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Analyses of rainfall using probability distribution and Markov chain models for crop planning in Daspalla region in Odisha, India

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Abstract Rainfed agriculture plays and will continue to play a dominant role in providing food and livelihoods for an increasing world population. Rainfall analyses are helpful for proper crop planning under changing environment in any region. Therefore, in this paper, an attempt has been made to analyse 16 years of rainfall (1995–2010) at the Daspalla region in Odisha, eastern India for prediction using six probability distribution functions, forecasting the probable date of onset and withdrawal of monsoon, occurrence of dry spells by using Markov chain model and finally crop planning for the region. For prediction of monsoon and post-monsoon rainfall, log Pearson type III and Gumbel distribution were the best-fit probability distribution functions. The earliest and most delayed week of the onset of rainy season was the 20th standard meteorological week (SMW) (14th–20th May) and 25th SMW (18th–24th June), respectively. Similarly, the earliest and most delayed week of withdrawal of rainfall was the 39th SMW (24th–30th September) and 47th SMW (19th–25th November), respectively. The longest and shortest length of rainy season was 26 and 17 weeks, respectively. The chances of occurrence of dry spells are high from the 1st–22nd SMW and again the 42nd SMW to the end of the year. The probability of weeks (23rd–40th SMW) remaining wet varies between 62 and 100 % for the region. Results obtained through this analysis would be utilised for agricultural planning and mitigation of dry spells at the Daspalla region in Odisha, India.

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1 Introduction

Globally, rainfed agriculture accounts for ~80 % of total cultivated area and produces 60 % of the world's food (Rockström et al. 2007); rainfed food production systems are under pressure due to changes in rainfall pattern and hydrological regimes and greater dependency on land and water resources (Khan and Hanjra 2009). India ranks first among the countries that practice rainfed agriculture both in terms of extent (86 Mha) and value of production (Sharma et al. 2010). To meet the future food demands and growing competition for water among various sectors, a more efficient use of water in rainfed agriculture will be essential. In eastern Indian ecosystem, more than 70 % of net sown area is rainfed where the yield of the predominant rainy season crop, i.e. rice, is very low as compared to that of irrigated ecosystem. The most important factor for low yield is the lack of assured water supply (Panigrahi and Panda 2002). Increased climate variability has made rainfall patterns more inconsistent and unpredictable (Kumar et al. 2005). The demand of water in other sectors especially to meet the increasing demand for rapid growing industrialisation and urbanisation will dwindle the share of water available for agriculture in the future. Further, depletion of groundwater aquifer and reduced stream flows (Khan et al. 2008) affect drinking water supplies, health and rural livelihoods (Meijer et al. 2006); for instance, in India, the implications for social equity for the poor and groundwater-dependent communities for drinking and irrigation are quite large (EPW 2007). Excessive extraction of groundwater has occurred in northern Indian states, viz. Rajasthan, Punjab and

Haryana, and a reliable estimate showed that groundwater was depleted at a rate of 54 ± 9 km^3 per year between April 2002 and June 2008 (Tiwari et al. 2009); the depletion was equivalent to a net loss of 109 km^3 of water during August 2002 to October 2008 (Rodell et al. 2009). With subsidised energy, farmers have few incentives to limit pumping (Scott and Shah 2004; Ghouri 2006). With rising energy prices, groundwater pumping may become unaffordable, leaving smallholders dry and hungry, especially if subsidies are discontinued (Kumar et al. 2005; Narayanamoorthy and Hanjra 2006). Growing demand has been exceeding the replenishable groundwater causing a steady lowering of the water table even in Dhaka, Bangladesh (Hoque et al. 2007). In USA also, excessive rate of groundwater depletion suggested that 35 % of the southern irrigated high plains would be unable to support irrigation within the next 30 years (Scanlon et al. 2012).

Rainwater management and its optimum utilisation is a prime issue of present-day research for sustainability of rainfed agriculture. Kothari et al. (2007) opined that on the basis of water harvesting, water can be utilised for saving of crops during severe moisture stress. In order to address the issue, detailed knowledge of rainfall distribution can help in deciding the time of different agricultural operations and designing of water harvesting structures for providing round the year full irrigation (Srivastava 2001; Srivastava et al. 2009). For sustainable crop planning, rainfall was characterised based on its variability and probability distribution by previous researchers (Mohanty et al. 2000; Sharda and Das 2005; Bhakar et al. 2008; Jain and Kumar 2012) for different regions of India. Odisha, an eastern Indian province, is mainly an agrarian state where about 70 % of the population is engaged in agricultural activities and 50 % of the state's economy comes from agricultural sector (Panigrahi et al. 2010). Agricultural development rests heavily on the management of natural resources which have to be utilised optimally to obtain food, nutrition and environmental security for future generation (Kar and Singh 2002). Crop planning for an area depends upon the number of factors, namely type of crop, cropping intensity, available water resources, climate, crop water requirements, method of irrigation, drainage, efficiency of the irrigation system, soil characteristics, topography, socio-economic conditions, etc. However, in rainfed areas, it mainly depends upon the magnitude and distribution of rainfall both in space and time (Shetty et al. 2000).

In order to stabilise the crop production at certain level, it is essential to plan agriculture on a scientific basis in terms of making best use of rainfall pattern of an area. This necessitates studying the sequences of dry and wet spells of an area so that

necessary steps can be taken up to prepare crop plan in rainfed regions (Srinivasareddy et al. 2008). Prediction of wet and dry spell analysis for proper cropping planning and agricultural operations may prove useful to farmers for improving productivity and cropping intensity. Markov chain probability model has been used previously for finding out the frequency of wet spells in Greece (Tolika and Maheras 2005), dry spells in Croatia (Cindrić et al. 2010) and computation of probability of occurrence of daily precipitation. Previous researchers (Pandarinath 1991; Banik et al. 2002; Barron et al. 2003; Deni et al. 2010) have used Markov chain model to study the probability of dry and wet spell analysis in terms of the shortest period like week and also demonstrated its practical utility in agricultural planning.

The forward and backward accumulation of rainfall is essential to determine the onset and withdrawal of monsoon. Pre-monsoon showers help in land preparation and sowing of rainy season crops. Late onset of monsoon delays sowing of crops resulting in to poor yields. Similarly, early withdrawal affects the yield due to severe moisture stress especially when the rainy season crops are at critical growth stages of grain formation and development (Dixit et al. 2005). It is essential to forecast the date of onset of effective monsoon since a slight delay in sowing of rainfed crops may lead to drastic reduction in grain yield and may affect the next crop too. Therefore, this study was carried out at Daspalla block of Nayagarh District by using rainfall of 16 years (1995–2010) with the following objectives: (1) for prediction of monsoon and post-monsoon rainfall using six probability distribution functions, (2) for forecasting the onset and withdrawal of rainy season, (3) for analyses of initial, conditional and consecutive dry and wet spells by using Markov chain model and (4) efficient crop planning and water management for this region based on the analysis of rainfall data.

2 Materials and methods

2.1 Description of study site and data

This study was carried out in the Daspalla region of Nayagarh district (Fig. 1) in Odisha, an eastern Indian state. It is located at 20° 21′ N latitude and 84° 51′ E longitude at an elevation of 122 m above mean sea level. Nayagarh District has eight blocks (Bhapur, Daspalla, Gania, Khandapara, Nayagarh, Nuagaon, Odagaon, Ranpur). The geographical area of Daspalla block is 571.57 km^2. This study site comes under Agro-Eco Sub-Region 12.2 (AESR 12.2) and Agro-Climatic Zone 7 (ACZ 7) according to NBSS&LUP (ICAR) and Planning Commission, Govt. of India classification, respectively. The dominant soils of this region are clay and sandy clay to sandy clay loam. Soil was slightly acidic to neutral (pH 6.0–7.4) in

Fig. 1 The study area, Daspalla region in Odisha, an eastern Indian state
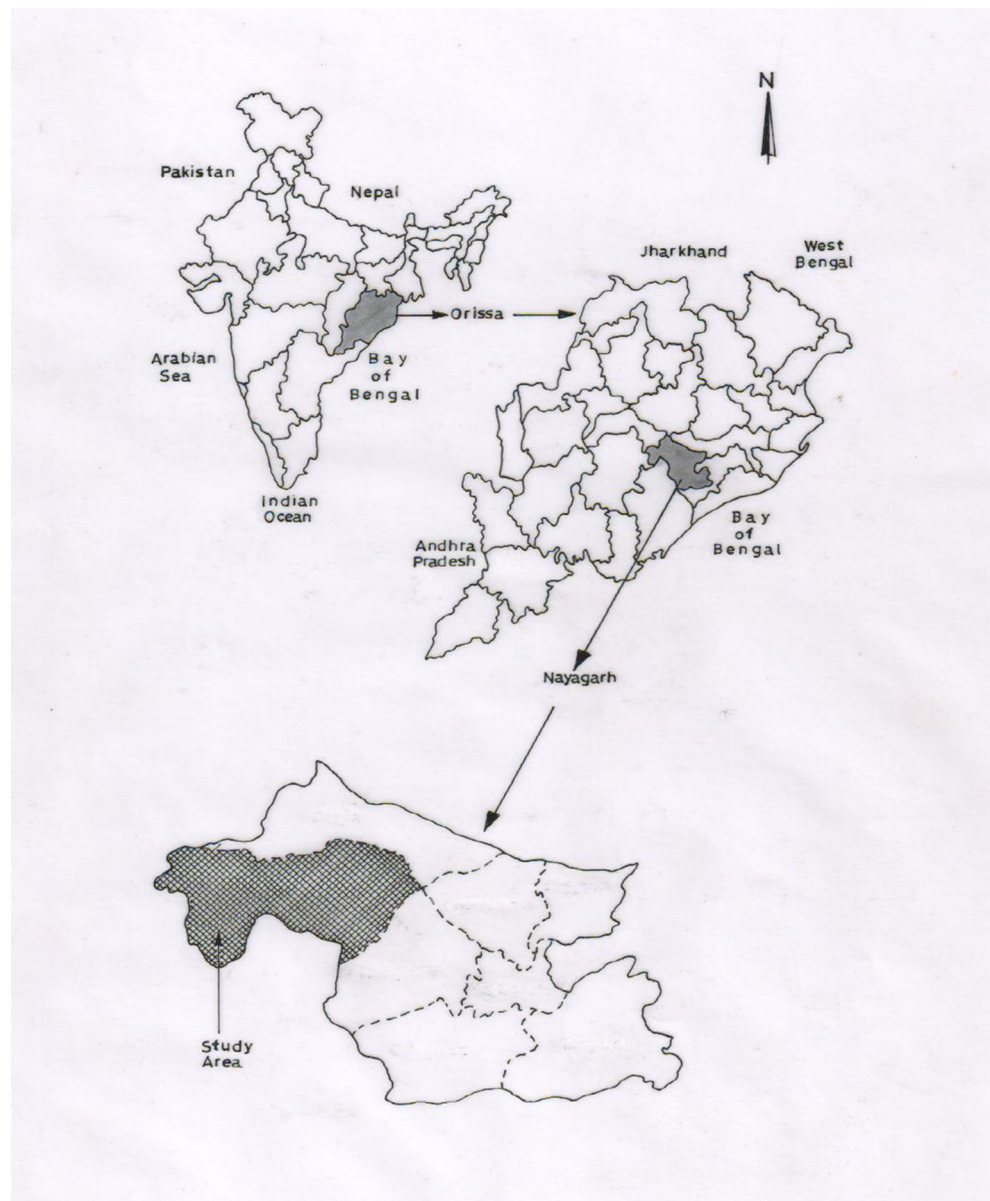
the upper layers and alkaline (pH 7.0–9.0) at 60–120-cm soil depths. Bulk density of the soil varied between 1.46 to 1.50 Mg m^{-3}. The water retention at field capacity (-33 kPa) ranged from 0.228 to 0.465 m^3 m^{-3} and permanent wilting point ($-1,500$ kPa) ranged from 0.158 to 0.302 m^3 m^{-3} depending upon the soil texture and bulk density (Mandal et al. 2013).

Rainfall data for 16 years (1995–2010) were collected from meteorological observatory of Kuanria Dam, Daspalla, Nayagarh. Rainfall data are categorised into four seasons, viz. pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–December) and winter (January–February) season. Monthly effective rainfall was calculated using Eqs. 1 and 2 following the USDA Soil Conservation Service method. This method is being widely used in India for calculation of monthly effective rainfall. The

same method has been used for calculation of effective rainfall for rainfed districts of India by Sharma et al. (2010) and also used by All India Coordinated Research Project for estimation of effective rainfall at different locations (AICRP 2009).

$$P_e = P_t(125 - 0.2\,P_t)/125 \text{ (when } P_t < 250 \text{ mm)} \qquad (1)$$

$$P_e = 125 + 0.1\,P_t \text{(when } P_t \geq 250 \text{ mm)} \qquad (2)$$

where P_e=monthly effective rainfall (millimetres) and P_t=total monthly rainfall (millimetres).

2.2 Calculation and probability distribution functions

In this study, rainfall was predicted by six probability distribution functions (PDFs), i.e. normal, two-parameter log normal, three-parameter log normal, Pearson type III, log Pearson

type III and Gumbel distribution by using the DISTRIB 2.13 component of SMADA 6.43 (Storm Water Management and Design Aid). Different probability distribution functions are given in the succeeding sections.

2.2.1 Normal distribution

$$p_x(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]} \tag{3}$$

where μ=mean of the population of x and σ=variance of the population of x.

2.2.2 Two-parameter log normal distribution

$$p_x(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e^{\left[-\frac{\left(y-\mu_y\right)^2}{2\sigma_y^2}\right]} \tag{4}$$

where $y=\ln(x)$, μ_y=mean of the population of y and σ_y=variance of the population of y.

2.2.3 Three-parameter log normal distribution

$$p_x(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e^{\left[-\frac{\left(y-\mu_y\right)^2}{2\sigma_y^2}\right]} \tag{5}$$

where $y=\ln(x-a)$, μ_y=mean of the population of y and σ_y=variance of the population of y.

2.2.4 Pearson type III distribution

$$p_x(x) = p_o(1 + x/\alpha)^{\alpha/\delta} e^{-x/\delta} \tag{6}$$

where δ=difference between mean and mode ($\delta=\mu-X_m$), X_m=mode of population x, α=scale parameter of distribution and p_o=value of $p_x(x)$ at mode.

2.2.5 Log Pearson type III distribution

$$p_x(y) = p_{yo}(1 + y/\alpha)^{\alpha/\delta y} e^{-y/\delta y} \tag{7}$$

where δy=difference between mean and mode ($\delta_y=\mu_y-Y_m$), Y_m=mode of population y, α=scale parameter of distribution and p_{yo}=value of $p_x(y)$ at mode.

2.2.6 Gumbel distribution

This is also referred to as Fisher-Tippett type I, double exponential, Gumbel type I and Gumbel extremal distribution and is characterised by the probability density function,

$$p_x(x) = \frac{\alpha}{\beta-\gamma} \left(\frac{x-\gamma}{\beta-\gamma}\right)^{\alpha-1} e^{\left[\frac{x-\gamma}{\beta-\gamma}\right]^\alpha} \tag{8}$$

where α=scale parameter of distribution and β=location parameter of distribution.

All six PDFs were compared by chi-square test for goodness of fit as given in the following equation (Eq. 9):

$$\chi^2 = \sum \frac{(O-E)^2}{E} \tag{9}$$

where O is the observed value obtained by Weibul's method and E is the estimated value by probability distribution functions. Chi-square test was performed to obtain the best PDF following the method of Mohanty et al. (2000), and Kolmogorov-Smirnov (K-S) test statistic was also used to decide the appropriate PDF, and the model having least value was selected as the best-fit PDF (Sharma and Singh 2010).

2.3 Computation method for the onset and withdrawal of rainy season

The onset and withdrawal of monsoon largely determine the success of rainfed agriculture. A prior knowledge on this helps in deciding cropping pattern and choice of suitable crop varieties and also to plan comprehensive strategies for proper and efficient rainwater management for improving crop production per unit of available water (Das et al. 1998). Therefore, the onset and withdrawal of rainy season were computed from weekly rainfall data by forward and backward accumulation methods (Kothari et al. 2009). Each year was divided into 52 standard meteorological weeks (SMWs). The first SMW of any year starts from 1st–7th January and 52nd SMW is from 24th–31st December. Weekly rainfall was summed up by forward accumulation (20+21+…+52 weeks) until 75 mm of rainfall was accumulated. An accumulation of 75 mm of rainfall has been considered as the onset time for summer monsoon which helps in land preparation and sowing of crops (Panigrahi and Panda 2002; Kothari et al. 2009). This onset criterion has been chosen by previous researchers because of the condition that, prior to the onset of monsoon, soils become very dry especially in eastern India due to the prolonged and hot summer, land is difficult for ploughing and sowing of rainfed crops unless ~75 mm rainfall is received over a week in June. The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+…+30 weeks) data.

Twenty millimetres of rainfall accumulation was chosen for the withdrawal of the rainy season, which is sufficient for ploughing of fields after harvesting the first crop (Babu and Lakshminarayana 1997; Srinivasareddy et al. 2008). The percent probability (*P*) of each rank was calculated by arranging them in ascending order and by selecting the highest rank allotted for a particular week. The following Weibull's formula was used for calculating percent probability:

$$P = (m/N + 1) \times 100 \qquad (10)$$

where *m* is the rank number and *N* is the number of years of data used.

2.4 Computation of dry and wet spells using Markov chain probability models

In this study, weekly rainfall was computed from daily values and used for initial, conditional and consecutive dry and wet spell analysis based on Markov chain probability model as described by Pandarinath (1991). In this study, 20-mm or more rainfall in a week was considered as wet week; otherwise, dry. Initial, conditional and consecutive dry and wet spell analyses for 52 SMWs were made by using Eqs. 11–20.

2.4.1 Initial probability

$$P(\mathrm{D}) = F(\mathrm{D})/N \qquad (11)$$

$$P(\mathrm{W}) = F(\mathrm{W})/N \qquad (12)$$

where $P(\mathrm{D})$=probability of the week being dry, $F(\mathrm{D})$=frequency of dry weeks, $P(\mathrm{W})$=probability of the week being wet, $F(\mathrm{W})$=frequency of wet weeks and *N*=total number of years of data being used.

2.4.2 Conditional probabilities

$$P(\mathrm{DD}) = F(\mathrm{DD})/F(\mathrm{D}) \qquad (13)$$

$$P(\mathrm{WW}) = F(\mathrm{WW})/F(\mathrm{W}) \qquad (14)$$

$$P(\mathrm{WD}) = 1 - P(\mathrm{DD}) \qquad (15)$$

$$P(\mathrm{DW}) = 1 - P(\mathrm{WW}) \qquad (16)$$

where $P(\mathrm{DD})$=probability of a week being dry preceded by another dry week, $F(\mathrm{DD})$=frequency of dry week preceded by another dry week, $P(\mathrm{WW})$=probability of a week being wet preceded by another wet week, $F(\mathrm{WW})$=frequency of wet week preceded by another wet week, $P(\mathrm{WD})$=probability of a wet week preceded by a dry week and $P(\mathrm{DW})$=probability of a dry week preceded by a wet week.

2.4.3 Consecutive dry and wet week probabilities

$$P(2\mathrm{D}) = P(\mathrm{DW1}) \times P(\mathrm{DDW2}) \qquad (17)$$

$$P(3\mathrm{D}) = P(\mathrm{DW1}) \times P(\mathrm{DDW2}) \times P(\mathrm{DDW3}) \qquad (18)$$

$$P(2\mathrm{W}) = P(\mathrm{WW1}) \times P(\mathrm{WWW2}) \qquad (19)$$

$$P(3\mathrm{W}) = P(\mathrm{WW1}) \times P(\mathrm{WWW2}) \times P(\mathrm{WWW3}) \qquad (20)$$

where $P(2\mathrm{D})$=probability of two consecutive dry weeks starting with the week; $P(\mathrm{DW1})$=probability of the first week being dry; $P(\mathrm{DDW2})$=probability of the second week being dry, given the preceding week being dry; $P(3\mathrm{D})$=probability of three consecutive dry weeks starting with the week; $P(\mathrm{DDW3})$=probability of the third week being dry, given

Fig. 2 Average monthly rainfall and effective rainfall for the study area, Daspalla; *ER* is the effective rainfall
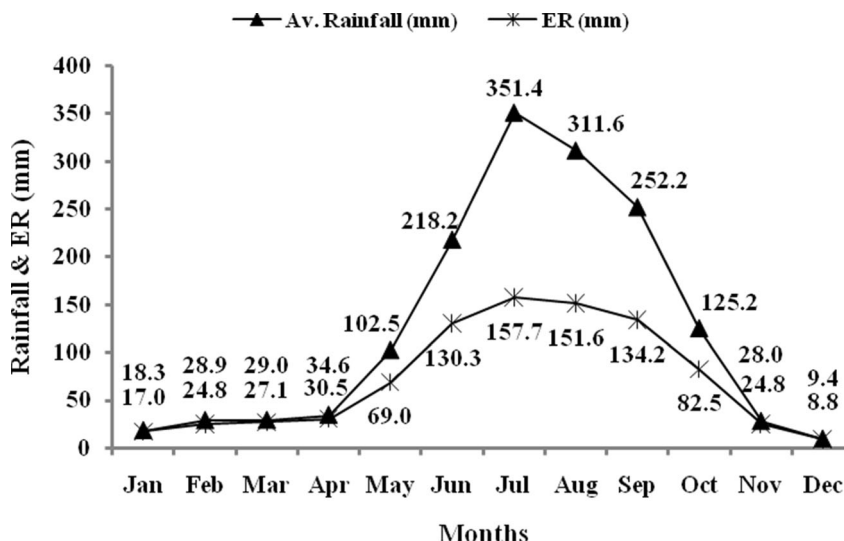
Table 1 Rainfall distribution in the Daspalla region over different seasons (data of 16 years for the period 1995–2010)

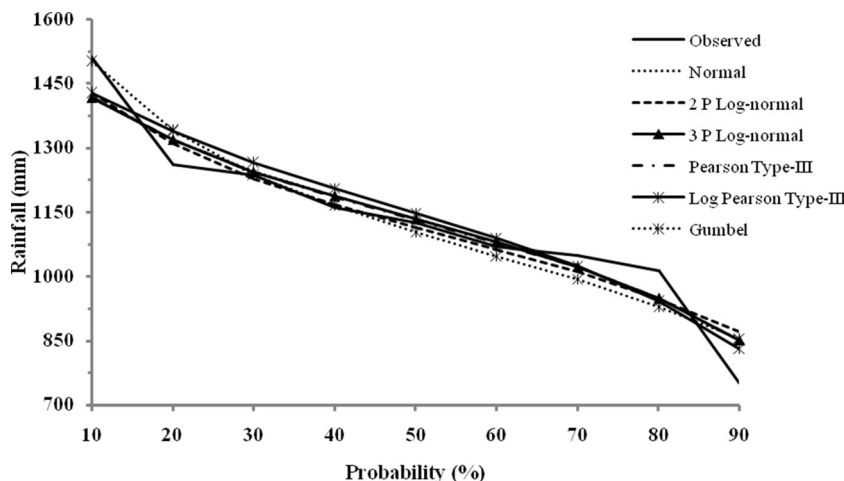| Seasons	Average rainfall (mm)	Percentage of total rainfall
Pre-monsoon (March–May)	166.1	10.8
Monsoon (June–September)	1,133.3	75.7
Post-monsoon (October–December)	162.6	10.4
Winter (January–February)	47.2	3.1

the preceding week dry; $P(2\ W)$=probability of two consecutive dry weeks starting with the week; $P(WW1)$=probability of the first week being wet; $P(WWW2)$=probability of the second week being wet, given the preceding week being wet; $P(3\ W)$=probability of three consecutive wet weeks starting with the week; and $P(WWW3)$=probability of the third week being wet, given the preceding week wet.

3 Results

3.1 Average rainfall, effective rainfall and distribution over seasons

Total annual rainfall in the Daspalla region ranged between 993.5 and 1,901.8 mm with an average of 1,509.2 mm (14.8 % coefficient of variation). If rainfall received in a year was equal to or more than the average rainfall plus 1 standard deviation for 16 years of rainfall (i.e. 1,509.2+223.8=1,733 mm), it was considered as excess rainfall year (Sharma and Kumar 2003). On four occasions (1995, 2001, 2003 and 2008), this region had received rainfall of more than 1,733 mm; these years were considered as excess rainfall years. Only 25 % of total years of analyses under this study received rainfall of more than 1,733 mm. It was also observed that 44 % of the total years of rainfall were below average (1,509.2 mm) which were considered as the deficit rainfall years. Monthly average and effective rainfall of the Daspalla region for 16 years are presented in Fig. 2.

It is revealed that mean rainfall of July was 351.4 mm, which was the highest and its contribution was 23.3 % (i.e. 1,509.2 mm). August rainfall was slightly lower than that in July (i.e. 20.6 % of annual average rainfall). December was the lowest rainfall month. Total annual effective rainfall (ER) was 858.2 mm which was 56.9 % of the total annual rainfall. Therefore, 651 mm of rainfall water was lost in the form of surface runoff, deep percolation and evaporation.

The distribution of rainfall for different seasons showed that the normal southwest monsoon, which delivers about 75.7 % of annual rainfall, extends from June to September (Table 1). This is also the main season (rainy season) for cultivation of rainfed crops. The monsoon rainfall (1,133.3 mm) was spread over few days with rain events of high intensity. It causes surface runoff and temporary water stagnation in agricultural fields. Winter season contributes only 3.1 % of the total annual rainfall; 10.8 and 10.4 % of the total annual rainfall occurred during pre- and post-monsoon season, respectively.

3.2 Prediction of rainfall using probability distribution functions

Annual rainfall for the region was predicted by using the DISTRIB 2.13 component of SMADA 6.43 for six different probability distribution functions. Six predicted annual rainfall values were obtained for six PDFs by running the software (Figs. 3 and 4). After that, the chi-square value for each PDF was estimated by using Eq. 9. Observed rainfall at different probability levels for monsoon and post-monsoon months was

Fig. 3 Observed and predicted rainfall (millimetres) at different probability levels for the monsoon season

Fig. 4 Observed and predicted rainfall (millimetres) at different probability levels for post-monsoon season in the study area
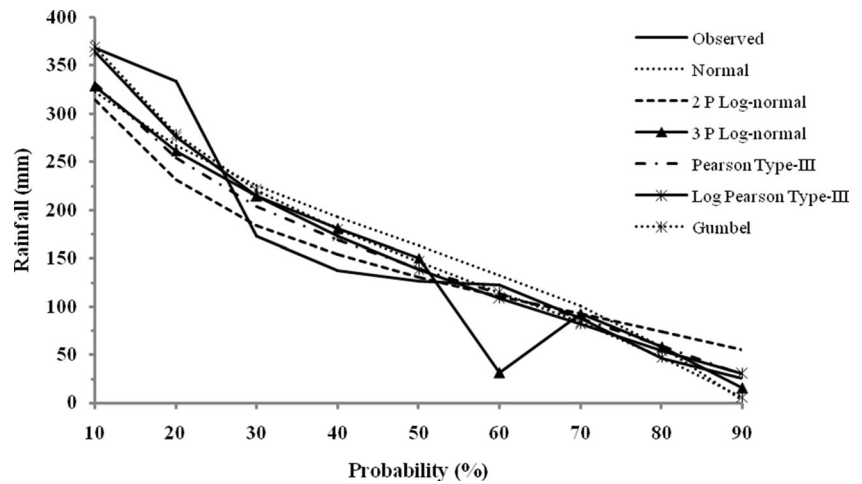
determined by using Weibul's formula and presented in Table 2. It is revealed that, during monsoon season, the observed monsoon rainfall was 1,049.6 mm at 70 % probability level and all the probability distribution functions predicted almost comparable rainfall. In total, the chi-square values varied from 29.2 to 58.8 for six PDFs for the rainfall of monsoon season; non-parametric K-S test statistics varied from 0.123 to 0.196 (Table 3). Least chi-square values as well as lowest K-S test statistic were estimated for log Pearson type III distribution. Hence, log Pearson type III distribution is considered as the best-fit PDF for prediction of monsoon rainfall in Daspalla. In this region, about 86 % of the total annual rainfall occurs during monsoon and post-monsoon season and agricultural activities are almost totally dependent on the performance of south-west monsoon. Therefore, prediction of monsoon and post-monsoon rainfall is more important than annual rainfall for raising crops successfully with high and stable yields. With regard to the post-monsoon rainfall (Fig. 4), the chi-square values were 48.8 to 189.8, and the K-S test statistics were 0.137 to 0.251 for six PDFs (Table 3). The lowest value, with chi-square and K-S test, was obtained with Gumbel distribution; however, log Pearson type III distribution was also comparable with Gumbel distribution for prediction of post-monsoon rainfall.

3.3 Analyses of rainfall for onset and withdrawal of monsoon season

The data on onset, withdrawal and duration of the rainy season (difference between onset and withdrawal time) and its variability for the Daspalla region are presented in Table 4. Weekly rainfall data (1995–2010) indicated that the monsoon started effectively from the 23rd SMW (4th–10th June) and remained active up to the 43rd SMW (22nd–28th October). Therefore, mean length of rainy season was found to be 21 weeks (147 days). The earliest and delayed week of onset of rainy season was the 20th SMW (14th–20th May) and 25th SMW (18th–24th June), respectively. Similarly, the earliest and delayed week of cessation of rainy season was the 39th SMW (24th–30th September) and 47th SMW (19th–25th November), respectively. The longest and shortest length of rainy season was coincided with the 26th and 17th weeks, respectively. The probabilities of the onset and withdrawal of rainy season were calculated by using Weibull's formula, and results are presented in Table 5. The results reveal that there was 94 % chance that the onset and withdrawal of rainy season would occur during the 25th and 47th SMW, respectively.

Table 2 Observed rainfall at different probability levels for monsoon and post-monsoon months

Probability (%)	June	July	August	September	October	November	December
10	415.2	724.0	523.3	450.0	322.0	105.5	47.6
20	333.3	469.8	413.1	381.5	274.1	47.7	29.7
30	217.0	365.8	356.5	354.0	123.1	29.7	2.8
40	196.6	337.5	321.1	301.3	116.2	20.9	0.3
50	194.8	282.8	299.7	227.4	87.5	14.8	–
60	182.8	270.0	275.2	177.8	77.4	11.8	–
70	158.0	244.4	274.2	164.9	57.9	6.2	–
80	132.4	217.3	180.6	141.6	28.0	1.0	–
90	105.9	181.9	164.5	75.4	16.9	–	–

Table 3 Chi-square and Kolmogorov-Smirnov (K-S) test statistics for each probability distribution function for monsoon and post- monsoon seasons

Probability distribution functions (PDFs)	Monsoon season		Post-monsoon season	
	Chi-square test statistic with p value	K-S test statistic with p value	Chi-square test statistic with p value	K-S test statistic with p value
Normal	58.8 (0.91)	0.196 (0.93)	78.4 (0.88)	0.187 (0.83)
2-parameter log normal	57.0 (0.92)	0.187 (0.95)	91.7 (0.90)	0.217 (0.89)
3-parameter log normal	49.7 (0.94)	0.151 (0.93)	189.8 (0.91)	0.251 (0.92)
Pearson type III	50.0 (0.95)	0.145 (0.95)	99.4 (0.94)	0.176 (0.94)
Log Pearson type III	29.2 (0.98)	0.123 (0.99)	57.3 (0.95)	0.141 (0.99)
Gumbel distribution	38.8 (0.91)	0.138 (0.92)	48.8 (0.98)	0.137 (0.96)

Figures in parentheses are the corresponding p values

3.4 Markov chain model

Results of initial and conditional probabilities of dry and wet weeks are presented in Table 6 for the 52 standard meteorological weeks. The results reveal that the probability of occurrence of dry week was high until the end of the 22nd SMW. The range of probability of occurrence of dry week from the 1st to 22nd SMW was between 56 and 100 %. The probability of occurrence of dry week preceded by another dry week (P_{DD}) and that of dry week preceded by another wet week (P_{DW}) varied from 54 to 100 % and 28 to 100 %, respectively, during the periods of the 1st–22nd SMW. However, from the 23rd to 40th SMW, the probability of both P_D and P_{DD} were low. The probability that these weeks (23rd–40th SMW) remaining wet (P_W) varied between 62 and 100 %. The conditional probability of wet week preceded by another wet week (P_{WW}) varied between 30 and 100 %. The chances of occurrence of dry spells were again high during the period from the 42nd SMW to the end of the year.

The analyses of consecutive dry and wet spells (Table 7) revealed that there were 31 to 100 % chances that two consecutive dry weeks (P_{2D}) would occur within the first 22 weeks of the year. Similarly, the probabilities of occurrence of three consecutive dry weeks (P_{3D}) were also very high (15–86 %) in the first 22 weeks of the year. The corresponding values of two and three consecutive wet weeks (i.e. P_{2W} and P_{3W}) from the 1st to 22nd SMW were very low with values ranging from 0 to 31 % and 0 to 13 %, respectively. From the 23rd to 40th SMW, the chances of occurrence of two and three consecutive dry weeks were only within 0 to 19 % and 0 to 15 %, respectively. Conversely, there are chances of 36 to 100 % and 28 to 87 % that the weeks from the 23rd to 40th SMW would be getting sufficient rain with two and three consecutive wet weeks, respectively. This study reveals that the last 12 weeks of the year, i.e. from 41 to 52th SMW, may remain under stress on an average, as there were 75 % chances of occurrence of two consecutive dry weeks. The corresponding value for three consecutive dry weeks during the period was 67 %.

4 Discussion

Effective rainfall is that fraction of total rainfall received on the ground which enters into the root zone and remains there for utilisation by crops (i.e. the soil moisture in the root zone). About 86 % (i.e. 559 mm) of the total rainfall is lost only during monsoon months due to surface runoff, deep percolation and evaporation. In case of rainfall of high intensity, only a part of it enters and stored in the root zone and the quantity of

Table 4 Characterisation of rainy season at the study site, Daspalla (1995–2010)

Particulars	Week no.	Date
Mean week of onset of rainy season	23	4–10 June
Earliest week of onset of rainy season	20	14–20 May
Delayed week of onset of rainy season	25	18–24 June
Mean week of withdrawal of rainy season	43	22–28 October
Earliest week of withdrawal of rainy season	39	24–30 September
Delayed week of withdrawal of rainy season	47	19–25 November

Table 5 Probability of onset and withdrawal of rainy season at the study site, Daspalla

Probability of onset and withdrawal

Onset								
SMW	20	21	22	23	24	25		
P (%)	17.6	29.4	35.3	64.7	82.4	94.1		
Withdrawal								
SMW	39	40	41	42	43	44	45	46	47
P (%)	5.9	11.8	23.5	41.2	47.1	64.7	76.5	88.2	94.1

SMW standard meteorological week, *P* probability in percentage

Table 6 Initial and conditional probabilities of dry and wet spells of rainfall at the study site, Daspalla region

SMW	Initial probabilities (%)		Conditional probabilities (%)			
	P_D	P_W	P_{DD}	P_{WD}	P_{WW}	P_{DW}
1	100.0	0.0	–	–	–	–
2	87.5	12.5	100.0	0.0	0.0	100.0
3	87.5	12.5	85.7	14.3	0.0	100.0
4	93.8	6.2	86.7	13.3	0.0	100.0
5	93.8	6.2	93.3	6.7	0.0	100.0
6	93.8	6.2	100.0	0.0	100.0	0.0
7	87.5	12.5	92.9	7.1	0.0	100.0
8	87.5	12.5	92.9	7.1	50.0	50.0
9	81.3	18.7	92.3	7.7	33.3	66.7
10	81.3	18.7	84.6	15.4	33.3	66.7
11	87.5	12.5	78.6	21.4	0.0	100.0
12	93.8	6.2	86.7	13.3	0.0	100.0
13	87.5	12.5	92.9	7.1	0.0	100.0
14	87.5	12.5	85.7	14.3	0.0	100.0
15	93.8	6.2	86.7	13.3	0.0	100.0
16	93.8	6.2	93.3	6.7	0.0	100.0
17	81.3	18.7	100.0	0.0	33.3	66.7
18	93.8	6.2	80.0	20.0	0.0	100.0
19	68.8	31.2	100.0	0.0	20.0	80.0
20	56.3	43.7	66.7	33.3	28.6	71.4
21	56.3	43.7	77.8	22.2	71.4	28.6
22	68.8	31.2	54.5	45.5	40.0	60.0
23	18.7	81.3	66.7	33.3	30.8	69.2
24	37.5	62.5	33.3	66.7	90.0	10.0
25	25.0	75.0	50.0	50.0	66.7	33.3
26	18.7	81.3	66.7	33.3	84.6	15.4
27	18.7	81.3	33.3	66.7	84.6	15.4
28	31.2	68.8	20.0	80.0	81.8	18.2
29	0.0	100.0	0.0	100.0	68.8	31.2
30	12.5	87.5	0.0	100.0	100.0	0.0
31	6.2	93.8	0.0	100.0	86.7	13.3
32	12.5	87.5	0.0	100.0	92.9	7.1
33	18.7	81.3	0.0	100.0	84.6	15.4
34	0.0	100.0	0.0	100.0	81.3	18.7
35	12.5	87.5	0.0	100.0	100.0	0.0
36	12.5	87.5	0.0	100.0	85.7	14.3
37	37.5	62.5	0.0	100.0	80.0	20.0
38	18.7	81.3	66.7	33.3	69.2	30.8
39	31.2	68.8	40.0	60.0	90.9	9.1
40	37.5	62.5	33.3	66.7	70.0	30.0
41	56.3	43.7	44.4	55.6	57.1	42.9
42	56.3	43.7	88.9	11.1	85.7	14.3
43	81.3	18.7	69.2	30.8	100.0	0.0
44	75.0	25.0	91.7	8.3	50.0	50.0
45	81.3	18.7	76.9	23.1	33.3	66.7
46	93.8	6.2	86.7	13.3	100.0	0.0

Table 6 (continued)

SMW	Initial probabilities (%)		Conditional probabilities (%)			
	P_D	P_W	P_{DD}	P_{WD}	P_{WW}	P_{DW}
47	93.8	6.2	93.3	6.7	0.0	100.0
48	100.0	0.0	93.8	6.2	0.0	100.0
49	93.8	6.2	100.0	0.0	0.0	100.0
50	87.5	12.5	100.0	0.0	50.0	50.0
51	93.8	6.2	86.7	13.3	0.0	100.0
52	100	0.0	93.8	6.2	0.0	100.0

Probabilities are mentioned under "Materials and methods"

effective rainfall is low. In this region, in general, farmers keep their lands fallow after harvesting of rainy season rice because only 162.6 mm of rainfall takes place during post-monsoon season. Further, post-monsoon rainfall is more uncertain and erratic; of course, few farmers grow green gram and black gram utilising the residual soil moisture and post-monsoon rainfall; high water requiring crops are not grown depending on the rainfall only. During winter and pre-monsoon season rainfall was quite less, as indicated in Table 1. Therefore, it is essential that every farm entity to have a service reservoir (Srivastava et al. 2009) so that the farmer can use the harvested water at his convenience.

The storage tanks or reservoirs would help mitigation of dry periods due to uneven distribution of rainfall; these would harvest rainwater during rainy season and meet irrigation water demand by crops during post-monsoon season (Jain and Kumar 2012). Adoption of pressurised irrigation, as advocated by previous researchers (Srivastava et al. 2010), during post-monsoon season would be useful. Another approach would be growing of short duration and low water-requiring crops like groundnut, maize, sorghum, green gram, soybean, sunflower, field bean, cowpea and others which have high monetary return. Pigeon pea is a very good crop for growing in this area under upland situation and on the bunds separated by rice fields. Another advantage of growing short duration cereals, pulses and oilseeds in the first fort-night of June is that these crops can be harvested by the end of September (39th SMW) and short duration post-monsoon crops can be sown during 40th–43rd SMW (1st–28th October). Harvesting the excess rainfall, even a small fraction, and utilising the same for supplemental irrigation would mitigate the impacts of devastating dry spells in rainfed regions (Rockström 2001).

A rainfall of 105.9 mm was observed in the month of June at 90 % probability level (Table 2). Therefore, rainy season crops can be sown and rice nurseries can be prepared in the month of June with the commencement of southwest monsoon. In the month of July at 90 % probability level the observed rainfall was 181.9 mm. Rice transplanting can be performed by utilising this high amount of rainfall during this

Table 7 Analyses of consecutive dry and wet week probabilities of rainfall at the study site

SMW	Consecutive dry week probabilities (%)		Consecutive wet week probabilities (%)	
	P_{2D}	P_{3D}	P_{2W}	P_{3W}
1	100.0	85.7	0.0	0.0
2	75.0	65.0	0.0	0.0
3	75.8	70.8	0.0	0.0
4	87.5	87.5	0.0	0.0
5	93.8	87.1	6.3	0.0
6	87.1	80.8	0.0	0.0
7	81.3	75.0	6.3	2.1
8	80.8	68.3	4.2	1.4
9	68.8	54.0	6.3	0.0
10	63.8	55.3	0.0	0.0
11	75.8	70.4	0.0	0.0
12	87.1	74.6	0.0	0.0
13	75.0	65.0	0.0	0.0
14	75.8	70.8	0.0	0.0
15	87.5	87.5	0.0	0.0
16	93.8	75.0	2.1	0.0
17	65.0	65.0	0.0	0.0
18	93.8	62.5	1.3	0.4
19	45.8	35.6	8.9	6.4
20	43.8	23.9	31.3	12.5
21	30.7	20.5	17.5	5.4
22	45.8	15.3	9.6	8.7
23	6.3	3.1	73.1	48.8
24	18.8	12.5	41.7	35.3
25	16.7	5.6	63.5	53.7
26	6.3	1.3	68.8	56.3
27	3.8	0.0	66.5	45.7
28	0.0	0.0	47.3	47.3
29	0.0	0.0	100.0	86.7
30	0.0	0.0	75.8	70.4
31	0.0	0.0	87.1	73.7
32	0.0	0.0	74.0	60.2
33	0.0	0.0	66.0	66.0
34	0.0	0.0	100.0	85.7
35	0.0	0.0	75.0	60.0
36	0.0	0.0	70.0	48.5
37	25.0	10.0	43.3	39.3
38	7.5	2.5	73.9	51.7
39	10.4	4.6	48.1	27.5
40	16.7	14.8	35.7	30.6
41	50.0	34.6	37.5	37.5
42	38.9	35.7	43.8	21.9
43	74.5	57.3	9.4	3.1
44	57.7	50.0	8.3	8.3
45	70.4	65.7	18.8	0.0

Table 7 (continued)

SMW	Consecutive dry week probabilities (%)		Consecutive wet week probabilities (%)	
	P_{2D}	P_{3D}	P_{2W}	P_{3W}
46	87.5	82.0	0.0	0.0
47	87.9	87.9	0.0	0.0
48	100.0	100.0	0.0	0.0
49	93.8	81.3	3.1	0.0
50	75.8	71.1	0.0	0.0
51	87.9	–	0.0	–
52	–	–	–	–

Probabilities are mentioned under "Materials and methods"

month. The transplanting of rice in the first week of July will have additional advantages of assured irrigation through rain during the growing periods of rice in the months of August and September. To increase the rain water use efficiency and productivity, rice can be substituted with other low-water-requiring high-value crops through sole or intercropping. In these intercropping practices under upland situations, water does not stagnate in the field. Thus, weed management should be appropriate for a clean crop stand. Since the rainfall after October is uncertain and erratic, sowing of high-value crops without supplementary irrigation is not possible.

The probability distribution functions, viz. log Pearson type III for monsoon rainfall and Gumbel distribution, for post-monsoon rainfall in the Daspalla region were found to be the best fit. These PDFs have comparatively better and adequate strength to describe the entire data set of 16 years of rainfall than other PDFs, viz. normal, two-parameter log normal, three-parameter log normal and Pearson type III. The scale parameter of distribution is taken into account by the log Pearson type III, Gumbel distribution and Pearson type III. Additionally, the location parameter is included in Gumbel, which avoids gross approximation (Sharda and Das 2005). Hence, the best-fit PDFs have more strength. The log Pearson type III and Gumbel distribution have weaknesses also as these are not suitable for studying flood frequency (Kroll and Vogel 2002; Ashkar and Mahdi 2003) and drought analysis (Quiring and Papakryiakou 2003). However, our results of log Pearson type III corroborate the previous findings of rainfall distribution characteristics of the Chia-Nan plain area in Southern Taiwan (Lee 2005) and in Nigeria as reported by Olofintoye et al. (2009).

Since the probability of occurrence of wet week was more than 30 % (Table 6) during the 19th–21st SMW (7th–27th May) and average weekly rainfall ranged from 24.1 to 40.7 mm, the pre-monsoon rain could be utilised for summer ploughing and initial seed bed preparations. The mean onset of rainy season was the 23rd SMW. Thus, sowing operations could be done during the 22nd SMW (28th May–3rd June)

because the probability of wet week was more than 31 % and average weekly rainfall was more than 15 mm. Sowing operations performed on the 22nd SMW would favour good germination of seeds and help avoiding moisture stress period during the 24th–26th SMW. In the event of delayed start of rainy season, the sowing operations could be taken up latest by the 27th SMW (2nd–8th July) and further delay in sowing might cause very low productivity and even crop failure. With the significant contribution of weekly rainfall (>46 mm) during the 36th–40th SMW and high consecutive wet week probability during the 36th–40th SMW, there is a potential for harvesting excess runoff water for supplemental irrigations. Similarly, greater probabilities of consecutive dry weeks after the 44th SMW, hints for need of supplementary irrigations and moisture conservation practices are to be taken up. Even in the event of midseason dry weeks, mulching and other moisture conservation practices would help in reducing soil evaporation and conserve moisture in the soil.

5 Conclusions

The analyses of rainfall data for the Daspalla region in Odisha, India revealed that a considerable amount of rainfall (651 mm) was lost due to the processes of runoff, deep percolation and evaporation. This implies that the excess rainfall could be stored in on-farm reservoirs or water harvesting tanks. By knowing the most probable date of the onset and withdrawal of effective monsoon, agricultural operations could be planned in advance and also corrective and contingency measures can be taken up during dry periods to avoid crop loss or reduction in crop yield due to soil moisture stress. Since post-monsoon rainfall is more uncertain and erratic than southwest monsoon, growing of high-value post-monsoon crops without supplementary irrigation would be risky. Since mean length of rainy season was 21 weeks (147 days), rice crop variety of ~130–140-day duration could easily be grown with little fear of drought, and the rice crop could be harvested before withdrawal of monsoon. Hence, the chances of reduction of rice yield due to water stress would be reduced. On the other hand, long-duration rice has every chance to undergo a period of drought or water stress situation, and yield reduction may happen because of the coincidence that the critical growth stage of rice, i.e. the reproductive phase, may fall during the receding phase of monsoon. In case of delayed onset and earlier withdrawal of monsoon season, short-duration rice variety of ~100 days can be grown. Our analyses reveal that the log Pearson type III and Gumbel probability distribution functions can be used for prediction of monsoon and post-monsoon rainfall, respectively, for the region under study. The analyses of rainfall using Markov chain model highlighted the knowledge of probability of dry spells and wet weeks in a year. This would form a useful guide for contingency crop planning; the appropriate soil and crop management would reduce risks associated with

erratic rainfall pattern and mitigation of dry spells. Mulching and other moisture conservation practices would help reducing soil evaporation and conserve moisture in the soil even during the midseason dry weeks. The emphasis and importance should be given to the rainfed agricultural activities similar to irrigated areas. It requires concerted water governance and management priorities, efforts involving institutional capacities, policy frameworks and generation of knowledge on natural resources management.

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