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Statistical Analysis for Prediction of Hydrological Events of Budelkani Watershed Area for Planning Rainfed Rice

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ABSTRACT

Statistical analysis of hydrological event like rainfall was carried out for 23 years (1993-2015) for prediction of other hydrological events such as occurrence of effective monsoon (OEM), critical dry spell (CDS) and withdrawal of monsoon (WM). All events predicted by FLOOD software developed by IIT Kharagpur, West Bengal, India for different probability of exceedence (PE) levels from 10-90%. Their performances were indicated by the Chi-square test, mean absolute relative error (MARE), model efficiency (ME), root mean square error (RMSE) and coefficient of determination (CD). At 50% PE level, for OEM and WM, Gumbel (Extreme value minimum) and Pareto distributions were best fitted with 168th and 269th Julian days, representing June 17 and September 26, respectively. Average duration between OEM and WM was found to be 102 days. There were two critical dry spells (CDS) dominated at study area named to be CDS_1 and CDS_2. These two dry spells were occurred on 213th and 235th Julian days with 12 days duration each with starting date from 1st August and 24th August, respectively. Pareto and Beta distribution function were best fitted for the above CDSs on the aforesaid Julian Days (i.e. on 213th and 235th Julian days), while Gumbel (Extreme value minimum) and Beta distribution function were found to be the best for deciding the occurrences of CDS of 12 days duration at 50% PE level. The study revealed that the short duration rice would face less drought stress than the long duration rice. Hence, short duration rice variety of 100-110 days duration was selected.

KEYWORDS: CDS, FLOOD software, Julian days, OEM, WM

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1. INTRODUCTION

Predictions of hydrological events have great impact on agriculture, hydrology and other environmental resources, because of erratic distribution of rainfall. Analysis of rainfall probability provides the general information about the rainfall pattern of a specific region on temporal scale (Raju and Bhatia, 2013). While change in climate continuously increases pressure on hydrological events on regional basis, which pressurizes on the availability of water resources (Caloiero and Coscarelli, 2020). In that sense it is crucial to understand variation of onset and withdrawal of monsoon in different parts of the country. Also, there is a tremendous impact on effective agricultural planning, food security and lives of labour in agriculture and other allied sectors due to change in monsoon duration (CRS Research Report, 2020). The knowledge of the rainfall i.e., its onset, amount, distribution, withdrawal, effective rainfall, the dry and wet spell(s), probability of distribution and forecasting, is an important input in the effective management of water and agronomical operations i.e., seedbed preparation, sowing, weeding, harvesting, threshing and drying of agriculture crops (Nandgude, et al., 2010; Mandal, et al., 2013; Pawar, et al., 2019; Rajan and Desamsetti, 2021). Additionally, it minimizes the risk on the crops and optimise the utilisation of limited resources i.e., water, labour, fertilizer, herbicides and insecticides (Movi and Tupper, 2004). The analysis of dry and wet spell helped in determining the pattern of intra-seasonal drought and management techniques of the interested region (Kumar and Rao, 2005; Cindric and Pasaric, 2018; Sirangelo et al., 2019; Adane et al., 2020).

Researchers across the world have attempted numerous quantitative approaches to determine onset and withdrawal of the monsoon over India and other countries of South-East Asia and East Asia. In this context, Taniguchi and Koike (2006) determined the onset date of Indian monsoon using three factors (vertically integrated water vapour, moisture transport and low-level wind) in an objective manner. Zeng and Lu (2004) calculated Livio's Golden Ratio (GR) using daily normalized precipitation data globally available for 1° grid cells and used unified threshold to the GR (=0.618) to determine the onset and retreat dates of the various monsoons. Zhang et al. (2004) proposed two conditions for the onset of the monsoon over the tropical Asian region (South of 20°N) (i) Formation of a zonal vertical shear, with low-level westerlies (850 Hectopascal (hPa)) and upper-level easterlies (200 hPa). (ii) A pentad that emits outgoing long wave radiation (OLR)<240 Wm^{-2} (Watt per Square metre). The onset date is determined when the Local Hydro-Meteorological Index (LHMI) exceeds 1.0 and the General and Regional Atmospheric Circulation Intensity Index (GARACII) exceeds the specified threshold. According to the report of Indian Institute Tropical Meteorology, the arithmetic means of the LHMI and GARACHI is calculated for withdrawal date. When the mean falls below the specified threshold value, the first day of the 30-day period is used as the withdrawal date (Singh and Rande, 2010). Dabral et al. (2014) studied dry and wet spell probabilities with the objectives of forecasting dry and wet spell using Markov Chain model and finding out the exact time of onset and termination of monsoon. Probabilities of dry and wet spells have been investigated by several other researchers (Fitsume and Desalegn, 2013; Eze et al., 2016).

The methodology used by these researchers is not possible to use by everyone because of huge data requirement and expensive instruments required to collect data. Also, everyone has not required knowledge to operate the instruments to collect data. Some researchers have concluded that the deterministic prediction of monsoon system evolution has proven to be a difficult task (Krishnamurthy and Shukla, 2012; Evin, et al., 2018; Dawley, et al., 2019). The study of probability distribution function provided an easy methodology, which can be used by anyone and anywhere with minimum expenditure. Hence the objective of this research paper is to predict the hydrological events like OEM, CDS and WM., which may be obtained through the analysis of probability distribution functions.

2. MATERIALS AND METHODS

2.1. Study area

The Budelkani micro-watershed area situated in the rainfed region of Sundargarh district, Odisha, India. It includes three villages namely Budelkani, Majhapara and ledimong with total geographical area of 651.25 ha. The watershed is situated at distance of 32 km from the Sundargarh district. It is situated between N 22°0' 33'' to 22° 1' 22'' Latitude and E 84° 10' 57'' to 84° 13'14'' Longitude. The data was collected from the KVK Sundargarh over a period of 23 years from 1993-2015. The mean annual rainfall of this watershed is 1138.62 mm. The maximum temperature was observed to be 45°C in the month of May and minimum was 4°C in the month of December, respectively. The minimum and maximum relative humidity varied from 23.1–94.3% in month of February and September, respectively. The wind speed in the area was very low at 0.27–1.6 ms^{-1}. The climatic condition of study area is humid and subtropical in nature. The elevation of Budelkani watershed is 265 m from the mean sea level.

2.2. Onset of effective monsoon (OEM)

Effective monsoon is defined as the monsoon that leaves enough moisture in the seeding zone after meeting the evaporation losses to take up agricultural operations. While deciding the criteria of OEM, type of soil and the crop to be grown in the field should be considered. Based on the above-mentioned considerations, Verma and Sarma (1990a) presented the following criteria for determining the occurrence of OEM, are as

a. The amount of rain on the first day of a seven-day period should not be less than 'e' mm, where 'e' is the average daily seasonal pan evaporation.

b. During the seven-day period, total rainfall, should not be less than effective onset rainfall.

c. At least three out of seven days are rainy days having at least 2.5 mm rain each day.

If the above criteria are satisfied in a week of any month but followed by prolonged dry spells then it should be considered as a pre-monsoon spell, not OEM.

The effective onset rainfall is computed as:

$EOR=0.75\times(FC-WP)\times d_e+(5\times e) + SR$.......................(1)

Where, EOR = Effective Onset Rainfall, mm; FC and WP = Moisture content on volume basis at field capacity and at permanent wilting point respectively, percent; d_e = Effective seeding zone depth or the ploughing depth whichever is more, cm; e=Average daily pan evaporation, mm; SR=Surface runoff, mm.

2.3. Withdrawal of monsoon (WM)

Withdrawal of monsoon plays a crucial role in rainfed farming system in deciding the duration of monsoon. Some literatures are available for defining the criteria of WM are (Panigrahi et. al., 2002): (i) last two days in the seven days of the last wet spell of season should have at least 2.5 mm rain, (ii) the rain in the seven days spell should be more than (2e+10) mm (where 'e' is the average daily seasonal daily pan evaporation), and (iii) one of the rainy days in the last wet spell should have rain more than 'e' mm.

2.4. Critical dry spell (CDS)

Deficiency of rainfall in crop growing season results in drought. Ashok Raj (1979) suggested that the dry spell is an interval between the end of the seven-day spell beginning with OEM and another seven-day spell beginning with a rainy-day having rainfall of 5×e mm in which 4 days should be rainy days. Rainfall of each day should be more than 2.5 mm. Tiwari and Saxena (1987) defined a day with rainfall less than the crop water requirement considered as dry from the point of view of crop production. The dry days for two or more consecutive days constitute a dry spell.

Verma and Sarma (1989) suggested two criteria for wet spell and the intervening period was defined as dry spell. The criteria are: (i) a rainy day having at least 'e' mm rainfall (where 'e' is the average daily seasonal pan evaporation), (ii) a spell of two rainy days with rainfall at least 5 e mm; or a week during which at least three rainy days with total rainfall amount of at least 5 e mm for rice crop, If the dry spell exceeds 10 days, then it is called as CDS (Tiwari and Saxena, 1987; Singh et al., 1989).

The occurrence of OEM, WM and duration of different CDS were determined using 23 years of climatic data which are shown in Table 1. The data of different hydrological events were converted to Julian days, with the first January being 1, the second January being 2,…….., and so on. The five model performance indicators such as, Chi-square test, Mean absolute relative error (MARE), Model efficiency (ME), Root mean square error (RMSE) and Coefficient of determination (CD) were used to find out the best fit distribution among them.

The hydrological events statistically analyzed by "FLOOD" software with 11 probability distribution functions. These functions are. (i) Normal (ii) Log normal (2p) (iii) Generalized Pareto distribution (Pareto) (iv) Gamma (v) Gumbel (Extreme value maximum) (vi) Gumbel (Extreme value minimum) (vii) Beta (Viii) Pearson (ix) Log-pearson (x) Extreme value type III (EV Type III) (xi) Generalized extreme value (GEV).

3. RESULTS AND DISCUSSION

3.1. Onset of effective monsoon (OEM)

Rice is the major crop grown in rainy season in Eastern India. Average values of FC and WP for the dominant loamy sand and sandy loam soil having depth of 0-60 cm are found to be 19% and 9% on volumetric basis, respectively. The effective seeding zone depth of rice for good germination was assumed to be 15 cm. The maximum possible ploughing depth by bullock power was found to be 20 cm. Therefore, computation of EOR by using equation (1), the value of d_e was assumed as 20 cm. Surface runoff is considered as 10% of the onset week rainfall for the sandy loam soil of the study area (Verma and Sarma, 1990a). Average daily pan evaporation was observed to be 4.5 mm (Table 1).

The model for predicting the OEM was calculated by FLOOD software at different probability of exceedence (PE) (10-90%) with 10% interval. Julian days for OEM varies from 175.39 and 157.42 at 10% and 90% of probability of exceedence (PE). It was observed that OEM data series in Julian days skewed with a co-efficient of skewness (C_s) values of 1.247. The mean, standard deviation and coefficient of variation found to be 166.217, 6.22 and 0.0374, respectively. The best fit probability distribution function for OEM was obtained by Chi-square, ME, RMSE, CD, MARE and were found to be (0.00548), (0.99582), (0.31719), (0.98797), and (0.00164), respectively. The occurrence of OEM by Gumbel (Extreme value minimum) distribution function was found to be 168th day i.e. on June 17. Figure 1 represented the estimates of Julian days for OEM by different probability distribution functions and Table 2 helped us to identify the best fit probability distribution function.

Table 1: Occurrence of OEM, WM, CDS and duration of CDS during rainy season

Year	OEM	WM	Number of Days	CDS_1	Number of Days	CDS_2	Number of Days
1993	14-Jun	25-Sep	103	06-Aug	12	0	0
1994	11-Jun	23-Sep	106	14 July	10	09-Sep	11
1995	10-Jun	28-Sep	110	14-Sep	11	0	0
1996	12-Jun	02-Oct	112	15-Sep	13	0	0
1997	10-Jun	25-Sep	107	17-Jun	12	0	0
1998	18-Jun	26-Sep	99	26-Jun	12	29-Aug	12
1999	11-Jun	29-Sep	109	16 July	13	19-Aug	12
2000	14-Jun	21-Sep	99	0	0	0	0
2001	02 July	02-Oct	91	14-Aug	18	0	0
2002	19-Jun	28-Sep	101	07-Sep	11	0	0
2003	23-Jun	27-Sep	96	0	0	0	0
2004	13-Jun	21-Sep	100	20-Jun	11	24-Aug	10
2005	22-Jun	29-Sep	99	27-Aug	13	0	0
2006	19-Jun	23-Sep	96	0	0	0	0
2007	09-Jun	26-Sep	109	0	0	0	0
2008	10-Jun	23-Sep	106	0	0	0	0
2009	02 July	07-Oct	97	22 July	13	15-Aug	10
2010	14-Jun	20-Sep	97	08-Aug	10	04-Sep	11
2011	11-Jun	25-Sep	105	7 July	10	23 July	10
2012	14-Jun	23-Sep	100	0	0	0	0
2013	13-Jun	02-Oct	111	21-Aug	13	0	0
2014	15-Jun	23-Sep	99	14-Aug	13	0	0
2015	22-Jun	22-Sep	91	29-Jun	10	04-Aug	13

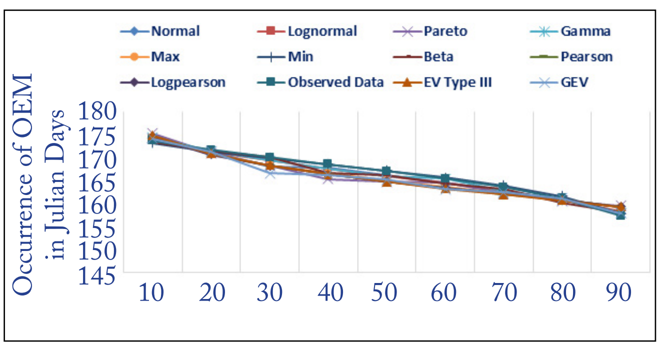

Figure 1: Occurrence of OEM in different Julian days with different probability of exceedence (PE)

3.2. Withdrawal of monsoon (WM)

Withdrawal of monsoon plays a crucial role in rainfed farming system for deciding the duration of monsoon. An advance prediction of WM will help farmers to plan the seed bed preparation for the winter crops. The dates of WM in the study area from September 20-October 7 (Table 1).

The data series of WM in Julian days skewed with co-

Table 2: Model performance indicators of probability distribution function for OEM in Julian days

PDF	Chi-square	ME	RMSE	CD	MARE
Normal	0.04838	0.96279	0.94683	0.97651	0.00403
Log normal	0.0345	0.97369	0.79616	0.97133	0.00451
Pareto	0.19297	0.85293	1.88245	0.98384	0.01083
gamma	0.02755	0.9789	0.71299	0.97458	0.00436
Gumbel (max)	0.12367	0.98506	0.60000	0.90753	0.00841
Gumbel (min)	0.00548	0.99582	0.31719	0.98797	0.00164
beta	0.06036	0.95417	1.05089	0.98648	0.01266
pearson	0.15224	0.88426	1.66994	0.94086	0.0094
Log-pearson	0.15431	0.88271	1.68112	0.91292	0.0094
EV Type III	0.16836	0.87208	1.75562	0.97268	0.00992
GEV	0.17953	0.863	1.81691	0.98355	0.00964

efficient of skewness (C_s) values of 0.7827. The mean, standard deviation and coefficient of variation were found to be 268.34, 3.962 and 0.01477, respectively. The result showed that the Pareto distribution function was best fitted for WM out of different probability distribution functions. The mean absolute relative error was 0.00225 and the best fitted value for Chi-square was 0.0177. Other indicators like Model efficiency, RMSE and Coefficient of determination were found to be 0.9637, 0.7227 and 0.9143, respectively. The occurrence of WM by Pareto distribution function was found to be 269th Julian day i.e., on September 26. Figure 2 represented the estimates of Julian days of WM by different distribution functions and Table 3 represented the best fit probability distribution function.

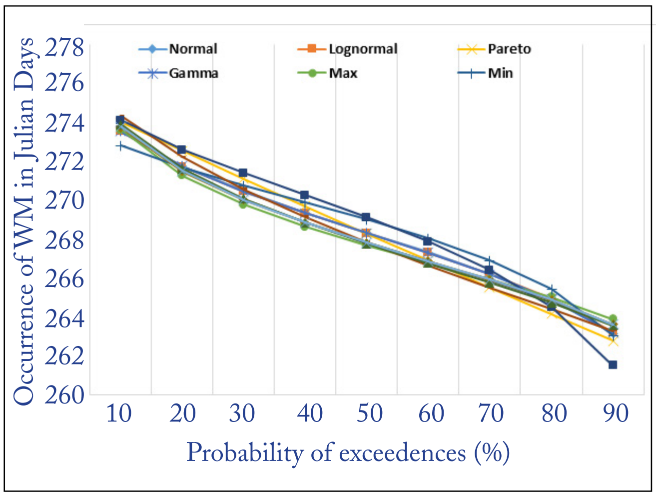

Figure 2: Occurrence WM in Julian days at different probability of exceedence

Table 3: Model performance indicators of probability distribution function for WM in Julian days

PDF	Chi-square	ME	RMSE	CD	MARE
Normal	0.02449	0.94954	0.85245	0.6885	0.00283
Log normal	0.02598	0.94648	1.55608	0.68199	0.00291
Pareto	0.0177	0.96372	0.72277	0.91435	0.00225
gamma	0.02553	0.94741	0.87021	0.68587	0.00289
Gumbel (max)	0.06258	0.871	1.36296	0.62039	0.00455
Gumbel (min)	0.025	0.94836	0.86235	0.59747	0.0027
beta	0.03475	0.92859	1.01406	0.85085	0.00326
pearson	0.04774	0.90163	1.19019	0.67367	0.00395
Log-pearson	0.04823	0.90062	1.19629	0.66791	0.00397
EV Type III	0.04741	0.90235	1.18585	0.71089	0.00389
GEV	0.04798	0.90113	1.19322	0.67108	0.00395

3.3. *Critical dry spell*

There were only two critical dry spells which were observed in the 23 years of rainfall record (1993-2015). While mostly one critical dry spell dominates in the area with 11-18 days timespan. First critical dry spell was observed to be from Jun 17-August 21, but the highest days of CDS of 18 days duration was occurred in 2001 from August 1. Second CDS rarely occur from July 23-September 9, with 10-13 days duration.

The best fitting distribution showed that the first CDS commences on July 30 and second on August 23 and both continued up to12 days duration. The CDS_1 and CDS_2 in Julian days skewed with co-efficient of skewness (C_s) values of 0.06622 and -0.5678, respectively. Similarly, Coefficient of skewness (C_s) for CDS_1 and $CDs_2$for occurrence of Number of days were found to be 1.679 and 0.4878, respectively. The mean, standard deviation and coefficient of variation were 211th Julian days, 28.87, 0.1366 for CDS_1 and 231thJulian days, 15.15, 0.0656 for CDS_2 in Julian Days, respectively. Likewise, for occurrence of Number of days the mean, standard deviation and coefficient of variation were 12.05, 1.89, 0.157 for CDS_1 and 11.12,1.053, 0.0946 for CDS_2, respectively. Pareto and Beta distribution function were best fitted at 50% PE level, with performance indicators of Chi-square, ME, RMSE, CD and MARE having values of 0.27339, 0.98812, 2.58624, 0.99656 and 0.00213 for CDS_1 and similarly 0.06359, 0.99226, 1.30047, 0.99117 and 0.00134 for CDS_2. The best fitting distribution showed that the first CDS commences at 168th Julian day i.e., on July 30 and second at 235th Julian day i.e., on August 23 and continued upto12 days. Figure 3 to 6 represented the estimates of Julian days of CDS by different distribution functions and Table 4 to 7 represented the best fit probability distribution function out of eleven probability distribution functions.

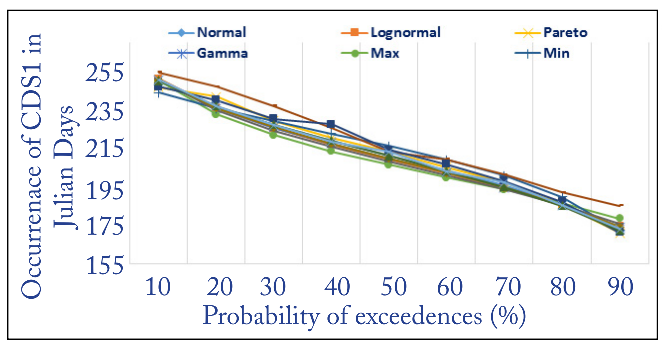

Figure 3: Estimates of occurrence of CDS_1 in Julian days at different probability of exceedence

3.4. *Crop planning in rainfed rice land*

Rice is to be grown under rainfed condition so that it

Table 4: Model performance indicators of probability distribution function (PDF) for CDS_1 in Julian Days

PDF	Chi-square	ME	RMSE	CD	MARE
Normal	0.61442	0.97356	3.85898	0.94334	0.00978
Log normal	1.12552	0.95228	5.18401	0.95648	0.01643
Pareto	0.27339	0.98812	2.58624	0.99656	0.00213
gamma	0.95675	0.95934	4.78513	0.94154	0.01443
Gumbel (max)	2.44024	0.89892	7.54512	0.84209	0.02621
Gumbel (min)	0.35513	0.98457	2.94763	0.82598	0.00855
beta	1.86864	0.92387	6.5477	0.98708	0.02761
pearson	1.53796	0.93553	6.02573	0.92665	0.02032
Log-pearson	0.97885	0.95839	4.8411	0.95094	0.01476
EV Type III	0.63201	0.97294	3.9035	0.99153	0.01054
GEV	0.61907	0.97324	3.88222	0.96807	0.01193

Table 5: Model performance indicators of probability distribution function for CDS_1 in number of days

PDF	Chi-square	ME	RMSE	CD	MARE
Normal	0.04662	0.96845	0.2444	0.86445	0.01008
Log normal	0.05449	0.96086	0.27223	0.86284	0.01911
Pareto	0.05863	0.95715	0.28484	0.84034	0.04233
gamma	0.0897	0.93979	0.33762	0.85863	0.01615
Gumbel (max)	0.09261	0.93303	0.35607	0.87537	0.0288
Gumbel (min)	0.01818	0.9868	0.15808	0.89675	0.01093
beta	0.15992	0.88784	0.46082	0.86219	0.05047
pearson	0.08495	0.9406	0.33536	0.8835	0.04096
Log-pearson	0.19033	0.8669	0.502	0.83675	0.03692
EV Type III	0.1585	0.88898	0.45848	0.77848	0.04237
GEV	0.18366	0.87093	0.49435	0.78326	0.03551

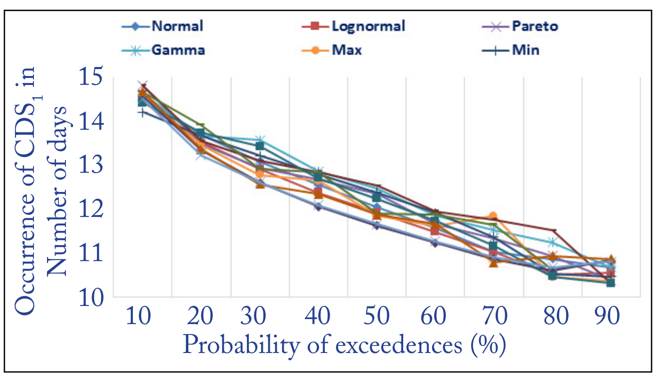

Figure 4: Occurrence of CDS_1 in Number of days at different probability of exceedence

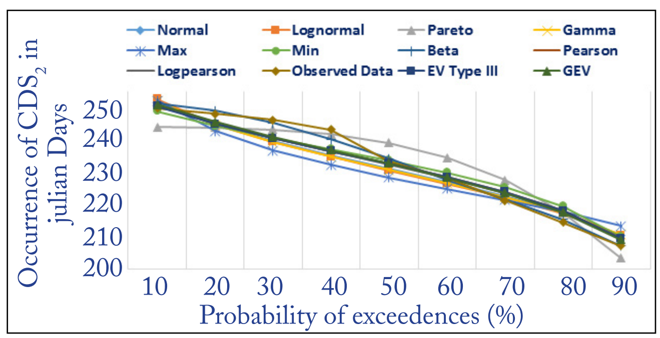

Figure 5: Occurrence of CDS_2 in Julian days at different probability of exceedence

effectively utilizes the entire monsoon rain of the region. In this study short duration rice harvested after the monsoon withdrawal. To predict the yield potential of rice a water balance model of rainfed rice was run without considering supplemental irrigation (SI). The root zone soil moisture, which affects the growth and yield of rice was computed by running the water balance model considering the effective root zone depth (45 cm) as a single layer. The groundwater

Table 6: Model performance indicators of probability distribution function for CDS_2 in Julian days

PDF	Chi-square	ME	RMSE	CD	MARE
Normal	0.64489	0.92327	4.09549	0.72213	0.00651
Log normal	0.70469	0.91605	4.28385	0.7495	0.00811
Pareto	0.86482	0.89747	4.73429	0.81897	0.017
gamma	0.71118	0.91545	4.29913	0.7214	0.00766
Gumbel (max)	1.41037	0.83429	6.01861	0.64692	0.01458
Gumbel (min)	0.57531	0.93223	3.84881	0.62972	0.00261
beta	0.06359	0.99226	1.30047	0.99117	0.00134
pearson	0.48166	0.94278	3.53651	0.7061	0.00212
Log-pearson	0.4832	0.94259	3.54262	0.71307	0.00269
EV Type III	0.47325	0.94374	3.50696	0.70776	0.00177
GEV	0.39582	0.95284	3.21089	0.74632	0.00267

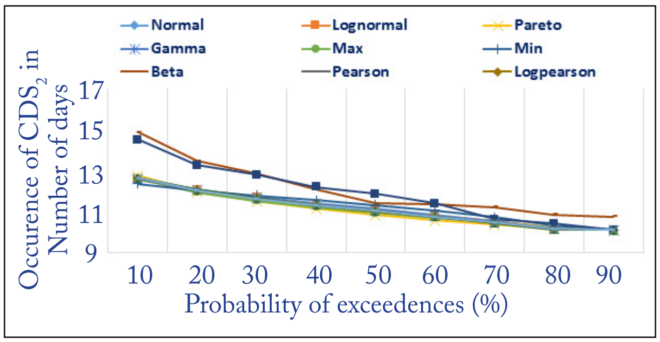

Figure 6: Occurrence of CDS_2 in Number of days at different probability of exceedence

table in the region lies more than 1.5 m below the effective root zone depth of rice, hence water balance model for rice is given as:

$$SMC_i = SMC_{i-1} + P_i - AET_i - SP_i \quad \text{.....} \quad (2)$$

Where, SMC = Soil moisture content, mm; P=Rainfall, mm; SP = Seepage and percolation loss, mm; AET=Actual evapotranspiration, mm; and i=time index taken as 1 day in the study.

Computation of the parameters AET and SP in the above water balance model was done according to the methodologies suggested by Panigrahi and Panda (2001). The values of crop coefficient of rice during the crop establishment (CE), crop development (CD), mid-season critical growth stage (CGS) and late season stage (LS) were assumed as 1.05, 1.10, 1.10 and 0.95, respectively (FAO 56). For short duration rice of 104 days, duration for each different growth stage, for CE, CD, CGS and LS is 24, 20, 30 and 26 days, respectively (Figure 7). Of the four-growth stages of rice, the most important is the CGS, which includes booting, flowering and milking and which occurred between 49 and 78 days after sowing (DAS) for short duration rice of 100 days (Mandal, 1990).

Table 7: Model Performance indicators of probability distribution function for CDS_2 in number of days

PDF	Chi-square	ME	RMSE	CD	MARE
Normal	0.65132	0.63738	0.93357	0.26616	0.00825
Log normal	0.67544	0.62542	0.94884	0.26699	0.01148
Pareto	0.81269	0.5597	1.02871	0.30388	0.02742
gamma	0.66623	0.63021	0.94276	0.27129	0.01077
Gumbel (max)	0.79527	0.565	1.0225	0.25952	0.02006
Gumbel (min)	0.65244	0.63474	0.93695	0.22293	0.00481
beta	0.12425	0.93453	0.39667	0.3066	0.0042
pearson	0.6961	0.61535	0.9615	0.27319	0.01403
Log-pearson	0.7123	0.6074	0.9714	0.27364	0.01583
EV Type III	0.68407	0.62221	0.95289	0.28893	0.01478
GEV	0.69484	0.61635	0.96026	0.27823	0.01473

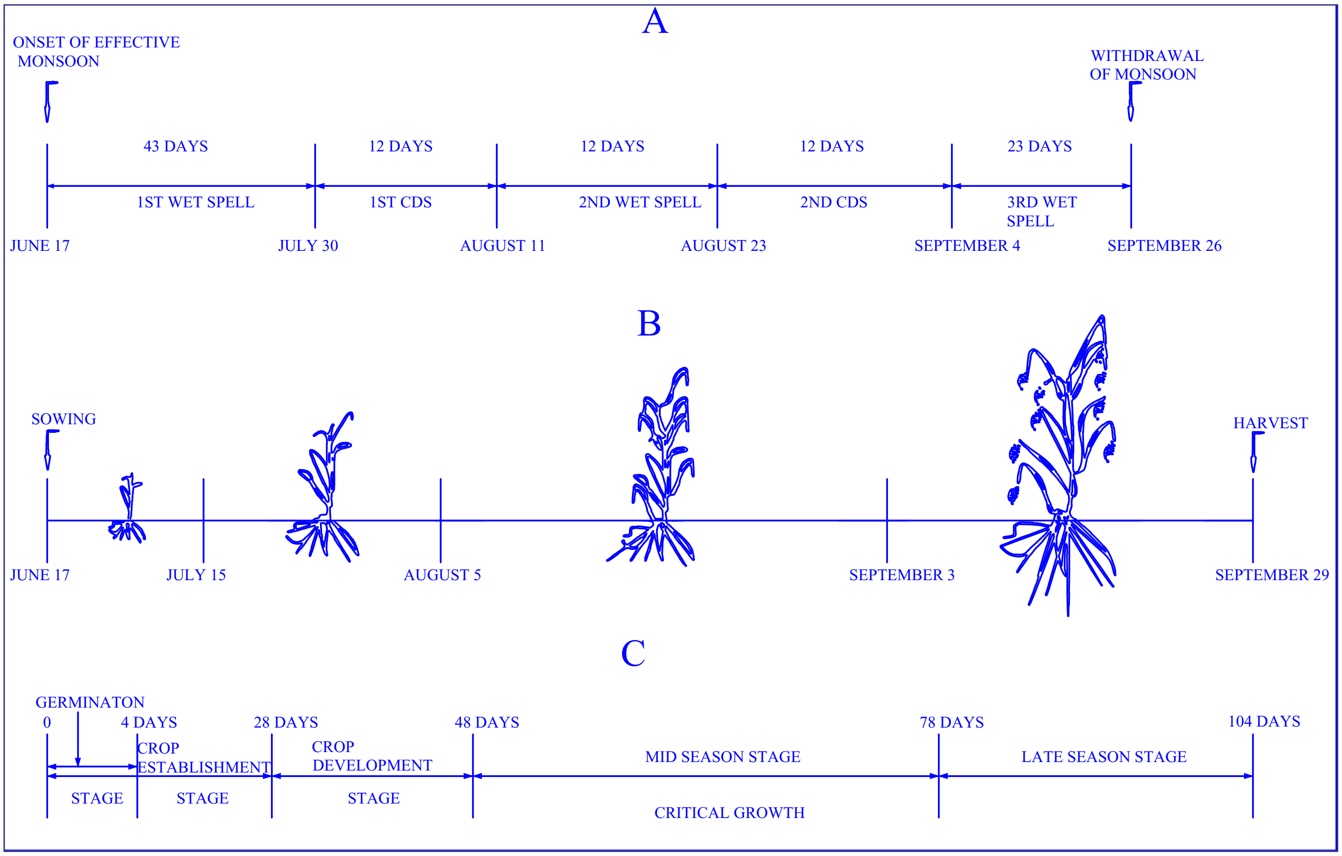

Figure 7: Schematic representation of different growth stages of rice with occurrence of wet and dry spells

The simulation was run for 23 years (1993–2015) from the onset of EM until the harvest of each year using the available meteorological, soil and crop data of the study site. The total duration of simulation for short duration rice was 104, considering first four days of the germination phase, the soil is under bare condition. Bare soil evaporation was computed as proposed by Jensen et al. (1993) and was used in place of AET in the water balance model.

4. CONCLUSION

The best fitting distribution that monsoon started on 17th June and withdrawn on 26th September; thus, the monsoon remained active for an average duration of 102 days in the region. Difference between the onset and the withdrawal of monsoon also varied from 91-112 days. Hence, to utilize the monsoon rain effectively; short duration rice variety of about 100 days duration or less might have grown in the rainy season in the study region.

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