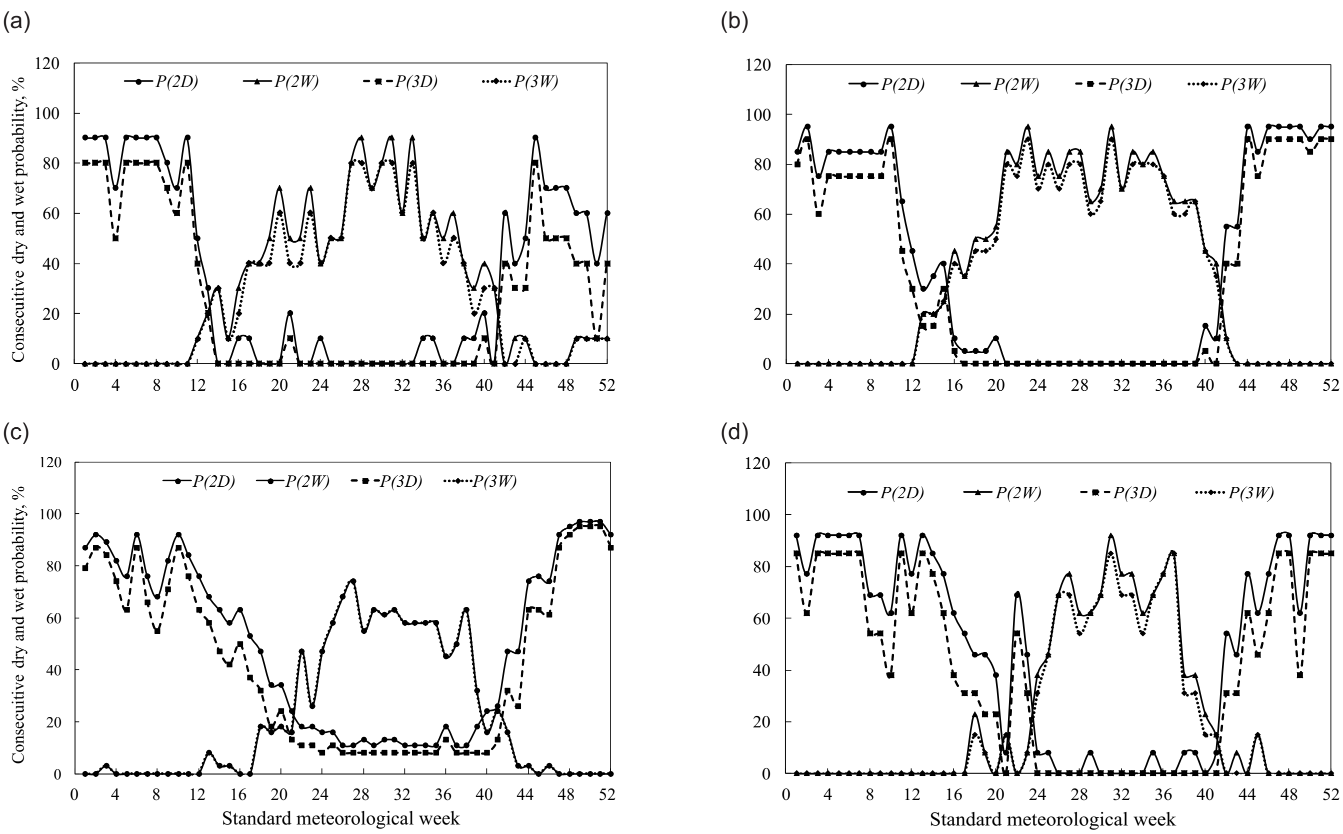

Fig. 4. Consecutive probability of dry and wet weeks in (a) Nagaon, (b) Pundibari, (c) Barrackpore, and (d) Bhubaneswar

part of India. For the sake of the analysis of wet and dry spell during jute season, we have divided the whole season into three distinct parts *viz.,* pre-jute season (1-12 SMW), jute season (13-29 SMW) and post-jute season (30-52 SMW). The region wise analysis of marginal and conditional probabilities as well as consecutive probabilities of wet and dry spell (Fig's. 3 and 4) revealed that chances of dry weeks in pre-jute season varied from 75-100% in Nagaon and Pundibari and 84-97% in Barrackpore and Bhubaneswar, whereas during jute growing season this variation ranged from 0 to 60% for Nagaon and Pundibari. For Barrackpore this range is 18-82% and for Bhubaneswar it is 8-100%. The conditional probability of occurrence of dry week preceded by another dry week in pre-jute season is highest in Barrackpore followed by Nagaon, Bhubaneswar and Pundibari (84%, 83%, 80% and 64%, respectively). During jute season there is 41-87% chance of occurrence of dry week preceded by another dry week in Barrackpore and for the rest three regions the maximum possibility is 60-100%. Chances of two and three consecutive dry weeks was also found maximum in Barrackpore during pre-jute (68-92% and 55-87%, respectively) and jute season (11-68% and 8-58%, respectively). For all the regions, dry weeks prevails in pre-jute seasons which will develop soil moisture deficit for sowing of jute crop and its germination. To overcome it, pre-sowing irrigation will be helpful for assured germination of the jute crop. The consecutive two or three dry weeks were also observed from 13-16 MSW during jute growing season which warrants to give supplemental irrigation for optimum jute growth and yield.

Analyses of rainfall for onset and withdrawal of rainy season

The results of analysis for onset and withdrawal of monsoon are presented in Table 3. The analysis of forward accumulation of 75 mm rainfall (starting from 22nd SMW) reveals that onset of rainy season ranged from 22-24 SMW with >70% probability on an average for Nagaon, Pundibari and Barrackpore and 24-26 SMW for Bhubaneswar with > 60% probability on an average. In Nagaon, there was 90.9% chance of onset of monsoon in 24th SMW and 81.8% chance in 22nd SMW. In Pundibari and Barrackpore, there were 80% and 87.5% chances of onset of rainy season in 23rd SMW. In Barrackpore, maximum chance of onset of monsoon is in 25th SMW with 96.9% probability. In Bhubaneswar, the chances of onset of monsoon were in 24th SMW with 92.9% probability. The results of the backward accumulation of 200 mm rainfall (starting from 52nd SMW) revealed that with highest probabilities, the withdrawal of monsoon started in 40th SMW (81.8%), 38th SMW (65%), 41st SMW (81.3%) and 36th SMW (78.6%) from Nagaon, Pundibari, Barrackpore and Bhubaneswar, respectively. So we can expect a good monsoon season of 16 weeks in Nagaon (11th June - 07th Oct) and Barrackpore (18th June - 14th Oct), 15

Table: 3
Probability of having 75 mm and 200 mm accumulated rainfall (forward accumulation) and 200, 300 and 500 mm accumulated rainfall (backward accumulation)

	Forward accumulation (from 22nd week)				Backward accumulation (from 52nd week)					
	#75 mm	Probability (%)	+200 mm	Probability (%)	*200 mm	Probability (%)	**300 mm	Probability (%)	**500 mm	Probability (%)
Nagaon	22 SMW	81.8			36 SMW	72.7	38 SMW	90.9		
	23 SMW	72.7			40 SMW	81.8				
	24 SMW	90.9								
Pundibari	22 SMW	75.0	22 SMW	95.0	38 SMW	65.0	39 SMW	80.0		
	23 SMW	80.0			39 SMW	60.0				
Barrackpore	23 SMW	87.5	24 SMW		41 SMW	81.3	34 SMW	90.6	39 SMW	96.9
	24 SMW	93.8	25 SMW		42 SMW	75.0	38 SMW	93.8		
	25 SMW	96.9			44 SMW	68.8	40 SMW	84.4		
Bhubaneswar	24 SMW	92.9			36 SMW	78.6	38 SMW	85.7		
	25 SMW	64.3			38 SMW	71.4	43 SMW	92.9		
	26 SMW	71.4			43 SMW	64.3				

*#75 mm accumulation of rainfall is considered as the onset time of sowing of rainfed crop; +200 mm accumulated rainfall for initiation of puddling time of wet land preparation of rice field; *200 mm accumulated rainfall (Backward accumulation starting from 52nd week) is the time for termination of monsoon; ** It is considered that 500 and 300 mm accumulated rainfall values represents the week after which sufficient rain would be expected to sustain a second rice crop after monsoon crop assuming fully charged soil at planting.*

weeks in Pundibari (4th June - 23rd September) and 12 weeks in Bhubaneswar (11th June - 09th September).

4. CONCLUSIONS

MC analysis revealed that in a year there are two distinct transitional phases of dry and wet weeks' sequences for all the four locations, *viz.,* Nagaon (12th and 41st SMW), Pundibari (16th and 40th MSW), Barrackpore (23rd and 42nd MSW), and Bhubaneswar (16th and 42nd MSW). The MC model based study for planning jute-based cropping system is the first report to the best of our knowledge. We found that the ideal sowing time of jute crop is between 26th March and 1st April in all the four regions for effective use of the pre-monsoon showers. However, the probabilities of dry week and two consecutive dry weeks from 26th March to 3rd June varied from 10-60% and 0-40%, respectively, in Nagaon and Pundibari, and 37-82% and 16-68% in Barrackpore, and 50-100% and 38-92% in Bhubaneswar. Therefore, life saving and supplemental irrigations are needed up to 3rd June (22 SMW) and thereafter no irrigation is required for jute and then rice or any other *kharif* crops because monsoon starts and remains active for 16 weeks in Nagaon (11th June - 7th Oct) and Barrackpore (18th June to 14th Oct), 15 weeks in Pundibari (4th June - 23rd Sept) and 12 weeks in Bhubaneswar (11th June - 9th Sept). From 1st Jan to 25th March (1-12 SMW), the probability of dry week varied from 70-100% in Nagaon and Pundibari and from 85-100% in Barrackpore and Bhubaneswar. From 15th Oct to 31st Dec (42-52 SMW), and 1st Jan to 25th March (1-12 SMW), the probabilities of two consecutive dry weeks varied from 40-90% in Nagaon, 45-95% in Pundibari, 50-97% in Barrackpore, and 50-92% in Bhubaneswar. The supplemental irrigations are therefore needed for growing any crop in all the four study regions from 22nd Oct to 25th March.

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REFERENCES

Barman, D., Kundu, D.K., Ghorai, A.K. and Mitra, S. 2014. Determination of evapotranspiration and crop coefficient of *tossa* jute (*Corchorus olitorius*). *J. Agril. Physics*, 14(1): 67-72.

Barman, D., Saha, R., Roy, S., Alam, N.M., Bhowmick, T., Das, S. and Kar, G. 2020. Spatial and temporal variability of extreme rainfall and air temperature related to jute production in West Bengal. *J. Agril. Physics*, 20(2): 148-156.

Chattopadhyay, N. and Ganesan, G.S. 1995. Probability studies of rainfall and crop production in coastal Tamil Nadu. *Mausam,* 46(3): 263-274.

Dabral, P.P., Purkayastha, K. and Aram, M. 2014. Dry and wet spell probability by Markov chain model - a case study of North Lakhimpur (Assam), India. *Int. J. Agric. Biol. Eng.,* 7(6): 8-13.

Dash, M.K. and Senapati, P.C. 1992. Forecasting of dry and wet spell at Bhubaneswar for agricultural planning. *Indian J. Soil Cons.,* 20(1&2): 75-82.

Gill, K.K., Aggarwal, R. and Goyal, P. 2015. Rainfall probabilities for crop planning in Ludhiana by Markov chain analysis. *Indian J. Ecol.*, 42(1): 16-20.

Joseph, A. and Tamilmani, D. 2017. Markov chain model of weekly rainfall probability and dry and wet spells for agricultural planning in Coimbatore in western zone of Tamil Nadu. *Indian J. Soil Cons.,* 45(1): 66-71.

Kar, G. 2003. Initial and conditional probabilities of rainfall and wet dry spell for red and Lateritic zones of West Bengal using Markov Chain Model. *Indian J. Soil. Cons.,* 31(3): 287-290.

Khambete, N.N. and Biswas, B.C. 1984. Application of markov chain model in determining drought proneness. *Mausam,* 35(3): 407-410.

Kothari, A.K., Jain, P.M. and Kumar, V. 2009. Analysis of weekly rainfall data using onset of monsoon approach for micro level crop planning. *Indian J. Soil Cons.,* 37(3): 164-171.

Pandharinath, N. 1991. Markov chain model probability of dry and wet weeks during monsoon period over Andhra Pradesh. *Mausam,* 42(4): 393-400.

Panigrahi, B. and Panda, S.N. 2002. Dry spell probability by Markov chain model and its application to crop planning in Kharagpur. *Indian J. Soil Cons.,* 30(1): 95-100.

Patel, C.S. and Mandal, A.K. 1983. Effect of moisture regimes and level of fertilizer application on yield and water requirement of jute (*Corchorus olitorius* L. and *C. capsularis* L.). *J. Agric. Sci., Cambridge,* 101(2): 311-316, doi.org/10.1017/S0021859600037606.

Rai, S.K., Kumar, S., Rai, A.K., Satyapriya and Palsaniya, D.R. 2014. Climate change, variability and rainfall probability for crop planning in few districts of central India. *Atmos. Clim. Sci.,* 4: 394-403. http://dx.doi.org/10.4236/acs.2014.43039.

Sastry, P.S.N. 1976. *Climate and rice.* International Rice Research Institute, Los Banos, Phillipines, pp 51-63.

Shilpashree, G.S., Singh, K.K., Attri, S.D., Baxla, A.K. and Singh, P. 2019. Dry and wet spell probability by Markov chain model over Medak district of Telangana. *J. Agrometeorology*, 21: 223-228.

Singh, G., Singh, R.M., Chandola, V.K. and Nema, A.K. 2019. Rainfall analysis for crop planning under rainfed condition at Mirzapur district in Vindhya plateau of Indo-Gangetic plain. *Indian J. Soil Cons.,* 47(1): 30-36.

Singh, M. and Bhandari, S.C. 1998. Wet and dry spells analysis using Markov chain model for mid region of Himachal Pradesh. *Indian J. Soil Cons,* 26(2): 147-152.

Singh, S.P., Hundal, S.S. and Aujla, M.S. 2004. Dry and wet spell sequences for crop planning at Bathinda, Punjab - A markov chain approach. *J. Agrometeorology*, 6(Special Issue): 242-246.

Subash, N., Sikka, A.K. and Haris, A.A. 2009. Markov chain approach - dry and wet spell rainfall probabilities for rice-wheat planning. *Indian J. Soil Cons.*, 37(2): 91-99.

Victor, U.S. and Sastry, P.S.N. 1979. Dry spell probability by Markov chain model and its application to crop development stages. *Mausam*, 30: 479-484.

W.M.O. 1982. *Frequency and probability of dry and wet spells.* Technical Note No. 179, pp 149-158.