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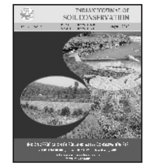

Rainfall analysis for crop planning under rainfed condition at Mirzapur district in Vindhya plateau of Indo-Gangetic Plain

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ABSTRACT

The spatial and temporal inconsistency of rainfall has increased during the recent decade, particularly in rainfed regions of the country. The rainfed areas face deficit and surplus distribution of rainfall during critical stages of crop growth. Therefore, planning of different agricultural activities consistent with these changes and specific crop is envisaged as key to safe guard against crop failure. In this study, analysis of 36 years (1980-2016) rainfall data using Markov chain model is used to find initial, conditional and consecutive dry and wet week probability and rainfall at different probability levels using incomplete gamma distribution. The forward and backward accumulation of rainfall is used for assessment of onset and withdrawal of rainy season. The weekly water balance for water deficit and surplus is carried using Thornthwaite method and best fit frequency distribution is identified for annual water deficit using chi square test. The average annual rainfall of Mirzapur district is found to be 1022.17 mm with 21.6% coefficient of variation. The onset and withdrawal of rainy season starts effectively from 24th week (11-17 June) and under delayed condition, rainy season starts by 26^{th} week (25 June-01 July). Under normal conditions, the rainy season starts by 25^{th} week (18-24 June). The rainy season ends at earliest by 42^{th} week (18-24 October) and under delayed condition rainy season may end by 50^{th} week (11-16 December). Under normal condition rainy season ends by 46^{th} week (10-16 November).The Gumbel distribution is found suitable for predicting annual water deficit based on Chi-square test.

1. INTRODUCTION

The rainfed agriculture is highly erratic depending on the rainfall distribution during the critical stages of crop growth (Rockstrom *et al.*, 2000). Rainfall is a key aspect in crop production planning in rainfed ecosystems as about 60% of the Indian agriculture is rain reliant, varied, complex, under endowed, risky, distress prone and vulnerable (Kumar *et al.*, 2018). The spatial and temporal variability of rainfall is compounded due to increase in frequency and intensity of extreme rainfall events due to global climate change (Ghosh *et al.*, 2012). The agricultural crop productivity largely depends on the rainfall distribution and its intensity during the rainy season. The characterization of extreme weather events is helpful in framing out the strategies to minimize the risk toward sustainable agricultural production (Kumari *et al.*, 2014). The analysis of annual, decadal and seasonal rainfall of a region is useful to design water harvesting structure for agricultural operations, field preparation, seeding, irrigation, fertilizer application and overall in field crop planning (Sharma *et al.*, 1979, Panigrahi and Panda, 2001). Rainfall analysis for crop planning was carried out in different regions of the country by (Sathyamoorthy *et al.*, 2018; Rajeshkumar *et al.*, 2018; Singh *et al.* 2018, Bhavyashree *et al.*, 2018; Panigrahi, 1998). To optimize agricultural productivity in the region, there is an urgent need to quantify rainfall variability at a local and seasonal level as a first step of combating extreme effects of persistent dry spells and crop failure (Kumar *et al.*, 2007). Since rainfall that is heterogeneous, in particular, is the most critical factor determining rainfed agriculture, knowledge of its statistical properties derived from long-term observation could be utilized in developing optimal cropping strategies in the area. Apart from analyzing the variability, some authors have utilized probability analysis (Gill *et al.*, 2015) for crop planning. Studies by Seleshi and Zanke (2004) and Tilahun (2006) noted high variations in annual and seasonal rainfall totals and rainy days and their importance in crop planning. On the other hand, the much-needed information on inter-/intra-seasonal variability of rainfall in the region is still inadequate despite its critical implication on soil water distribution and final crop yield (Jagannathan, 2017).The initial and conditional probabilities of occurrence of dry and wet spells with respect to a threshold amount of rainfall is extremely useful for crop planning, farming operations and planning of soil and water conservation measures (Nema *et al.*, 2013). The Markov chain probability model is used by several researchers due to its ease in application, to study the occurrence of dry and wet spells (Thiyagaraj *et al.*, 1995; Chattopadhyay and Ganesan, 1995; Kar, 2003; Subhash *et al.*, 2009). In context of above, for crop planning under rainfed conditions at Mirzapur district an attempt is made to analyze the initial and conditional probability of dry and wet spells, probability consecutive two and three weeks dry and wet spell, probable date of onset and withdrawal of monsoon, weekly water balance for deficit and surplus and best fit distribution of annual water deficit for Mirzapur district of Uttar Pradesh.

2. MATERIALS AND METHODS

2.1 Study Area and Data Used

The meteorological data is collected for a period of 36 years (1980-2016) from Indian Meteorological Department, Pune and soil data is collected from annual report of All India Coordinated Research Project on Dry land Agriculture, Rajiv Gandhi South Campus of Banaras Hindu University at Barkachha, Mirzapur located between 23º31'12"-25º19'12"N latitude and 82º42'0"-83º19'48"E longitude at 80 m above mean sea level (AMSL). The maximum and minimum temperature at Mirzapur district range between 40-45°C and 8-10ºC during summer and winter, respectively. The average relative humidity ranges from 42.2 to 70.5%. Dominant soil texture is sandy loam with poor organic matter. The field capacity and wilting point of soil varies from 20.0% to 9.8%, respectively. The farmers in this region mostly grow paddy as a major crop during *kharif* season (90% of total cultivated area) and mustard, lentil, chickpea and pea during *rabi* season on residual moisture in rainfed parts of the district.

2.2. Conditions for Dry and Wet Spell

The dry and wet spell analysis is carried out for weekly rainfall data using Markov chain model considering less than 20 mm rainfall in a week as dry week and 20 mm or more as a wet week (Pandharinath, 1991).

2.3 Condition for Onset and Withdrawal of Rainy Season

The onset and withdrawal of rainy season is computed for weekly rainfall data using forward and backward accumulation method, respectively. The minimum 75 mm of weekly rainfall accumulation is considered as the onset week for land preparation for sowing of dry seeded crops (Babu and Lakshminarayana, 1997; Panigrahi and Panda, 2002). The 200 mm of weekly accumulated rainfall is considered as the end of rainy season, which is sufficient for ploughing of fields after harvesting the crops (Babu and Lakshminarayana, 1997).

The concept of estimating probabilities with respect to a given amount of rainfall is extremely useful for agricultural planning (Singh *et al.*, 2013). The initial and conditional probabilities are the relative chance of occurrence of a given amount of rainfall (Mahanta *et al.*, 2018). The parameters estimated for initial, conditional and consecutive wet and dry weeks probability is computed using Markov chain probability and rainfall at different probability level using incomplete gamma distribution. The Food and Agriculture Organization (FAO) Penman-Monteith equation is used for computation of reference and actual evapotranspiration is calculated based on crop coefficient of different crops. The weekly water balance is computed using Thornthwaite equation. The weekly soil moisture index (SMI) and moisture availability index (MAI) is carried out using standard methods described below. The observed and predicted annual water deficit computed using Gumbel, Log normal and Log Pearson distribution is compared by chi-square test to identify the best fit probability distribution at different probability levels and return periods.

2.4 Incomplete Gamma Distribution for Weekly Rainfall at Different Probability Levels

The incomplete gamma distribution (Sharma and Singh, 2010) is applied to calculate probability density function $f(x)$ for wet and dry week at different probability levels for two parameters that is determined using eq. 1 and 2.

$$f(x) = \frac{(x)^{\alpha-1}}{\beta^{\alpha}\Gamma(a)} exp\left(\frac{-(x)}{\beta}\right) \quad ...(1)$$

$$f(x) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(a)} exp\left(\frac{-(x-\gamma)}{\beta}\right) \quad ...(2)$$

Where, $\gamma \leq x < +\infty$, α, is shape parameter ($\alpha > 0$), β is scale parameters ($\beta > 0$), γ is location parameter yield two parameter gamma distribution ($\gamma = 0$), Γ is Gamma function, $\alpha \rightarrow \infty$ gamma distribution approaches to normal distribution.

2.5 Markov Chain Initial Probability of Dry and Wet Weeks

The initial probability of dry and wet week is computed using eq. 3 and 4.

$$P_d = \frac{F_d}{n} \quad ...(3)$$

$$P_w = \frac{F_w}{n} \quad ...(4)$$

Where, P_d is probability of dry week, P_w is probability of wet week, F_w is number of wet week, F_d is number of dry weeks, n is total number of years.

2.6 Markov Chain Conditional Probability of Dry and Wet Weeks

The conditional probability of dry and wet week is computed using eq. 5, 6, 7 and 8, respectively.

$$P_{dd} = \frac{F_{dd}}{n} \quad ...(5)$$

$$P_{ww} = \frac{F_{ww}}{n} \quad ...(6)$$

$$P_{wd} = 1 - P_{dd} \quad ...(7)$$

$$P_{dw} = 1 - P_{ww} \quad ...(8)$$

Where, P_{dd} is probability of dry week preceded by dry week, F_{dd} is number of dry week preceded by dry week, P_{ww} is probability of wet week preceded by wet week, F_{ww} is number of wet week preceded by wet week, P_{wd} is probability of dry week preceded by wet week, P_{dw} is probability of wet week preceded by dry week.

2.7 Markov Chain Consecutive Dry and Wet Week Probability

The consecutive dry and wet week probability is computed using eq. 9, 10, 11 and 12.

$$P_{2d} = P_{d1} \times P_{d2} \quad ...(9)$$

$$P_{2w} = P_{w1} \times P_{w2} \quad ...(10)$$

Where, P_{2d} is probability of consecutive two dry weeks, P_{d1} is probability of first dry week, P_{d2} is probability of second dry week, P_{2w} is probability of consecutive two wet weeks, P_{w1} is probability of first wet week, P_{w2} is probability of second wet week.

$$P_{3d} = P_{d1} \times P_{d2} \times P_{d3} \quad ...(11)$$

$$P_{3w} = P_{w1} \times P_{w2} \times P_{w3} \quad ...(12)$$

P_{d3} is probability of third dry week, P_{3d} is probability of consecutive three dry weeks, P_{w3} is probability of third wet week, P_{3w} is probability of consecutive three wet weeks.

2.8 Estimation of Reference and Actual Evapo-transpiration

The FAO Penman-Monteith given in eq. 13 (Cai *et al.,* 2007) is used to estimate daily ET_o.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\mu_2)} \quad ..(13)$$

Where, ET_o is reference evapotranspiration (mm day^{-1}), R_n is net radiation of crop surface (MJ m^{-2}day^{-1}), G is soil heat flux density (MJ m^{-2}day^{-1}), γ is psychometric constant (kPa^{o}C^{-1}), T is mean daily air temperature (^{o}C), u_2 is average daily wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), and Δ is slope of saturation vapour pressure curve (kPa^{o}C^{-1}).

The actual evapotranspiration (Allen, 1998) is computed using eq. 14 .

$$ET_a = K_c \times ET_o \quad ...(14)$$

ET_a is actual evapotranspiration (mm day^{-1}), K_c is crop coefficient (dimensionless), ET_o is reference evapo-transpiration (mm day^{-1}).

2.9 Thornthwaite Weekly Soil Moisture Balance

The weekly soil moisture balance (Thornthwaite and Mather, 1955; 1957) is computed using eq. 15.

$$STOR = AWC \times e^{\frac{\sum_{i=1}^{n}(P - ET_o)}{AWC}} \quad ...(15)$$

Where, $STOR$ is actual storage of soil moisture (mm), AWC is moisture storage capacity of soil (mm), P is precipitation (mm), ET_o is reference evapotranspiration (mm).

2.10 Soil Moisture Index (SMI)

The weekly SMI (Meshram *et al.,* 2018) is computed using eq. 16.

$$SMI = \frac{(SM_{max} - SM_{actual})}{(SM_{max} - SM_{min})} \quad ...(16)$$

Where, SMI is soil moisture index (dimensionless), SM_{max} is maximum soil moisture (mm), SM_{min} is minimum soil moisture (mm), SM_{actual} is actual soil moisture (mm).

2.11 Moisture Availability Index (MAI)

The MAI (Hargreaves, 1975) is computed using eq. 17.

$$MAI = \frac{AE}{PE} \quad ...(17)$$

Where, MAI is moisture availability index (dimensionless), AE is actual evapo-transpiration (mm), PE is potential evapo-transpiration (mm).

2.12 Gumbel Distribution for Annual Water Deficit

The Gumbel distribution function (Sharma and Singh, 2010) is used for computing predicted annual water deficit using eq. 18.

$$P(x) = e^{-e^{\frac{-(x-\mu)}{\beta}}} \quad ...(18)$$

Where, x is annual water deficit for year t (mm), $P(x)$ is Gumbel probability of annual water deficit for year t (dimensionless), μ is mode (mm), β is scale factor (dimensionless), e is 2.718.

2.13 Log Normal Distribution for Annual Water Deficit

The log normal probability distribution (Sharma and Singh, 2010) is used for computation of annual water deficit using eq. 19.

$$P(x) = \frac{1}{S\sqrt{2\pi x}} e^{\frac{-(ln-M)^2}{(2S^2)}} \quad ...(19)$$

Where, x is annual water deficit for year t (mm), $p(x)$ is probability of annual water deficit (dimensionless), S is standard deviation of annual water deficit (mm), M is mean annual water deficit (mm), π is 3.14, e is 2.718.

2.14 Log Pearson Distribution for Annual Water Deficit

The log Pearson Type-III distribution (Sharma and Singh, 2010) is used for computation of annual water deficit using eq. 20.

$$logD_T = \mu_{logD} + K_T \sigma_{logD} \quad ...(20)$$

Where, D_T is log transformed annual water deficit for year t (mm), μ_{logD} is mean of log transformed annual water deficit (mm), K_T is frequency factor based on return period T (dimensionless), σ_{logD} is standard deviation of annual water deficit (mm).

2.15 Chi-square Test

Chi-square test is carried out to identify the best fit distribution for annual water deficit at different probability levels and return period (Sharma and Singh, 2010).

$$\chi^2 = \sum \frac{(O-E)^2}{E} \quad ...(21)$$

Where, χ^2 is calculated value of Chi-square, O is observed annual water deficit (mm), E is estimated annual water deficit (mm).

3. RESULTS AND DISCUSSION

The start and end of rainy season under early, late and mean condition for Mirzapur district is given in Table 1. The start of rainy season at earliest is found to be 24th week (11-17 June) and under delayed condition, start of the season is by 26th week (25 June-01 July). Under normal conditions, the rainy season starts by 25th week (18-24 June). In Mirzapur district rainy season ends at earliest by 42nd week (15-21 October) and under delayed condition rainy season ends by 50th week (10-16 December). Under normal condition rainy season ends by 46th week (12-18 November). The rainfall in Mirzapur district reaches its peak by 31st week (30 July-05 August) with highest probability of 82.76% and withdraw by the end of 46th week (12-18 November) with highest probability level (96.43%).

Table: 1
Characteristics of start and end of rainy season using forward and backward accumulation at Mirzapur

Station	Start of rainy season			End of rainy season		
	Early	Late	Mean	Early	Late	Mean
Standard meteorological week	24th	26th	25th	42th	50th	46th

3.1 Initial and Conditional Probability of Dry and Wet Week

The initial and conditional probability of dry and wet week as shown in Fig.1 and 2. The probability of occurrence of dry week is high (more than 50%) until end of 24th week (11-17 June). The probability of occurrence of dry week proceeded by another dry week and dry week preceded by another wet week vary from 25 to 100% and from 0 to 100%, respectively during 1st to 24th standard meteorological week. However, from 24th (11-17 June) to 38th week (17-23 September) (usually termed as monsoon season) the probability of dry week and that of dry week preceded by another dry week is less than 1%. The chances of occurrence of dry spells are again high from 39th week (24-30 September) to end of the year. Probability of occurrence of wet week preceded by another wet week during these periods is between 0 to 89.47%. Also there is 75.86 to 100% risk that the weeks from 39th (24-30 September) to 52nd (24-31 December) will remain dry.

3.2 Probability of Consecutive Two, Three and Four Dry and Wet Week

The analysis of consecutive dry and wet week analysis at Mirzapur district as shown in Fig. 3 and 4 shows that there is more than 50% probability of two consecutive dry weeks within the first 22 standard meteorological week in a year (01 Jan-03 June).

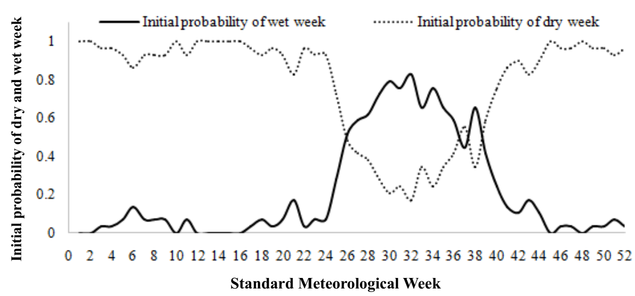

Fig. 1. Initial probability of dry and wet week at Mirzapur district

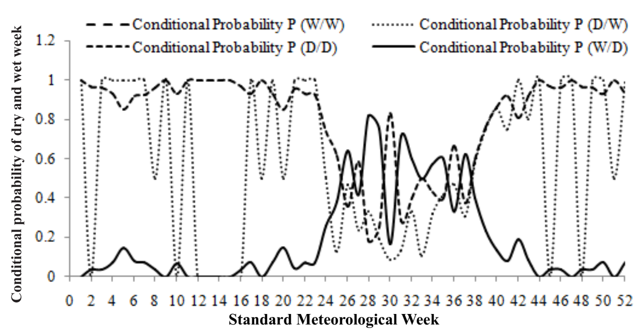

Fig. 2. Conditional probability of dry and wet weeks at Mirzapur district

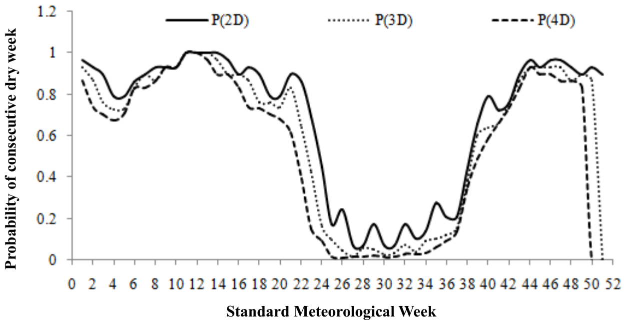

Fig. 3. Probability of consecutive two, three and four dry weeks at Mirzapur district

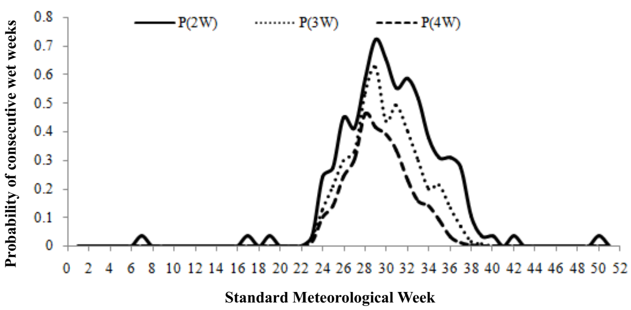

Fig. 4. Probability of consecutive two, three and four wet weeks at Mirzapur district

Similarly, the probability of three consecutive dry weeks is also very high (63.86-100%) in first 21 SMW in a year. The corresponding values of rainfall for two and three consecutive wet weeks is very low with values ranging from 0 to 3.45 mm. The rainfall values estimated from 22nd (28 May-3 June) to 37th (10-16 September) week shows that probability of two and three consecutive dry weeks ranges within 3.45-72.41% and 3.02-62.54%, respectively.

3.3 Incomplete Gamma Distribution of Weekly Rainfall at Different Probability Levels

The incomplete gamma distribution of weekly rainfall at different probability levels is shown in Fig. 5 which depicts that Mirzapur receives effective rainfall for crop from 27th SMW (2-8 July) to 37th SMW (10-16 September). The probability of onset of monsoon is from 23rd to 26th SMW and withdrawal of monsoon starts from 39th-40th SMW at probability level of more than 50%. The incomplete gamma distribution analysis of weekly rainfall at different probability shows that a continuous period from 27-40th SMW has assured (more than 50% probability) of receiving rainfall so prerequisites for agriculture should be completed upto 26th SMW in rainfed areas. Since, the effective monsoon continue in Mirzapur district for atleast 13 weeks, so rainfed farmers can utilize this period effectively for growing short duration, early maturing and drought resistance varieties of crop.

3.4 Thornthwaite Water Balance for Weekly Surplus and Deficit

Thornthwaite method of water balance is used for analysis of weekly surplus and deficit soil moisture at Mirzapur district as shown in Fig. 6. The Fig. 6 shows that there is an assured weekly surplus of at least 80 mm from 27th week to 35th week. The Fig. 7 shows SMI and MAI for standard meteorological week at Mirzapur district. The surplus water available from 27th to 35th is most critical period for rain water management, as this harvested water can be effectively utilised for irrigation of crops during dry spell from 36th to 40th week. Therefore, the excess water conserved in water harvesting structure at the farm can be efficiently used during prolonged dry spell to protect the crop during *kharif* season.

3.5 Chi-square Test of Observed and Predicted Annual Water Deficit

Chi-square test is performed to identify the best fit probability distribution for prediction of annual water deficit at Mirzapur district of Uttar Pradesh. The values of maximum annual water deficit computed using different

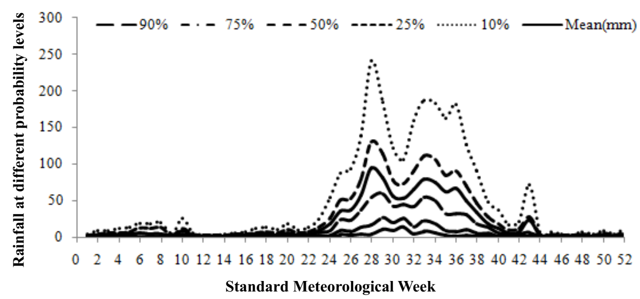

Fig. 5. Incomplete gamma distribution of rainfall at different probability levels for Mirzapur district

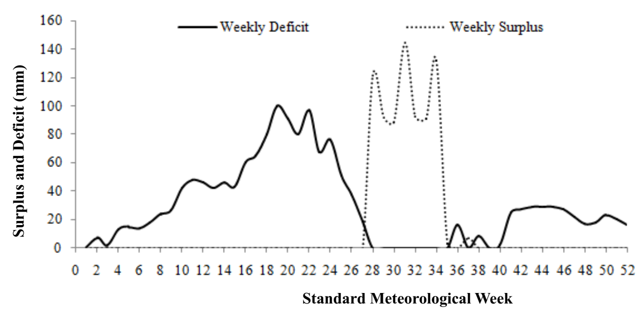

Fig. 6. Average weekly soil moisture surplus and deficit at Mirzapur district

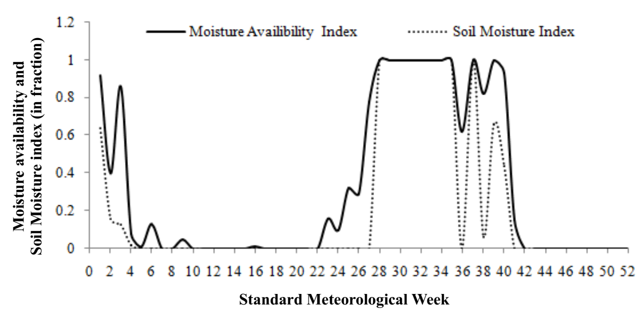

Fig. 7. Average weekly moisture availability and soil moisture index at Mirzapur district

probability distribution is given in Table 2. The annual maximum water deficit values computed using different probability distribution, probability levels and return period revealed that, lowest Chi-square values were obtained for Gumbel distribution. The statistical comparison by Chi-square test for goodness of fit as shown in Fig. 8 clearly indicates that Gumbel distribution is the best probability model for predicting annual maximum water deficit at Mirzapur district.

4. CONCLUSIONS

The Mirzapur district is characterized with undulated topography, having hot and moist semi-arid agro-ecological region with deep, loamy soils and slightly eroded rocky tracts, low to medium available water content and length of growing period is found to be maximum 12-14 weeks or 84-98 days which is less than 120-150 days for most of the crops. The rainy season in Mirzapur district is expected by 31th week with highest probability of 82.76% and withdraw by the end of 46th week with highest probability level of 96.43%. The probability of occurrence of dry week is high (more than 50%) until end of 24th week (11-17 June). The probability of occurrence of dry week proceeded by another dry week and dry week preceded by another wet week vary from 25-100% and 0-100%, respectively during 1st to 24th SMW. However, from 24th (11-17 June) to 38th week (17-23 September) (usually termed as monsoon season) the probability of dry week and that of dry week preceded by another dry week is less than 1%. The chances of occurrence of dry spells are again high from 39th week (24-30 September) till end of the year. Probability of occurrence of wet week preceded by another wet week during these periods is between 0 to 89.47%. Also there is 75.86-100% risk that the weeks from 39th (24-30 September) to 52nd (24-31 December) will remain dry. There is more than 60% probability of two or more consecutive dry weeks within the first 22 standard meteorological week in a year. There is an assured weekly surplus of at least 80 mm from 27th week to 35th week estimated using Thornthwaite method. The seven weeks from 27th to 35th is most critical period for rain water management for crop growth with moisture availability from 36th to 40th week. Therefore, the excess moisture conserved during 27th to 35th standard meteorological week can be utilized for irrigation during dry spells from 36th to 40th weeks. The Chi-square test to identify best fit probability distribution at different probability and return period shows that Gumbel distribution is best for prediction of annual water deficit at Mirzapur district. The sequence cropping (Rice-Chickpea, Rice-Lentil, Rice-Mustard, Rice-Barley, Rice-Wheat, Pearl millet-Chickpea, Pearl millet-Lentil, Sorghum-Chickpea, and Sorghum-Lentil) with deep rooted crop during *Rabi* season and intercropping of pigeon pea with pearl millet is recommended with conservation tillage, wider spacing of crops, weed management by mulching with locally available materials, split doses of fertilizers, thinning of crop population, use of conservation furrow, and intercultural operation for surface water management. The suitable varieties for drought resistance characteristics should be adopted by the farmers during *rabi* Season for combat with the situation under rainfed condition with soil moisture conservation measures.

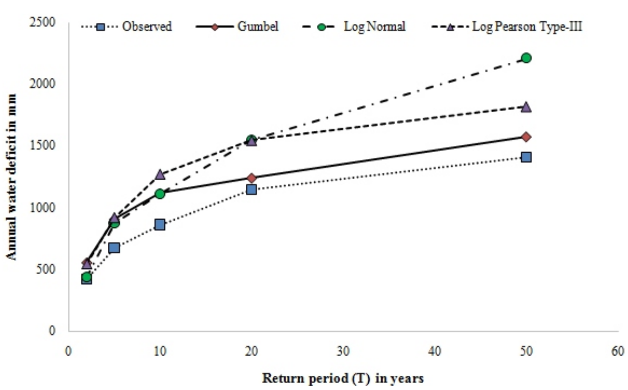

Fig. 8. Observed and simulated annual water deficit for different return period at Mirzapur district

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Table: 2
Chi-square test for observed and predicted maximum annual water deficit at Mirzapur district

P	T	OAD	PAD (mm)		
			Gumbel	Log Normal	Log Pearson Type-III
50	2	420.91	557.41	437.82	543.42
20	5	672.17	906.62	874.99	918.25
10	10	859.21	1115.74	1107.89	1268.60
5	20	1146.26	1240.85	1546.13	1540.70
2	50	1404.26	1574.06	2206.25	1814.70
			178.56	498.43	419.49

P is Probability in %, T is return period in years, OAD is observed annual water deficit in mm, and PAD is simulated annual water deficit in mm.

REFERENCES

Allen, R.G. 1998. Crop Evapotranspiration-Guideline for computing crop water requirements. *Irrig. Drain.*, 56:300.

Babu, P.N. and Lakshminarayana, P. 1997. Rainfall analysis of a dry land watershed-Polkepad: A case study. *J. Indian Water Res. Soc.*, 17: 34-38.

Bhavyashree, S. and Bhattacharyya, B. 2018. Fitting Probability Distributions for Rainfall Analysis of Karnataka, India. *Int. J. Curr. Microbiol. App. Sci.*, 7(3): 1498-1506.

Cai, J., Liu, Y., Lei, T. and Pereira, L.S. 2007. Estimating reference evapotranspiration with the FAO Penman–Monteith equation using daily weather forecast messages. *Agr. Forest Meteorol.,* 145(1-2): 22-35.

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

Ghosh, S., Das, D., Kao, S.C. and Ganguly, A.R. 2012. Lack of uniform trends but increasing spatial variability in observed Indian rainfall extremes. *Nat. Clim. Change*, 2(2): 86.

Gill, K.K., Aggarwal, R. and Goyal, P. 2015. Rainfall Probabilities for Crop Planning in Ludhiana by Markov Chain Analysis. *Indian J. Ecol.*, 42(1): 16-20.

Hargreaves, G.H. 1975. Moisture availability and crop production. *Trans. ASAE*, 18(5): 980-984.

Jagannathan, R. 2017. Characterization of Rainfall and Length of Growing Period Over North Western Zone of Tamil Nadu. *Indian J. Ecol.*, 44(2): 232-238.

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

Kumar, A., Pal, R. and Sharma, H.C. 2007. Probability analysis of monsoon rainfall data of Saharanpur for Agricultural planning. *Indian J. Soil Cons.,* 35(2): 122-124.

Kumar S., Kumar, S. and Sharma, R.P. 2014. Probability of Wet Spells, Expected Amount and Long-Term Trends of Rainfall for Crop Planning in Bihar. *Indian J. Ecol.*, 41(2): 243-246.

Kumar, A., Tripathi, P., Gupta, A., Singh, K.K., Singh, P.K., Singh, R. and Tripathi, A. 2018. Rainfall variability analysis of Uttar Pradesh for crop planning and management. *Mausam*, 69(1): 141-146.

Kumari, P., Ojha, R. K., Wadood, A. and Kumar, R. 2014. Rainfall and drought characteristics for crop planning in Palamau region of Jharkhand. *Mausam*, 65(1): 67-72.

Mahanta, J., Dey, S. and Khosro, P. 2018. Analyzing Rainfall Condition of Bangladesh: An Application of Markov Chain. *Thail. Stat.*, 16(2): 203-212.

Meshram, S.G., Gautam, R. and Kahya, E. 2018. Drought analysis in the Tons River Basin, India during 1969-2008. *Theor. Appl. Climatol.*, 132(3-4), 939-951.

Nema, A.K., Bisen, Y., Singh, S.R. and Singh, T. 2013. Markov Chain Approach–Dry and Wet Spell Rainfall Probabilities in Planning Rainfed Rice Based Production System. *Indian J. Dryland Agril. Res. Dev.*, 28(2): 16-20.

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

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

Rajeshkumar, N.K., Balakrishnan, P., Reddy, G.S., Gowdar, B.P. and Satishkumar, U. 2018. Rainfall Probability Distribution Analysis in Selected Lateral Command Area of Upper Krishna Project (Karnataka), India, Springer, Singapore. *Hydrol. Modeling,* pp. 3-12.

Rockström, J. and Falkenmark, M. 2000. Semiarid crop production from a hydrological perspective: gap between potential and actual yields. *Crit. Rev. Plant Sci.*, 19(4): 319-346.

Sathyamoorthy, N.K., Ramaraj, A.P., Senthilraja, K., Swaminathan, C. and Jagannathan, R. 2018. Exploring Rainfall Scenario of Periyar Vaigai Command Area for Crop Planning. *Indian J. Ecol.*, 45(1): 11-18.

Seleshi, Y. and Zanke, U. 2004. Recent changes in rainfall and rainy days in Ethiopia. *Int. J. Climatol.*, 24(8): 973-983.

Tiwari, K.N., Paul, D.K. and Gontia, N.K. 2007. Characterization of meteorological drought. *Hydrol.*, 30(1-2): 15-27.

Sharma, M.A. and Singh, J.B. 2010. Use of probability distribution in rainfall analysis. *NY Sci. J.*, 3(9): 40-49.

Singh, G., Kumar, R., Mishra, C.D., Meshram, S. and De, N. 2013. Precipitation management under rice based rainfed cropping system: a case study for transect 4 of Indo-Gangetic plain. *Int. J. Agron. Plant Prod.*, 4 (Special Issue), 3782-3790.

Singh, P.K., Tripathi, M.P., Sahu, R.K. and Tirath, K. 2018. Rainfall analysis for agricultural planning in Mungeli region of Chhattisgarh plain. *Environ. and Ecol.*, 36(1A), 243-246.

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

Thiyagaraj, M. 1995. A Markov chain model for daily rainfall occurrences at east Thanjavur district. *Mausam*, 46: 383-388.

Thornthwaite, C.W. and Mather, J.R. 1955. The water balance. Centerton: Drexel Institute of Technology, Laboratory of Climatology. *Pub. Climatol.*, 8(1):104.

Thornthwaite, C.W. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Institute of Technology, Laboratory of Climatology. *Pub. Climatol.*, 10(3): 185-311.

Tilahun, K. 2006. Analysis of rainfall climate and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half a century. *J. Arid Environ.*, 64(3): 474-487.