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Probability of occurrence of drought in relation to rainfed rice productivity in the old alluvial region of West Bengal

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Abstract
Climate change makes conditions suitable or unsuitable for growing crops in different regions. The greatest threat posed by climate change is change in monsoon. A period of drought is defined by low average precipitation, poor rain or higher evaporation rates which reduces crop growth and yield. In this study, an attempt was made to characterize agricultural drought with the help of rainfed rice crop yield rate and rainfall. Rainfall data and rainfed rice or Aman rice yield rate data from 1978 to 2020 of Malda district in West Bengal were analyzed for determining the probability of rainfed rice specific drought in Malda. An amount of 36.3 mm rainfall for three consecutive weeks was identified as drought threshold value in the test location. The recurrence of drought for the study area has also been studied.

Keywords: Drought, crop specific drought, probability and rainfed rice

1. Introduction
One of the most significant environmental issues confronting mankind is climate change. The greatest threat posed by climate change to lives and their means of subsistence is change in monsoon. A total rainfall of about more than 70% occurs in India, especially on four months of each year i.e., June to September [1]. Monsoon has been the source of economic uncertainty in India.

Around 60% of Indian agriculture is rainfed which accounts for about 20% global grain production, which is majorly contributed by monsoon season. Rice is one of the staple crops mostly grown in India in three seasons i.e., Aus, Aman, and Boro out of which there is an increasing dominance of monsoon season in rice ecosystems [8]. Rice production resultant are known to be strongly linked to monsoon conditions i.e., total rainfall and their temporal distributions i.e., on number of rainy days [3]. The rainfall distribution is uncertain, erratic and unpredictable causing mild to severe stress during different phases of plant growth [10].

Rice production system is most sensitive to climate change in agro-ecosystem [2]. The three monsoon characteristics has been regressed along with drought indicator, among which only total June-September rainfall and the drought indicator was significant. The regression result indicate that the rice yield decreased by 12% when a drought occurred. Indeed, due to extreme dry year a significant reduction in the rice yields was observed [4].

The success or failure of rice grown in monsoon season i.e., rainfed rice is anticipated by positively determined South West monsoon pattern [7]. During South West monsoon season precipitation is generally high in Malda district of West Bengal. Despite being a region that receives extreme rainfall at South West monsoon, it's also affected by climate change [6]. Monitoring of weekly rainfall is necessary since dry spell of more than a week affects rice crop growth [11].

2. Materials and Methods
Malda district which is located in the old alluvial zone of West Bengal was selected for the present investigation.

The rainfed rice or Aman Rice productivity data for Malda district from 1978 to 2014 was collected from Statistical Abstract, 2015 to 2020 from Directorate of Agriculture. Daily rainfall data for 43 years from 1978-2020 was collected from IMD (Indian Meteorological Department) Pune. The daily data was summed up for each Standard Meteorological Week (SMW) and the respective SMW which falls within Aman rice cultivation (i.e., 22nd SMW to 41st SMW) was used. The standard rainfed rice yield rate was obtained by taking mean of productivity of all given years for further analysis.

2.1 Drought threshold

A weekly sum from 22nd SMW (i.e., 28th May -03rd Jun) to 41st SMW (i.e., 08th Oct -14th Oct) was selected for calculating the 'n' week rainfall total, where $2 \leq n \leq 19$. The weekly total for every SMW week where $22 \leq m \leq 41$ was prepared. These totals add up to 'n' successive week rainfall. If $n = 5$, there will be 15 rainfall totals, each rainfall total consists of 5 consecutive week totals. The minimum value for each n^{th} week i.e., $2 \leq n \leq 19$ was plotted against the mean deviation of standard rainfed rice yield rate (kg ha^{-1}) for finding the threshold values. A drought threshold value is the minimum value below which a drought condition exists. For each value of 'n', the minimum rainfall total observed per year among these 'n' rainfall totals for different 'm' values were chosen.

2.2 Models fitted to drought threshold values

The models such as Linear, quadratic, Cubic, Inverse and Logarithmic was fitted to the drought threshold value for each n week total. The best fitted model was determined for obtaining the drought base values. The drought base values were used to estimate the amount of rainfall below which drought condition exists. This rainfall is the minimum rainfall in a particular region for a given number of successive weeks. So, for a given year if the total rainfall of 'n' weeks for any m^{th} week is lower than the drought base value, it indicates crop specific drought [5] & [9]. It's possible to determine whether a year suffered from drought or not by looking at the frequency of different length deficits within a year.

2.3 Probability of drought

The probability of crop specific drought was determined by relative frequency of drought incidence (i.e., $\frac{\text{Frequency}}{\text{No.ofyears}}$). The cumulative frequency over the years for every value that is less than the base value for every week of the 'n' week total rainfall gives the crop specific drought probability [5, 9].

3. Results and Discussion

The minimum rainfall for each week from $2 \leq n \leq 19$ were plotted against the standard rice yield rate (kg ha^{-1}). The deviations from standard yield rate were represented as points in the scatter plots shown in Fig. 1 for n =10 and Fig. 2 for n =19. The drought threshold value was selected from this Fig.1 for n =10 as 348 and for n =19 as 845.1. Similarly, for all $2 \leq n \leq 19$ values drought threshold values were selected and shown in Table 1. From these values, it ensures that drought threshold value escalate with increasing n weeks.

Table 1: n -week drought threshold value and predicted drought base value based on cubic model.

n	Threshold value (mm)	Base value (mm) based on cubic model	n	Threshold value (mm)	Base value (mm) based on cubic model
2	0	1.4	11	402	399.9
3	36.3	28.2	12	422.9	456.3
4	59.2	60.8	13	539.5	512.8
5	96.9	98.7	14	577.5	568.8
6	129.5	141.2	15	645.2	623.5
7	186.3	187.6	16	672.2	676.3
8	248.3	237.4	17	702.2	726.6
9	286.9	289.7	18	745.9	773.7
10	348	344.1	19	845.1	817.0

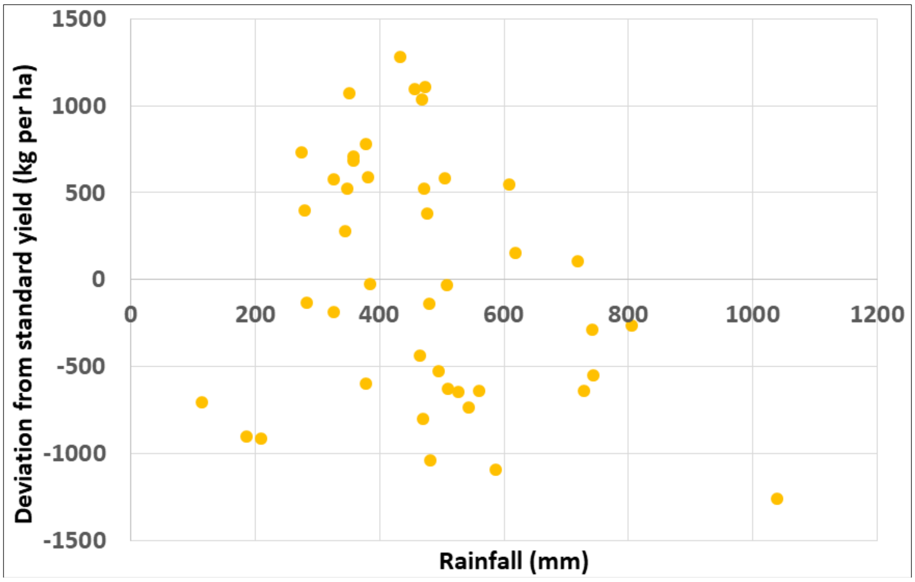

Fig 1: Deviation from standard yield rate for n = 10

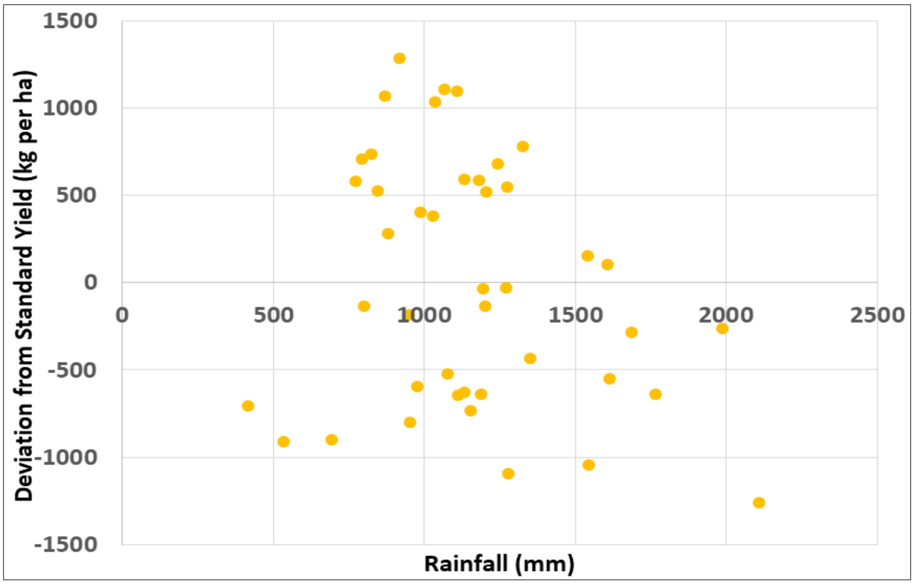

Fig 2: Deviation from standard yield rate for *n* =19

Models have been fitted to the *n* weeks as independent variable and drought threshold values as dependent variable. Linear, quadratic, cubic, inverse and Logarithmic models along with parameters were shown in Table 2. Based on Model validation technique- R^2 and Mean square error value, it was concluded that the Cubic model having the least MSE value (350.72) and highest R^2 value (0.996) is the best fit. In the cubic model, β_2 and β_3 parameter was found to be significant with p value less than 0.05. This cubic model was used to find the predicted drought base value as given in Table 1. For *n* =3, if three consecutive weeks total of any m^{th} week in a year is found to be less than 28.2 mm, then there exists a rainfed rice specific drought of 4 weeks long in Malda district of West Bengal.

Table 2: Models fitted to *n* -week and drought threshold value

Model	Model with parameters	R^2	Mean Square Error (M.S.E)	t-value with (p-value)			
				β_0	β_1	β_2	β_3
Linear	$Y = -145.14 + 50.56\,x + e$	0.992	631.40	-10.86 (0.000)	44.29 (0.000)	-	-
Quadratic	$Y = -102.11 + 39.72x + 0.52x^2 + e$	0.994	489.74	-4.72 (0.000)	8.49 (0.000)	2.372 (0.031)	-
Cubic	$Y = -31.87 + 9.24x + 3.92x^2 - 0.11x^3 + e$	0.996	350.72	-9.86 (0.341)	0.756 (0.462)	3.01 (0.009)	-2.64 (0.020)
Inverse	$Y = 643.20 - \frac{1818.76}{x} + e$	0.617	29867.42	9.89 (0.000)	-5.080 (0.000)	-	-
Logarithmic	$Y = -466.38 + 389.90\ln(x) + e$	0.878	9533.28	-5.37 (0.000)	10.72 (0.000)	-	-

The probability of crop specific drought for *n* week duration from *m* week are presented from 22nd SMW to 41st SMW respectively in the Table 3. The probability of *n* =5 for *m* =22, and for *n* =4 for *m* = 23 is 0.116. This implies that probability of consecutive five weeks and four weeks long duration drought occurring from 22nd SMW to 27th SMW and 23rd SMW to 27th SMW for a given year is 11.6%. Drought of this kind is possible to occur every 1/0.116 = 8.6 ≈ in 8 years. The rice growth phases that are affected by 4 weeks duration drought is from Land preparation to seedling transplanting (0.116) and 5 weeks duration drought is from Land preparation until seedling transplanting (0.116). From the table it is evident that the chance of occurrence of drought in 4 consecutive weeks ranges from 2.3% to 11.6%. Therefore, it was concluded that Malda District is receiving sufficient amount of rainfall in South West Monsoon season and the chance of occurrence of drought in rice growth stages is moderate.

Table 3: Probability of drought occurrence on different weeks of rainfed rice growth.

Week No. (*m*)	SMW	Rainfed Rice Growth	Week duration (*n*)				
			3	4	5	9	13
22 Week	28thMay-03rdJun	Land Preparation	0.093	0.093	0.116	0.023	0.116
23 Week	04thJun-10thJun	Land preparation	0.070	0.116	0.093	0.023	0.116
24 Week	11thJun -17thJun	Sowing to Germination	0.047	0.047	0.047	0.023	0.116
25 Week	18thJun- 24thJun	Emergence to seedling	0.023	0.023	0.047	0.023	0.070
26 Week	25th Jun- 01st Jul	Emergence to seedling	0.023	0.047	0.023	0.023	0.070
27 Week	02nd Jul -08th Jul	Seedling Transplanting	0.047	0.000	0.023	0.093	0.140
28 Week	09th Jul -15th Jul	Tillering	0.000	0.000	0.023	0.093	0.116
29 Week	16th Jul -22nd Jul	Tillering	0.000	0.000	0.023	0.070	
30 Week	23rd Jul -29th Jul	Tillering	0.000	0.000	0.023	0.093	
31 Week	30th Jul-05th Aug	Stem Elongation	0.023	0.000	0.070	0.070	
32 Week	06th Aug -12th Aug	Panicle Initiation	0.023	0.047	0.070	0.116	
33 Week	13th Aug-19th Aug	Booting	0.000	0.047	0.070	0.070	
34 Week	20th Aug -26th Aug	Heading	0.023	0.047	0.047		

35 Week	27th Aug- 02nd Sep	Flowering	0.047	0.070	0.047		
36 Week	03rd Sep- 09thSep	Grain Filling	0.023	0.023	0.023		
37 Week	10th Sep-16th Sep	Milking	0.023	0.023	0.000		
38 Week	17thSep -23rd Sep	Doughing	0.047	0.023			
39 Week	24thSep- 30th Sep	yellowing	0.093				
40 Week	01stOct - 07thOct	Ripening					
41 Week	08th Oct- 14th Oct	Maturity					

4. Conclusion
Rice is a water loving crop which is sensitive to drought in crop growth stages. Drought threshold were calculated for *n* consecutive weeks and different statistical models were fitted to the drought threshold values. Using the best fitted model criteria, cubic model was adjudged to be the best fit. Drought base values were predicted using the cubic model. These base values used for predicting the chance of occurrence of drought in *n* consecutive weeks help in finding the recurrence of Aman rice crop specific drought in Malda.

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