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Integrating rainfall probability and moisture availability index for crop planning during *kharif* rice (*Oryza sativa*) in eastern Indo-Gangetic basin

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ABSTRACT

In the eastern region of Indo-Gangetic basin (EIGB), India, more than 80% of the rice (*Oryza sativa* L.) cultivated area is rainfed and monsoon rainfall is the critical and deciding factor for rice production. The districts comprising Bihar, West Bengal, Uttar Pradesh, Madhya Pradesh and Jharkhand form the eastern Indo-Gangetic basin in India, broadly representing 10 agro-ecological sub-regions and one/two/three representative rain gauge sites depending on the size of the region in each sub-region was considered for analysis. The purpose of this study is to find out rainfall availability at different probability levels of 60, 70, 80 and 90% at weekly intervals during the crop season using Gamma distribution and also to find out initial and conditional probability of occurrence of dry and wet weeks and the probability of occurrence of two and three consecutive dry and wet weeks through Markov chain modeling approach. Weekly moisture availability index (MAI) was computed for 15 stations during the crop period, i e 18th Standard meteorological week (SMW) to 44th SMW to explore the weekly water availability (WA) and water demand (WD) of the area. The mean annual rainfall vary from 880.1 mm with a standard deviation of 213.6 mm at Jhansi (4.4 sub-region) to 1589.6 mm at Dhanbad (12.3 sub-region) with a standard deviation of 460.3 mm. The eastern part of the EIGB receives more rainfall compared to the other part of the region. For Allahabad (western IGB) site, it is noticed that at 70% probability level, MAI is higher (>0.5) from 28th weeks and continued up to 35th week. However, the MAI never reaches > 1.0 in any of weeks. This indicates the crop will be always in moist situation for seven weeks and in the remaining weeks the crop will be under stress condition. But for Krishnanagar (Eastern IGB) site, the MAI is more from 25th to 35th week. Weekly values of MAI at different probability levels will be highly useful for planners at different risk levels.

Key words: Evapo-transpiration, Gamma distribution, Initial and conditional probability, Indo-Gangetic Basin, Markov chain, Modeling approach, Moisture availability index

Water resources are one of the critical constraints, particularly its timely availability, sufficient quantity and good quality for enhancing rice production. Rainfall is the major source of water for rainfed agriculture. Even though the eastern Indian states of the Indo-Gangetic basin receive a good to heavy rainfall (mean annual rainfall of 1 279.9 mm), its erratic distribution pattern- temporal as well as spatial - affect the rice (*Oryza sativa* L.) growth and thereby production in one or other part of the region. Eastern IGB-India region comprises West Bengal, Bihar, Jharkhand, Uttar Pradesh and Madhya Pradesh, where 30% of the total population of India lives and rice is the most common staple food for the common man. The annual per capita rice consumption of this region is 133 kg against a national average of 81 kg (Singh and Singh 2000). Since 80% of the rice-cultivated area is rainfed, any aberrations of rainfall pattern such as delay of monsoon, breaks in the monsoon activity, continuous dry weeks during the crop season and even continuous flooding also affect the production. It is estimated that the rice demand for India will be 140 million tonnes in 2025 (Mishra 2004). Intermittent drought during vegetative and milky stages, flood during early stages, stagnation of water for long duration, unbalanced/improper usage of fertilizers and delay of sowing/transplanting are major constraints for low rice productivity in this region. The region is bestowed with abundant natural resources and

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called as 'High Potential, Low Productivity' region (CPWF 2003).

For better growth of rice a low water level should be maintained at the early stages of the crop. The knowledge of expected weekly rainfall at different probability levels may be more accurate and useful for better crop planning and management. Gamma probability distribution has been found to be good fit for weekly rainfall data of the country and used by several researchers for estimation of expected rainfall at different probability levels pertaining to different agro-climatic regions (Subash and Das 2004, Das *et al.* 2006). Weekly precipitation amount at different probability levels during rainy season are quite important for rice as it requires moisture throughout the season. Several researchers (Panigrahi and Panda 2002, Jat *et al.* 2003, Sharma and Kumar 2003, and Kar 2003) applied Markov chain model for determination of initial and conditional probability of dry and wet spells of different duration for different climatic conditions and suggested crop planning strategies. The integrated method suggested by Abrol and Gadgil (1999) involves estimation of rainfall at different probability levels and potential evapo-transpiration to get a clear understanding of water availability, water demand of the area and also in getting the appropriate effect of distribution of adequate amount of rainfall at different probability levels. In the present study, an attempt has been made to estimate the expected rainfall at 50, 60, 70, 80 and 90% probability levels and to compute the occurrence of initial and conditional probability of dry and wet spells and also the probability of occurrence of two and three consecutive dry and wet spell weeks using Markov chain model for selected representative stations in each agro-ecological zones of the EIGB India. The MAI at 50, 60, 70, 80 and 90% probability levels has also been computed to help the planners choose their own risk level for crop planning.

MATERIALS AND METHODS

In this study, the eastern IGB part of India (EIGB, India) region is considered and it consists of administrative districts of Bihar, Jharkhand, West Bengal, Uttar Pradesh and Madhya Pradesh. Summer monsoon, popularly called the south-west monsoon or monsoon (June to September) is of the greatest concern in this region and more than 80% of the annual precipitation is received during this period. One to three representative rain gauge sites depending on the size of the region from each agro-ecological sub-regions of EIGB were considered for the analysis. The long-term (at least 25 years) weekly rainfall and temperature (maximum and minimum) data were collected for these stations from India Meteorological Department, Government of India, Pune. Table 1 provides the geographical position and agro-ecological characteristics of the study sites. In most part of this region, rice–wheat is the predominant cropping system and rice is the important *kharif* crop. Generally, the field preparation for *kharif* rice starts from May and crop harvesting begins normally during September–October depending on the rice varieties. Hence, the rainfall data from 18th standard meteorological week (SMW) (30 April - 6 May) to 44th SMW (28 October– 4 November) were considered for all the analyses in this study.

Incomplete gamma distribution model

A random variable 'x' is said to have a gamma probability distribution with parameters α and β if its probability density function is given by:

$$f(x) = \frac{1}{\Gamma\alpha\,\beta^{\alpha}} x^{\alpha-1} e^{-\frac{x}{\beta}} \qquad 0<x<\alpha \qquad (1)$$

$$= 0 \qquad \text{otherwise.}$$

In this distribution, α and β are known as shape and scale parameters, respectively, and $\Gamma(\alpha)$ is the gamma function. Maximum likelihood estimation technique was employed for obtaining the estimates of α and β. Chi-square test was employed for testing the goodness of fit. Chi-square test statistic is defined as:

$$\chi^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{\beta^2\alpha} \qquad (2)$$

which is distributed as χ^2 with (n-1) degrees of freedom.

The distribution function of gamma probability model is defined as:

$$P(X \leq x) = F(\alpha, \beta, x) = \int_0^x f(x)\,dx = \frac{1}{\Gamma\beta^{\alpha}} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \qquad (3)$$

The expected rainfall at 50, 60, 70, 80 and 90 % probability levels for 18th SMW to 44th SMW was estimated using equation 3.

The methodology suggested by Pandharinath (1991) to determine probability of dry, wet weeks during monsoon period over Andhra Pradesh using Markov chain model is adopted in this analysis. The annual average of daily PET of a place underestimates/overestimates the PET of May–October, because of the high seasonality cycle of PET. For almost all the stations considered in this study, the 70% of the average weekly PET during May–October comes between 19.8 mm and 23.3 and hence the weekly dry and wet spell analysis were carried out considering less than 20 mm rainfall in a week as a dry week and 20 mm or more as wet week. The probabilities of dry, wet weeks, conditional probabilities of dry week preceded by a dry week, wet week preceded by a wet week, consecutive 2 or 3 dry/wet weeks starting with the week were calculated using the formulae suggested by Pandharinath (1991).

The methodology suggested by Abrol and Gadgil (1999) is used in this study to find out moisture availability periods

Table 1 Agro-ecological sub-regions of EIGB, India

Agro-ecological region		Agro-ecological sub-region and length of growing period (LGP)	Representative stations	Latitude (^{0}N) Longitude (^{0}E) Altitude (m)
Northern plains N8D2	4.3	Ganga Yamuna Doab, Rohilkhand and Avadh plain, hot moist semi-arid ESR with deep, loamy alluvium-derived soils, medium to high AWC and LGP 120-150 days (N8Dm4)	Allahabad	25.27,81.44, 98
	4.4	Madhya Bharat Plateau and Bundelkhand Uplands, hot, moist semi-arid ESR with deep loamy and clayey mixed Red and Black soils, medium to high AWC and LGP 120-150 days (N6Dm4)	Jhansi	25.27, 78.35, 251
Northern plains, hot sub-humid (dry) N8C3	9.2	Rohilkhand, Avadh and south Bihar Plains, hot dry sub humid ESR with deep loamy alluvium-derived soils, medium to high AWC and LGP 150-180 days (N8Cd5)	Lucknow Faizabad	26.52, 80.56, 111 26.45, 82.05, 102
Central highlands, hot sub-humid (dry) I6C3(4)	10.1	Malwa Plateau, Vindhyan Scarpland and Narmada valley, hot dry subhumid ESR with medium and deep clayey black soils, high AWC and LGP 150-180 days (I5Cd5)	Sagar	23.51,78.45, 551
	10.3	Vindhyan Scarpland and Bagelkhand Plateau, hot dry subhumid ESR with deep loamy to clayey mixed red and black soils, medium to high AWC and LGP 150-180 days (I6Cd5)	Satna	24.34,80.50, 317
Transitional AER	11.0	Moderately to gently sloping Chattisgarh/Mahanadi Basin, hot moist/dry subhumid transitional ESR with deep loamy to clayey red and yellow soils, medium AWC and LGP 150-180 days (J3Cd/Cm5)	Hazaribagh	23.59,85.22, 611
Eastern plateau and Eastern ghats, hot sub-humid J23C3(4)	12.3	Chhotanagpur plateau and Garjat Hills, hot, dry-subhumid ESR with moderately deep to deep loamy to clayey red and lateritic soils, medium AWC and LGP of 150-180 days (J2Cd5)	Dhanbad	23.47, 86.30, 156
Eastern plains, hot sub-humid (moist) O8C4	13.1	North Bihar and Avadh Plains, hot dry to moist subhumid transitional EST with deep, loamy alluvium-derived soils, low to medium AWC and LGP 180-210 days (O8Cd/Cm6)	Pusa Purnea Gorakhpur	25.39, 84.40, 52 25.46, 87.28, 38 26.45, 83.25, 78
	13.2	Foothills of Himalayas, warm to hot moist subhumid ESR with deep loamy to clayey Tarai soils, high AWC and LGP 180-210 days (B10Cm6)	Bahraich	27.34,81.36, 124
Asom and Bengal plains, hot sub-humid to humid Q8C(BA)5	15.1	Bengal basin and north Bihar Plain, hot moist subhumid ESR with deep loamy to clayey alluvium-derived soils, medium to high AWC and LGP 210-240 days (O8Cm7)	Asansol Krishnanagar Dumka	23.42, 87.01, 150 23.24, 88.31, 015 24.12, 87.15, 149

within the crop season. The moisture availability index (MAI) is the ratio of weekly expected rainfall at desired probability level and the potential evapo-transpiration of that week. The potential evapotranspiration was estimated based on modified FAO Penman-Monteith method (Allen *et al.* 1994). Weekly MAI at different probability levels starting from 50% to 90% were estimated and the weeks were classified with respect to rice as,

Dry: MAI (at desired probability level) < 0.50

Moist: MAI (atdesired probability level) between 0.5 and 1

Humid: MAI (at desired probability level) > 1

The desired probability level can be chosen by the planners

at different risk levels. Based on MAI during crop season, different crop planning and management strategies are also suggested in this study.

RESULTS AND DISCUSSION

Mean weekly rainfall of the study area

The mean annual rainfall varies from 880.1 mm with a standard deviation of 213.6 mm at Jhansi (4.4 sub-region) to 1589.6 mm at Dhanbad (12.3 sub-region) with a standard deviation of 460.3 mm (Table 2). The coefficient of variation of annual rainfall ranges from 43.9% at Lucknow (9.2 sub-region) to 21.9% at Asansol (15.1 sub-region). The eastern part of the EIGB receives more rainfall compared to other parts of the region. Table 3 shows the mean weekly rainfall, standard deviation and coefficient of variation of rainfall of last 25 years from 1980 to 2005 for 15 the selected stations of EIGB from 18th to 44th SMW. Allahabad (4.3 sub-region) and Jhansi (4.4 sub-region) sites of the same agro-ecological region receive rainfall > 70% of PET from 26th week (25 June, 1 July) to 38th week (17–23 September), with maximum rainfall of 77.1 mm and 92.4 mm, on 37th and 32th week, respectively. The coefficient of variation is below 100% from 28th to 36th week and from 27th to 33th week, for Allahabad and Jhansi, respectively. The distribution pattern indicates that Allahabad receives higher rainfall (more than 50 mm) from 28th to 37th week while Jhansi receives it from 27th to 32th week only. In the case of Lucknow and Faizabad sites of 9.2 sub-region, the coefficient of variation for almost all the weeks is above 100% with maximum rainfall received during the 37th week and 31th week, respectively and very limited pre-monsoon showers.

Rainfall>70% PET starts from 25th week onwards and continue upto 39th week for both the sites. Even though both sites fall under the same sub-region, the weekly rainfall distribution indicates that Faizabad site receives more rainfall compared to Lucknow site. Sagar (sub-region 10.1) and Satna (sub-region 10.3) sites of the Central highlands, hot sub-humid (dry) agro-ecological region receive rainfall of more than 70% PET from 25th week up to 38th week. Maximum rainfall of 125.4 mm and 102 mm, respectively is received during the 31th week at both the Sagar and Satna sites with only few weeks showing less than 100% coefficient of variation. Hazaribagh site of Jharkhand state receives a maximum rainfall of 96.8 mm during the 31st week followed by 91.3 mm during the 26th week. A maximum rainfall of 97.9 mm is received during the 27th week, followed by 97.4 mm during the 30th week at Dhanbad site (sub-region 12.3).

Table 2 Mean annual rainfall (mm), standard deviation and CV (%) of selected stations of EIGB

District/site	Mean annual rainfall (mm)	Standard deviation (mm)	Coefficient of variation (%)
Allahabad	964.3	265.1	27.5
Jhansi	880.1	213.6	24.3
Lucknow	1005.3	441.6	43.9
Faizabad	1158.6	337.5	29.1
Sagar	1243.4	381.0	30.6
Satna	1112.7	250.8	22.5
Hazaribagh	1252.3	302.6	24.2
Dhanbad	1589.6	460.3	29.0
Pusa	1222.4	328.4	26.9
Purnea	1538.0	426.1	27.7
Gorakhpur	1228.4	373.2	30.4
Bahraich	1266.8	354.8	28.0
Asansol	1435.2	314.8	21.9
Krishnanagar	1226.1	472.1	38.5
Dumka	1399.7	449.7	32.1

Pusa and Purnea sites (2 of the 3 in sub-region 13.1) receive maximum rainfall of 81.3 mm and 97.3 mm, respectively on 28th week (9–15 July). The mean rainfall is more than 70% of PET, from 24th week onwards at Pusa but the higher value of coefficient of variation indicate the higher risk factor. From 28th week onwards the coefficient of variation started decreasing and remained below 100% up to 36th week. In case of Purnea site, there are four weeks (29th, 31st, 37th and 39th) having more than 90 mm rainfall. Even though Purnea site is prone to floods during these periods, the high value of coefficient of variation indicates the higher year-to-year variability. Hence farmers of this region can grow their nursery during the last week of May or the first week of June, so that they can transplant their seedlings during the last week of June or the first week of July to utilize maximum rainfall.

The rainfall period lies between 23rd week (4–10 June) to 40th week (1–7 October) for Gorakhpur site (sub-region 13.1). The rainfall period falls between 24th week and 40th week, with a maximum rainfall (90.6 mm) on 28th week. For Bahraich site (sub-region 13.2) the weekly mean data indicate that Asansol site receives maximum rainfall of 86.8 mm during the 39th week (24–30 September), but higher value of standard deviation and coefficient of variation explain the higher year-to-year variability. But Krishnanagar and Dumka sites of the same region receive rainfall greater than 70% of PET from the 21st week onwards and continue up to 41st week. This indicates that this region gets good rainfall during the retreating monsoon period also, even though with higher variability. The weekly analysis shows that the eastern districts of EIGB receive higher rainfall as well as more pre-monsoon rains and this helps the farmers of this region to start their field preparations in advance.

Rainfall probability analysis

Gamma distribution is fitted to non-zero standard meteorological weekly rainfall data of all the sites. The parameters of the gamma probability distribution have been estimated using maximum likelihood method. On the basis of chi-square test, at 95% significance level, gamma

Table 3 Mean weekly rainfall (mm), standard deviation and coefficient of variation (%) of rainfall for selected stations of EIGB

SMW	Allahabad	Jhansi	Lucknow	Faizabad	Sagar	Satna	Hazaribagh
18	1.2±2.6(225)	1.4±4.0(282)	1.7±6(347)	1.2±4(346)	0.5±0.9(189)	1.1±2.2(204)	6.4±12.5(197)
19	2.1±6.5(312)	2.2±6.8(313)	2.3±3.7(158)	1.3±2.6(208)	1.8±4.3(247)	3.4±7.7(226)	12.6±15.5(123)
20	5.4±13.7(256)	2.5±6.2(250)	5.5±9.1(167)	8.6±12.9(150)	3.4±6.8(201)	5.7±11.3(197)	11.8±17.2(146)
21	3.1±9.5(301)	3.7±7.9(216)	5.3±18.1(343)	10.9±21.1(194)	3.4±9.6(283)	1.4±2.8(207)	14.4±19.5(136)
22	2.9±7.4(258)	2.0±5.1(249)	6.4±13.8(216)	5.8±10.3(178)	7.5±14.7(195)	3.3±5.7(175)	9.5±17.4(184)
23	14.8±32.8(222)	11.9±19.1(161)	17.5±34.8(199)	15.6±20.0(128)	20.4±39.4(193)	13.3±36.9(278)	32.3±45.7(142)
24	16.8±37.1(221)	12.6±27.4(217)	14.3±21.1(147)	24.5±28.7(117)	21.9±27.3(124)	10.8±14.4(133)	44.7±59.5(133)
25	29.8±32.8(110)	29.6±37.2(126)	31.4±45.9(146)	47.3±73.5(156)	48.2±58.5(121)	40.2±58.2(145)	38.4±32.8(86)
26	51.0±40.5(79)	44.5±63.1(142)	58.1±67.2(116)	40.3±39.7(99)	47.1±59.8(127)	72.3±60.7(84)	91.3±89.5(98)
27	41.1±54.1(132)	54.3±42.8(79)	42.5±51(120)	51.0±57.7(113)	62.4±76.5(123)	63.8±58.9(92)	62.8±59.6(95)
28	71.5±55.1(77)	62.3±47.1(76)	73.3±59.5(81)	78.9±77.9(99)	92.1±86.6(94)	64.6±37.9(59)	71.9±50.6(70)
29	54.8±49.7(91)	59.3±56.5(95)	61±65.7(108)	107.6±75.9(71)	83.8±82.4(98)	90.3±96.4(107)	89.3±67.5(76)
30	60.7±46.1(76)	63.8±60.9(95)	65±62.7(96)	55.4±44.1(80)	77.3±63(81)	62.6±57.9(93)	70.8±58.2(82)
31	60.8±59.8(98)	69.2±59.6(86)	54.5±51.3(94)	124.7±158.7(127)	125.4±116.8(93)	102±86.8(85)	96.8±77.7(80)
32	69.4±63.7(92)	92.4±83.8(91)	65.9±61.3(93)	99.2±78.7(79)	108.7±88.9(82)	81.8±71.3(87)	72.3±63.2(87)
33	53.7±47.2(88)	52.4±45.2(86)	56.1±58.8(105)	83.1±91.2(110)	95.8±90.5(95)	68.7±47.1(69)	50.9±36.8(72)
34	76.5±94.5(124)	54.0±70.0(130)	44.2±41.2(93)	39.3±30.8(78)	94.5±85.4(90)	70.1±49.8(71)	56.2±52.3(93)
35	70.6±66.8(95)	52.3±58.1(111)	70.8±110(156)	47.5±76.8(162)	73.3±84.4(115)	61.8±70.5(114)	43.6±37.2(85)
36	55.5±51.2(92)	44.6±64.6(145)	64.9±86.4(133)	52.9±56.0(106)	52.3±71.8(137)	72±100.9(140)	66.8±94.8(142)
37	77.1±111.1(144)	52.9±67.5(127)	76.9±117.5(153)	82.3±95(115)	53.6±66.8(125)	54.2±58.5(108)	73.2±74.5(102)
38	30.0±44.8(149)	29.0±49.8(172)	35.4±58.6(165)	45.8±102.3(223)	31±45.2(146)	37.6±47.5(126)	43.3±55.2(127)
39	12.8±17.4(137)	11.2±18.9(168)	25.1±48.8(195)	25.1±26.5(106)	21.6±34.8(161)	16.7±22.3(134)	48.5±51(105)
40	17±27.4(161)	13.6±25.3(186)	17±26.6(156)	39±42.5(112)	15.3±35.3(230)	12.1±17.5(145)	20.8±33(159)
41	8.6±21.7(251)	9.0±32.0(357)	14.5±55.9(386)	2.1±5.2(253)	10.5±26(248)	9.3±20.2(217)	16.5±34.5(209)
42	7.0±20.5(294)	3.4±11.3(330)	9.1±24.8(274)	19.3±43.5(226)	6.3±14.3(229)	6.7±19.9(296)	7.3±12.5(171)
43	0.4±1.9(479)	0.2±0.9(434)	0±0.0	0.6±1.9(346)	1.1±4.8(436)	1.9±6.0(321)	5.6±13.7(246)
44	1.2±4.6(385)	0.5±2.0(368)	4.6±18.9(413)	0.5±1.1(234)	0.2±0.9(433)	1.3±4.7(362)	2.4±5.2(222)

SMW	Dhanbad	Pusa	Purnea	Gorakhpur	Bahraich	Asansol	Dumka	Krishnanagar
18	14.3±22.0(154)	10.1±15.3(152)	18.9±19.4(103)	5.8±11.8(225)	5.1±11(215)	21.7 ±26.8(123)	18.1±30.9(171)	22.4 ±27.7(124)
19	13.4±21.2(159)	10.9±17.6(161)	23.7±26.1(110)	7.2±11.8(164)	7.1±10.4(147)	15±19.8(133)	15.2±26(171)	26.9±39.1(146)
20	21.9±23.9(109)	14.1±27(192)	32.1±30.5(95)	14.9±28.8(194)	10.6±15.8(148)	23.9±24.8(104)	15.2±17.2(113)	18.6±28.6(154)
21	12.6±19.7(157)	19.7±26(132)	25.7±24.8(97)	5.4±11.5(213)	9.9±19.4(197)	29.1±32.3(111)	23.7±30.1(127)	35.6±39.2(110)
22	15.3±20.1(132)	14.2±19(134)	49.5±75.8(153)	17.8±34.7(195)	17.1±38.3(224)	19.7±24.5(124)	21.3±23.3(109)	34±40.8(120)
23	40.0±48.5(121)	21.1±31.3(148)	65.2±103.6(159)	50.4±106.3(211)	13±18.6(143)	58.7+55.3(94)	44.1±44.3(101)	55.9±70.5(126)
24	49.5±42.1(85)	29.2±34.8(119)	53.8±60.8(113)	31.3±45.1(144)	46.1±83(180)	35.5+35.4(100)	47.7±51(107)	28.6±24.7(86)
25	71.5±57.6(81)	58±66.4(115)	52.3±38.7(74)	37.8±48(127)	45.6±46.5(102)	60.1+55.5(92)	55.7±54.5(98)	47±43.3(92)
26	89.7±70.9(79)	60.7±71.5(118)	73.6±68.6(93)	65.5±48.1(74)	56.5±51.8(92)	76.6+73.0(95)	58.4±61.3(105)	62.3±41.6(67)
27	97.9±78.4(80)	68.7±69(100)	88.7±77.8(88)	58.1±51.2(88)	68.8±85.1(124)	76.8+64.4(84)	75±57.8(77)	58.4±58.2(100)
28	68.1±36.6(54)	81.3±75.1(92)	97.3±73(75)	96.9±87.4(90)	104.6±81.7(78)	58.1+46.9(81)	81.2±75.2(93)	95.3±78.7(83)
29	88±78(89)	74.6±69.6(93)	94.5±58.6(62)	70.5±62.8(89)	90.6±92.9(103)	69.8+54.8(79)	76.8±64.5(84)	64.4±47.8(74)
30	97.4±65.4(67)	68.5±61.6(90)	64.8±45.9(71)	61±57.3(94)	75.7±68.4(90)	71.7+60.9(85)	80.8±55(68)	73.1±64.2(88)
31	82.1±68(83)	71.8±66.7(93)	92.7±82.9(90)	65.6±40.8(62)	63.1±51(81)	66.1+57.9(88)	56.8±49.9(88)	50.8±42(83)
32	79.9±57.9(72)	66.1±72.1(109)	51.6±40.2(78)	72.9±63.2(87)	62.8±46.1(73)	59.2+48.4(82.0)	77.8±56.4(73)	39.4±30.3(77)
33	74.4±44.2(59)	70.7±69.9(99)	61.2±69.2(113)	89.2±92.8(104)	76.7±72.7(95)	65.8+50.9(77.0)	75.2±49.2(65)	71±70.1(99)
34	58.3±58(100)	76.4±83.9(110)	76.6±78.6(103)	92±79.8(87)	76±102.4(135)	48.7+56.3(116)	57.6±42(73)	38±45.6(120)
35	82.7±76.4(92)	50.1±46.4(93)	53.3±62.3(117)	58.1±83.6(144)	62.9±69(110)	77.3+64.2(83)	68±67.7(100)	62.3±59.9(96)
36	73.5±63.9(87)	62.3±68.9(111)	68.4±69.5(102)	80.2±72.6(91)	81.2±129.5(159)	68.3+58(85)	57.7±48.8(85)	46.9±76.9(164)
37	83.9±54.9(66)	68±73.3(108)	95.7±83.7(87)	68±59.5(88)	87±118.3(136)	70.1+40.2(57)	61.8±40.9(66)	34.6±36.8(106)
38	59.3±78.5(132)	43.9±56.9(130)	33.4±45.3(135)	38.2±52.7(138)	42.4±64.9(153)	35.3+29.9(85)	48.3±49.4(102)	25.6±24.1(94)
39	90.1±86.9(96)	42.1±55.9(133)	92.1±90.9(99)	32.7±35.7(109)	36.7±72.2(197)	86.8+136.2(157)	79.6±94.2(118)	40.5±59.2(146)
40	58.8±74.3(126)	43.1±80.0(186)	48.5±78.4(162)	30.7±43.2(141)	31.5±62.6(198)	44.1+45.4(103)	62.1±75.9(115)	20.9±27.5(132)
41	35.7±58.8(165)	14.1±24.6(174)	20.5±39.4(192)	6±14.9(249)	14.5±33.1(228)	25.3+33.4(132)	25.5±29.4(194)	27.2±72.6(267)
42	16.0±38.5(240)	9.8±29.7(303)	19.2±45.7(238)	15.3±39.9(261)	9.3±24.7(265)	22.7+50.6(223)	14.8±28.8(235)	9.5±20(211)
43	6.7±14.2(213)	5.5±25.2(460)	2±9.3(458)	0.0±0	0.5±2(381)	8.6+22.8(265)	5.4±12.6(236)	13.8±32.1(233)
44	4.0±9.7(243)	3.2±9.9(309)	4.3±8.7(204)	1.2±4.3(359)	2.4±6.9(286)	7.6+18.6(246)	4.6±10.9(150)	4.7±11.5(246)

[Rainfall ± SD(CV)]

probability distribution is found to represent all the weekly data sets. The minimum expected weekly rainfall for starting field preparation depends mainly on the soil characteristics and evaporative demand of that place. But generally at least 20 mm weekly rainfall is required to start field preparation. The rainfall properties at 70% probability level of each site are summarized below;

A continuous rainfall period is expected between 26th week (25 June–1 July) to 35th week (27August–2 September), except 31st and 27th weeks, with a peak rainfall of 30.7 mm during the 28th and 30th weeks, followed by 30.5 mm during the 32nd week (6–12 August) at Allahabad site. While at Jhansi site, the rainfall period starts from 27th week (2–8 July) and continues up to 33rd week (13–19 August). Thus only 7 weeks are available with an expected rainfall > 20 mm. It is noticed that for Lucknow site, the rainfall period lies between 28th week (9–15 July) to 32nd week (6–12 August), except 29th week and there is probability of getting a maximum rainfall of 38.3 mm during the 28th week, followed by 24.9 mm during the 30th week (23–29 July). But in the case of Faizabad site, the rainfall period lies between 28th week (9–15 July) to 33rd week (13–19 August) with probability of getting a maximum rainfall of 58.4 mm during the 29th week, followed by 41.3 mm during the 33rd week (13–19 August). Even though these two sites are situated in the same agro-ecological region, there is a lot of variation between Lucknow and Faizabad sites.

The rainfall period starts from 28th week (9–15 July) and continues up to 34th week at the Sagar site. However, a peak rainfall of 56.9 mm is expected during the 32nd week (6–12 August), followed by 55.1 mm during the 31st week. While at Satna, rainfall period lies between 26th week (25 June- 1 July) to 34th week (20–26 August) with a peak rainfall of 43.2 mm during the 31st week (30 July- 5 August), followed by 42.1 mm during the 28th week (9–15 July). The expected rainfall pattern suggests no break in the rainfall period once monsoon sets in these sites. It is expected that rainfall of more than 20 mm is received from 26th week (25 June-1 July) to 34th week (20–26 August) at Hazaribagh site. Peak rainfall of 51.1 mm is expected during the 31st week (30 July - 5 August) followed by 46.5 mm during the 29th week (16–22 July). But in the case of Dhanbad site, the rainfall period starts from 24th week (11–17 June) and continues up to 41st week (8–14 October). This indicates probability of 18 weeks with an expected rainfall > 20 mm. However, a peak rainfall of 56.2 mm is expected during the 30th week (23–29 July) followed by 48.1 mm during the 32nd week (6–12 August).

The analysis shows that the rainfall period of Pusa lies between 27th week (2–8 July) to 37th week (10–16 September), except 32nd, 35th and 36th weeks. During this period, at least 20 mm rainfall/week at 70% probability level is expected. Peak rainfall of 30.5 mm is expected during the 28th week followed by 29.8 mm during the 29th week at 70% probability level. But in case of Purnea site, the rainfall period lies between 25th (18–24 June) to 37th week (10–16 September), except 33rd week. A peak minimum rainfall of 54.1 mm is expected at 70% probability level during the 29th week followed by 48.1 mm during the 28th week. Even at 90% probability level, during the 28th and 29th weeks (9–15 July and 16–22 July) there is an expected rainfall of at least 20 mm. The rainfall pattern indicated that there are two rainfall maxima within the monsoon season and this shows that there will be a small break within the monsoon activity after occurrence of heavy showers during the initial phase of monsoon. It is observed that rainfall period lies between 28th week (9–15 July) to 34th week (20–26 August) at Gorakhpur site and there is a chance of getting a maximum rainfall of 37.3 mm during the 28th week followed by 37.2 mm during the 31st week (30 July–5 August). But in the case of Bahraich site, the rainfall period starts from 26th week onwards and continues upto 34th week (20–26 August) and peak rainfall of 41.1 mm is expected during the 28th week (9–15 July), followed by 34.6 mm during the 29th week. For Asansol site, at least 20 mm rainfall is expected from 25th week (18–24 June) up to 39th week (24–30 September) except 34th and 38th weeks. Peak rainfall of 46.2 mm is expected during the 37th week (10–16 September), followed by 36.4 mm during the 26th week (25 June - 1 July). But in the case of Krishnanagar site, the rainfall period starts from 25th week onwards and continues upto 35th week only (27 August-2 September) and peak rainfall of 44 mm is expected during the 28th week (9–15 July). It is found that an expected rainfall of more than 20 mm is received from 27th week (2–15 July) to 37th week (10–16 September) at Dumka site.

Occurrence of dry and well spells

The probability of occurrence of a dry week is low (below 40%) from 28th week onwards and conditional probability of dry week preceded by a dry week is low from 30th week onwards for Allahabad site. The probability of occurrence of two and three consecutive dry weeks is low (below 40%) from 25th and 24th week onwards, respectively. The conditional probability of a wet week preceded by a wet week is high (more than 60%) from 27th week to 38th week. It is also noted that the probability of occurrence of three consecutive wet weeks reach 50% during 34th and 35th weeks. But in case of Jhansi site, the probability of occurrence of a dry week and the conditional probability of occurrence of a dry week preceded by a dry week are low from 27th and 28th week, respectively.

In the case of Lucknow site, the probability of occurrence of dry week is always above 30% except for the 28th week. The conditional probability of occurrence of a dry week preceded by a dry week is low from 29th week, but it is highly fluctuating in every week. However, the probability of occurrence of two or three consecutive dry weeks is low from 26th week to 36th week. The conditional probability of wet week preceded by a wet week is more (above 60%) from

27th week and up to 38th week. For Faizabad site, the probability of occurrence of a dry week is low from 27th week onwards and conditional probability of dry week preceded by a dry week is low from 29th week onwards. But the probability of occurrence of two and three consecutive dry weeks is low from 23rd and 22nd week onwards, respectively. In the case of Sagar site, the probability of occurrence of dry week is low from 28th week 34th week. The conditional probability of occurrence of wet week preceded by a wet week is high from 26th week onward and continues upto 37th week. For Satna site, the probability of occurrence of a dry week is low from 26th week onwards and conditional probability of dry week preceded by a dry week is low from 28th week onwards.

For Hazaribagh site, the probability of occurrence of a dry week and the conditional probability of occurrence of a dry week preceded by a dry week are low from 25th week. But the probability of occurrence of two consecutive dry weeks is low from 24th week 39th week and the probability of occurrence of three consecutive dry weeks is low from 23rd week to 39th week. The conditional probability of occurrence of wet week preceded by a wet week is high from 26th week up to 40th week. The probability of occurrence of a dry week is low from 24th week onwards and conditional probability of dry week preceded by a dry week is low from 25th week onwards for the Dhanbad site. But the probability of occurrence of two and three consecutive dry weeks is low from 23rd and 22nd week onwards, respectively. The conditional probability of a wet week preceded by a wet week is high from 25th week to 41st week.

In the case of Pusa site, the probability of occurrence of dry week is low from 26th week up to 39th week. But the conditional probability of occurrence of dry week preceded by a dry week is low from 29th to 39th week. However, this pattern is not continuous during 30th, 34th and 38th weeks. The conditional probability of occurrence of dry week preceded by a dry week is low from 26th week onwards, but probability of occurrence of two or three dry weeks is low from 19th week itself and continues up to 40th week for Purnea site. However, the conditional probability of occurrence of wet week preceded by a wet week is high from 24th week to 41st week except 36th and 39th week. The probability of occurrence of two consecutive wet weeks is more from 28th week, but for three consecutive weeks, it is fluctuating between low and high. The probability of occurrence of a dry week is low from 26th week to 37th week, but the conditional probability of occurrence of dry week preceded by a dry week is low from 26th week at Gorakhur site. For Bahraich site, it is observed that the initial probability of occurrence of dry week is low from 26th week to 37th week and the conditional probability of occurrence of dry week preceded by a dry week is low from 27th week to 37th week. The probability of occurrence of two consecutive dry weeks is low from 25th week and continues upto 38th week while the probability of occurrence of three consecutive dry weeks is low from 23rd week to 39th week.

The probability of occurrence of a dry week is low from 25th week onwards and conditional probability of dry week preceded by a dry week is low from 26th week onwards for Asansol site. But the probability of occurrence of two and three consecutive dry weeks is small from 23rd and 20th week onwards, respectively. The conditional probability of a wet week preceded by a wet week is high from 26th week onwards and continues up to 41st week. It is also revealed that the probability of occurrence of three consecutive wet weeks never reach 50%. But in Krishnanagar site, the probability of occurrence of a dry week is low from 26th week; however, from 32nd week onwards there is large fluctuation. The conditional probability of dry week preceded by a dry week is low from 26th week, but continued upto 31st week only. It is noticed that the probability of occurrence of two or three consecutive dry weeks started decreasing from 21st week onwards and continued up to 37th week. The conditional probability of occurrence of wet week preceded by a wet week is high from 27th week onwards, but after 34th week it shows large fluctuations and rapidly become zero during 41st week. For Dumka site, it is observed that the initial probability of occurrence of dry week is low from 24th week and the conditional probability of occurrence of dry week preceded by a dry week is low from 26th week to 38th week. The probability of occurrence of two or three consecutive weeks is low from 23rd week and continues upto 40th week.

Moisture availability index

It is noticed that at Allahabad at 70% probability level, MAI is higher (>0.5) from 28th weeks and continued up to 35th week. However, the MAI never reaches > 1.0 in any of weeks. This indicates the crop will be always in moist situation for 7 weeks and in the remaining weeks the crop will be under stress condition. In the case of Jhansi site, MAI attains maximum (> 1.0) during 27th week with the onset of monsoon and remains less than 1.0 during all the weeks. This indicates that at 70% probability level, the rice crop will be under moist situation during 28th week to 33rd week. As far as Lucknow site is concerned, there is only one week (28th week) which is having MAI more than 1.0 and from 29th week onwards MAI is less than one but greater than 0.5 and continued up to 33rd week. This indicates the crop will be in moist situation only for 5 weeks and in the remaining weeks the crop will be under stress condition. However, for Faizabad site of the same sub-region shows higher MAI from 29th week to 33rd week, except 30th week.

For the case of Sagar site, it is noticed that the MAI is higher than 0.5 from 28th to 35th week. Moreover, it is >1.0 during 31st week to 33rd week. In the case of Satna site, it is noticed that at 70% probability level, MAI is higher (>0.5) from 26th weeks and continued up to 34th week. However, the MAI reaches > 1.0 during 31st to 34th weeks. This indicates

that the crop will be under humid situation continuously for four weeks. From the analysis it is noticed that for Hazaribagh site, the MAI is more than 0.5 from 25th week and persists up to 37th week. But the value of MAI reaches higher than 1.0 during 26th to 32nd week, except 27th and 30th weeks. For Dhanbad site, it is noticed that at 70% probability level, MAI is > 0.5 from 24th week and continued up to 39th week. However, the MAI is higher from 26th week to 33rd week. This indicates the crop will be under humid situation for almost 2 months. In the case of Pusa site, MAI starts increasing from 24th week and reaches more than 0.5 from 27th week and continued up to 37th week. But it never reaches more than 1 during this period. This indicates that at 70% probability level, the rice crop will be always under moist situation. But for the case of Purnea site, MAI is more (>0.5) from 25th week to 39th week continuously. However, for Gorakhpur site, the MAI is more than 0.5 from 26th week to 37th week. Even though, these sites located in the same sub-region, moist period is larger for Purnea than for Gorakhpur. For Bahraich site, although the MAI is higher from 26th to 37th week, but MAI > 1.0 happened only during 28th week. This indicates that the rice crop will be under moisture stress from 38th week onwards at 70% probability level. For Asansol site, it is noticed that at 70% probability level, MAI is more (>0.5) from 25th weeks and continued up to 39th week except 34th week, but MAI is higher (>1.0) during 34th to 36th week, which normally coincides with the milky stage of the crop. But for Krishnanagar site, the MAI is more from 25th to 35th week, but for Dumka site, MAI is more than 0.5 during 27th to 37th week. Hence, moist period is lengthier for Asansol followed by Krishnanagar and Dumka.

Spatial variation of rice productivity and crop planning and management strategies

The spatial variation of rice productivity at the district level during the triennium ending 2000–01 indicated that a wide spatial variation in rice productivity. This spatial variation is mainly due to water availability during the crop period. There are only six districts with high rice productivity (> 2 500 kg/ha), 21 districts with medium productivity (2 000–2 500 kg/ha), 20 districts with medium-low productivity (1 500–2 000 kg/ha), 23 districts with low productivity (1 000–1 500 kg/ha) and 19 districts very low productivity (< 1 000 kg/ha). The low productivity is a result of bio-physical factors like low expected irrigation, undulating physiography and extreme climatic events like floods and droughts on one side and poor socio-economic status of rice farmers leading to poor crop management. The appropriate crop management strategies are given below,

Sub-regions 15.1: It is evident that the initial wet period starts from 22nd week and hence this period is suitable for transplanted rice from the first week of June. Medium (110–130 days) to long duration (140–150 days) varieties can be grown as this region has relatively long rainy period and seasonal surplus water availability. For long-duration varieties water stress will affect only after 39th week, by which time the crop will be near maturity. Ensuring right time of nursery raising and transplantation is most important in transplanted rice. Field bunding will help to conserve rain water. However for Krishnanagar and Dumka districts, it is better to plant short (90–100 days) and medium (110–125 days) duration varieties as water stress condition will start from 36th and 38th week, respectively. Long duration varieties will face water stress during milky and dough stages (grain development) and will thereby have reduced yield.

Sub-regions 13.1 and 13.2: Generally these sub-regions, moist period starts from 27th week up to 37th week (70days) and dry conditions period starts from 38th week onwards. This is good for medium duration varieties to be grown without water stress till maturity. Long duration varieties can be taken as transplanted rice in low land region where there is stagnant run off water. Timely planting is important as some areas face inundation from runoff water. In medium to uplands long duration varieties will suffer water stress during reproductive stages under rainfed condition. Purnea has a relatively longer rainy period (25–39th week) and well-distributed moist and humid periods and long duration rice varieties can be grown without water stress in this region as timely transplanting is possible as indicated by rainfall distribution.

Sub-regions 11 and 12.3: These regions have relatively larger rainfall duration. However, humid period dominates from 25–34th weeks. Direct seeded upland rice is the major crop in this region, which is suited to rainfall distribution and topography. Dry spell comes only towards the dough stage and ripening stage by which time the damage to crops is minimum. Medium duration varieties are ideal for this region. Introduction of direct-seeded and transplanted aerobic rice varieties in this region can increase productivity. In Dumka, though the region has prolonged rainfall, two dry spells come in 25th and 37th weeks. First dry spell may affect the tillering in early transplanted rice where as second dry spell can affect grain filling in case of medium and long duration varieties. However, residual moisture in the soil can save the situation. In uplands and incase of delayed sowing short duration (90–100 days) varieties, may be preferred for this region. In case of delayed sowing, pre monsoon tillage will help to conserve moisture and check weeds. Closer spacing is ideal for delayed sown conditions.

Sub-regions 4.3, 4.4 and 9.2: These sub-regions have relatively shorter monsoon season and variability in distribution is more. Early drought during seedling stage is a possibility. Summer ploughing can help conserve soil moisture in this region. Only short-duration varieties can be taken up in areas, which are purely rainfed. Long and medium duration varieties may suffer water stress from flowering period. Also this region has suitability for medium duration varieties on purely rainfall basis. However, dry spell during

panicle initiation is a cause of concern. *In situ* water harvesting and runoff collection measures are important to protect the crop with lifesaving irrigation.

Sub-regions 10.1 and 10.3: These region have dry spells during onset as well as later stage of monsoon. Early drought and stress during reproductive stage is a strong possibility. Here short-duration rice varieties may be preferred in purely rainfed situations. Direct sowing and drum seeding are possible options of sowing than transplanting.

The rainfall analysis indicate that the western part of the region is having more probability of water stress period (dry: MAI<0.5) during the critical phenophases of the crop and this is the main cause for the very low productivity in this region. To more closely meet the crop water requirements and water deficits during the critical growth periods, supplemental irrigation was recommended. Hence, in addition to the site specific management strategies mentioned above, adoption of run-off rainwater management conservation measures suited to small and marginal farmers, which enables the farmers to provide life saving irrigation to the crop wherever possible during long dry spells, may also recommended to increase the rice productivity of the region. Since most of the farmers in this region are poor, the adoption of non-monetary inputs like timely sowing, application of balanced dose of fertilizers, timely irrigation and timely harvesting of crops may also affect the productivity.

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