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Statistical modelling of weekly rainfall data for crop planning in Bundelkhand region of central India

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ABSTRACT

The historical rainfall data for the period of 46 years (1968-2013) of Datia district in Bundelkhand were analysed for selection of most appropriate probability distribution of rainfall. The best distribution among different data sets has been identified using probability plot and Anderson-Darling (AD) test for goodness-of-fit, along with the appropriateness of estimated percentiles. From the analysis, it was found that one single probability distribution has not been found appropriate to represent all the datasets though Weibull and Gamma distributions were found promising for most of the datasets. The best-fit distribution has been employed for obtaining the assured quantum of rainfall pertaining to Standard Meteorological Weeks (SMWs) (24-42) at various probability levels. Minimum assured rainfall at 40-50% probability level was found to be in close agreement with the long-term average weekly rainfall data. The minimum assured rainfall of 20 mm and more are expected from SMW27 onwards at 70% probability. This indicated that the sowing of *kharif* crops has to be done during the SMW 27 for maximum utilization of rain water.

1. INTRODUCTION

About 80% of world and 60% of Indian agriculture is rain-dependent, diverse, complex, under-invested, risky, distress prone and vulnerable (IMCT, 2008). Bundelkhand region of central India is one such area where drought used to cause havoc to the agriculture and needs proper crop planning. Since last one decade, Bundelkhand is struck by the occurrence of regular scarcity of water resulting in frequent droughts and affecting farming and agriculture which slowed down all the course of development and growth, as agriculture is the main livelihood of the area (Alam *et al*., 2012; Alam *et al*., 2014a).

Farming system of crops and livestock are the main occupations of the region, whereas out sourcing livelihood by seasonal migration minimizes risks and vulnerability. The region is dependent on scanty and uncertain distribution of the rainfall and is characterized by hard rock area with limited or inadequate ground water resources.

Water is very important not only for daily consumption but also for various other applications including hydrological and water related sectors such as agriculture and crop planning. Now a days, probability distributions of rainfall are widely used to understand the rainfall pattern of an area. Probability and frequency analysis of rainfall data enable us to determine the expected rainfall at various chances (Bhakar *et al*., 2008). Jana *et al*. (2015) analysed and studied the annual extreme rainfall characteristics using probability model (Generalize Extreme Value distribution) and predicted the changes of extreme rainfall behaviour in future climate for Doon valey. Williams (1952) used the probability model first time that fitted one-parameter model log series distribution for the dry spells in Harpenden, England.

The selection of the best fitted distribution has always been a key interest in the study of rainfall amount. Weekly distribution of rainfall and its probability is helpful in crop planning by identifying the period of drought, normal and excess rainfall (Ray *et al*., 1987). Two-parameter probability distributions (normal, log-normal, Weibull, logistic, log-logistic, smallest and largest extreme value), and three-parameter probability distributions (log-normal, gamma, Weibull, and log-logistic) have been widely used for studying flood frequency (Ashkar and Mahdi, 2003; Clarke, 2003) and drought analysis (Quiring and Papakryiakou, 2003; Alam *et al.,* 2014b). Sharda and Das (2005) compared several types of distributions to fit weekly rainfall amount in Doon valley, India. The rainfall pattern decides the cultivation of crops, their varieties, adoption of cultural operations and harvesting of excess rain water of any region (Sinhababu, 1977; Budhar *et al*., 1987; Thakur, 1998; Kar *et al.*, 2004). India Meteorological Department (IMD) (1995) computed minimum assured amount of rainfall at 40, 50, 60 and 70% probability levels for different stations employing two-parameter gamma probability distribution. Kumar *et al*. (2007) conducted a study to identify best fit trend of weekly rainfall data of 45 years (1955-1999) for the western Uttar Pradesh at various probability levels and expected rainfall frequency for crop planning and management to workout the irrigation period required for the crops, and found 70% probability level was useful for planning of *kharif* crops and to decide proper time for various agricultural operations. Alam *et al*. (2015) has done weekly rainfall analysis using different two and three parameter statistical distributions for *kharif* crop planning in Shivalik regions of India.

In Bundelkhand region, systematic study for selection of most appropriate distribution by comparing the probability distributions is lacking for describing non-Gaussian rainfall data. Keeping in view the above, in the present study, probability distributions have been compared and evaluated for their appropriateness to describe rainfall data using probability plot, AD test for goodness-of-fit and computing estimated percentiles. The developed probability distributions have been employed to obtain the minimum assured amount of rainfall at different probability levels in SMWs which can be useful for crop planning in the region.

2. MATERIALS AND METHODS

Study Area and Data

Bundelkhand region comprising of thirteen districts (seven districts of Uttar Pradesh and six districts of Madhya Pradesh) of central India, is located between 23°10' and 26°27' N latitude and 78°40' and 81°34' E longitude (Fig. 1). The geographical area of Bundelkhand region (7.08 m ha) is ravenous, undulating and hillocks. The region generally slopes from south to north. The elevations in the area range from 600 m above msl in southern part to 150 m above msl near Yamuna river. The region is characterized by hard rocks, undulating terrain of varied slope. The Yamuna flows along the northern boundary of the region, the other important rivers being the *Sindh*, the *Betwa*, the *Ken* and the *Baghain*, all of which ultimately drain into the *Yamuna*. The major tributaries of these rivers are *Sahjad, Sajnam, Jamni, Pahuj* and *Dhasan*. The main rivers often dry up during summer; however, they are the main sources of drinking and irrigation water. The cropping intensity in the region is about 115%. The net and gross irrigated areas of the state are 6.04 and 6.19 m ha, respectively. About 53% of the agricultural area in the Bundelkhand is rainfed. The major crops in the region are rice (*Oryza sativa*), maize (*Zea mays*), *sorghum* (*Sorghum bicolour*), pearl millet (*Pennisetum glaucum*), soybean (*Glycine max*), mung bean(*Vigna radiate*), pigeon pea (*Cajanus cajan*), black gram (*Vigna mungo*), sesame (*Sesamum indicum*), black mustard (*Brassica nigra*), ground nut (*Arachis hypogaea*), tomato (*Lycopersicon esculentum) etc.* However, due to climatic and edaphic limitations, the productivity of this area is below the state average. Occurrence of frequent droughts and ensuing crop failures are common in this region.

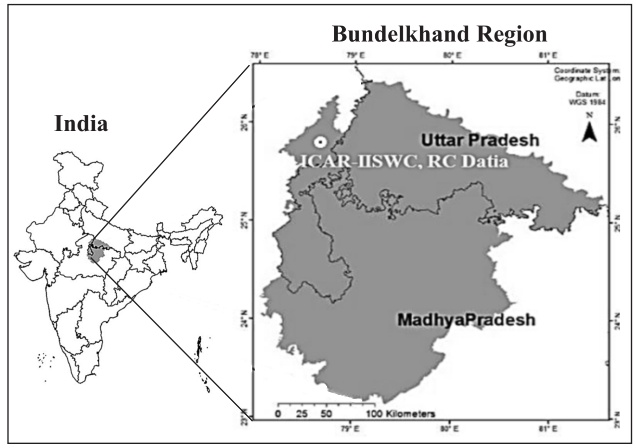

Fig.1. Bundelkhand region

The daily rainfall (mm) data for 46 years (1968–2013) recorded at the meteorological observatory of ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Datia, Madhya Pradesh has been used. The observatory is situated at 25º42'12.25" N latitude and 78º25'58.87" E longitude with 222 m above msl. The daily rainfall data was converted into SM weekly data employing standard procedure followed by India Meteorological Department (IMD). The SMW from 24^{th}(Jun 11–17) to 42^{nd}(15–21 October) have been considered for the analysis, as they cover the rainy season and rainfed crop growth period in the region. Season wise distribution of weekly and monthly rainfall over the study period is shown in Fig. 2.

The climate is subtropical semi-arid with average annual rainfall and evaporation is about 827 and 2565 mm, respectively. More than 90% of annual rainfall occurs during June to September. The average annual temperature is 25.6˚C with January being the coldest month having mean daily maximum temperature of 21.3˚C and minimum of 7.3˚C. The temperature of May can go up to 48°C. The erratic distribution of rainfall often forces the farmers to take up only *rabi* crops on stored moisture. The ground water table has gone down due to the occurrence of frequent droughts and also because of over-exploitation. Average weekly rainfall and reference ET value for all 52 standard weeks along excess/deficit analysis is shown in Fig. 3.

Statistical Analysis

Statistical methods can be used as a tool for predicting the occurrence of rainfall with an associated level of probability (Kumar and Kumar, 1989). Gupta *et al*. (1975) revealed that rainfall at 80% probability level can safely be taken as dependable rainfall while that of 50% probability level is the maximum limit for taking risk. Many probability distribution models are in vogue for realistic prediction of rainfall. In this study, seven distributions, *viz*., normal, log-normal, gamma, Weibull, logistic, log-logistic, extreme value distributions are considered for selection of most appropriate distribution to describe the weekly rainfall data. The probability distribution functions (pdf) for the rainfall random variable (x) of these seven distributions are as follows:

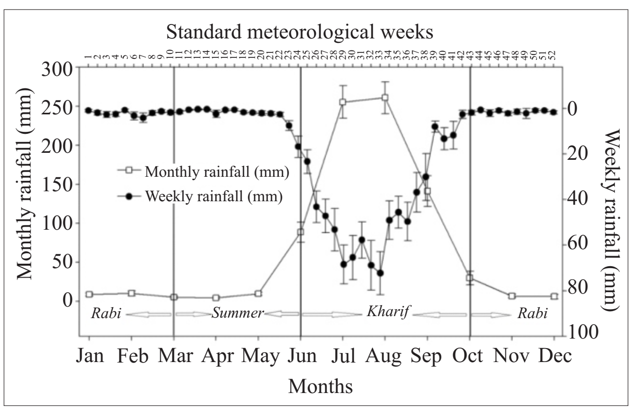

Fig. 2. Season wise distribution of weekly and monthly rainfall for Bundelkhand region

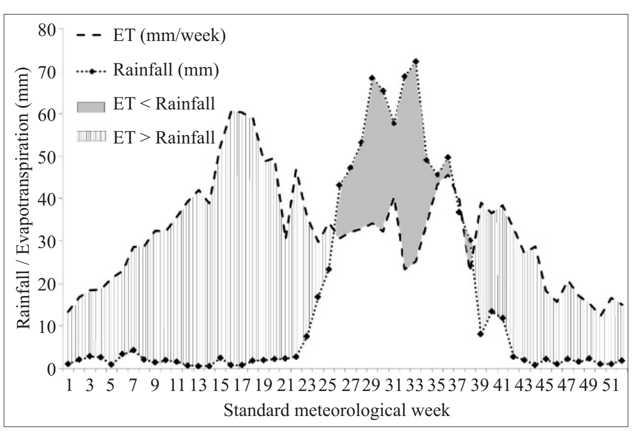

Fig. 3. Average weekly rainfall and ET value along excess/ deficit analysis

(i) Normal: $f(x;\mu,\sigma)=\dfrac{1}{\sigma\sqrt{2\pi}}\,e^{-\dfrac{(x-\mu)^2}{2\sigma^2}},\ x>0;$ with parameters μ (mean) and σ^2 (variance).

(ii) Log normal: $f(x;\mu,\sigma)=\dfrac{1}{x\sigma\sqrt{2\pi}}\,e^{-\dfrac{(\ln x-\mu)^2}{2\sigma^2}},\ x>0;$ with parameters μ (mean) and σ^2 (variance).

(iii) Gamma: $f(x;\mu,\theta)=\dfrac{x^{k-1}e^{-\frac{x}{\theta}}}{2\sigma^2},\ x>0;$ with parameters $k>0$ and $\theta>0$.

(iv) Weibull: $f(x;\lambda,k)=\dfrac{k}{\lambda}\left(\dfrac{k}{\lambda}\right)^{k-1}e^{-\left(\frac{x}{\lambda}\right)^k},\ x\geq 0;$ with parameters λ ($<x$) and $k>0$.

(v) Logistic: $f(x;\lambda,s)=\dfrac{\exp\left(\dfrac{x-a}{b}\right)}{b\left[1+\exp\left(\dfrac{x-a}{b}\right)\right]^2},\ x\in\mathbf{R};$ with parameters $a\in R$ and $b>0$.

(vi) Log logistic: $f(x;\alpha,\beta)=\dfrac{\left(\dfrac{\beta}{\alpha}\right)\left(\dfrac{x}{\alpha}\right)^{\beta-1}}{\left(1+\left(\dfrac{x}{\alpha}\right)^{\beta}\right)^2},\ x>0;$ with parameters $\alpha>0$ and $\beta>0$.

(vii) Extreme value distribution: $f(x;\mu,\sigma)=\dfrac{1}{\sigma}\exp\left(\dfrac{x-\mu}{\sigma}\right)\exp\left(-\exp\left(\dfrac{x-\mu}{\sigma}\right)\right),$ $x>0$; with parameters $\mu\in R$ and $\sigma>0$.

Anderson-Darling (AD) Test for Goodness of Fit Test

For testing normality of data sets, AD test (D'Agostino and Stephens, 1986) has been employed in the present study. The goodness of fit test measures the compatibility of random sample with the theoretical probability distribution. The goodness of fit test is applied for testing the null hypothesis that the annual rainfall data follow the specified distribution. In present study AD test is used for goodness of fit for the above said distributions on weekly rainfall data. The test statistics of AD test is defined as:

$$A^2=-n-\frac{1}{n}\sum_{i=1}^{n}(2i-1)\left[\ln F(X_i)+\ln\{1-F(X_{n-i+1})\}\right]$$

Where, n is the number of observations and F(X) is the Cumulative Density Function (CDF) for the data. The AD test statistic a p-value greater than or equal to the chosen a-level suggests that the probability distribution represents a good fit (Verma *et al.,* 2014).

Wald-Wolfowitz Run Test

Run test is used for examining whether or not a set of observations constitutes a random sample from a population. Test for randomness is a major importance because the assumption of randomness underlies statistical inference.

A run is defined as a sequence of letters of one kind surrounded by a sequence of letters of the other kind, and the number of elements in a run is usually referred to a length of the run. Critical value for the test is obtained from the table for a given sample size and at deserved level of significance (α). When sample size is greater than 25 the critical value r_c can be obtained using a normal distribution approximation with mean (μ) = (2n-1)/2 and variance (σ) = $\sqrt{\{(16n\text{-}29)/22\}}$.

A probability plot has also been used for visually checking the suitability of the distribution which includes points, middle line, left line and the right line. If the probability distribution is a good fit for the data, the points form a straight line and fall within 95% Confidence Interval (CI). All analysis has been performed in SAS-9.3 software.

3. RESULTS AND DISCUSSION

Data Distribution and Probability of Rainfall

Initial analysis of the data set reveals that during monsoon season the rainfall value is more than reference ET (Fig. 3). The farmers can grow crop during this season without using any supplemental irrigation. Non-normal behaviour and independence of the data set were tested by AD test and Wald-Wolfowitz Run test, respectively. Results of AD normality test and Wald-Wolfowitz test for independence pertaining to all data sets are presented in Table 1. AD test revealed that all the data sets were non-normal at 5% significance level. While for run test, the calculated Z values for all the SMWs are non-significant. Thus, the null hypothesis of independence of all the data sets can be accepted at 5% level of significance, showing departure from the expected trend of persistence in the hydrological series. The eight distributions mentioned above were tested for SMW from 24 to 42. Maximum Likelihood (ML) estimates of parameters probability distributions were obtained by using non-zero total weekly rainfall values. Weibull probability distribution was found to be most appropriate for SMW 24, 25, 27, 29, 31, 32, 34, 35, 37, 38 and 39, whereas for SMW 26, 28, 30, 33 and 36 Gamma distribution was best fitted distribution. Log logistic distribution was found appropriate for SMW 40 and 42 and log normal was best fitted for SMW 41. The best fitted model along with parameter estimates has been presented in Table 2.

By using non-zero total weekly rainfall values, data were tested through eight various continuous probability distribution functions. The "best" distribution is selected using AD test, probability plot and by studying the sign of estimated percentiles. ML estimates of parameters probability distributions were obtained by using non-zero total weekly rainfall values. Probability plots of four weeks *viz.*, 25, 30, 40 and 41 representing four different distributions are shown in Fig. 4.

Minimum assured amount of rainfall (mm) at different probability levels (0.1-0.9) was computed by using the "best" distribution for each of the SMW and the results are presented in Table 4. It is evident from the analysis

Table: 1
Normality and independence test for SMW from 24 to 42

SMW	Date	Normality test		Independence test	
		A-D value	P value	U value	P value
24	Jun 11-17	2.491	<0.05	1.143	0.253
25	Jun 18-24	1.993	<0.05	-0.283	0.777
26	Jun 25- Jul 1	0.955	<0.05	-0.614	0.539
27	Jul 2-8	1.620	<0.05	-0.426	0.670
28	Jul 9-15	3.108	<0.05	0.010	0.999
29	Jul 16-22	0.919	<0.05	-0.746	0.456
30	Jul 23-29	2.074	<0.05	-1.152	0.249
31	Jul 30-Aug 5	1.265	<0.05	1.143	0.253
32	Aug 6-12	2.114	<0.05	-0.655	0.512
33	Aug 13-19	2.245	<0.05	1.314	0.121
34	Aug 20-2	2.450	<0.05	-0.438	0.662
35	Aug 27-Sep 2	3.093	<0.05	1.166	0.135
36	Sep 3-9	1.017	<0.05	-1.605	0.109
37	Sep 10-16	2.428	<0.05	-0.283	0.777
38	Sep 17-23	4.044	<0.05	0.507	0.612
39	Sep 24-30	2.372	<0.05	-0.655	0.512
40	Oct 1-7	1.650	<0.05	0.218	0.827
41	Oct 8-14	0.759	<0.05	-0.650	0.519
42	Oct 15-21	0.832	<0.05	-0.655	0.512

Table: 2
Parameter estimates of best fitted distribution for rainfall during *kharif* season

SMW	Date	Distribution	Location	Shape	AD value	P value
24	Jun 11-17	Weibull	0.80	39.32	0.421	>0.250
25	Jun 18-24	Weibull	0.83	44.06	0.252	>0.250
26	Jun 25- Jul 1	Gamma	1.28	63.73	0.424	>0.250
27	Jul 2-8	Weibull	1.11	48.97	0.237	>0.250
28	Jul 9-15	Gamma	1.09	86.49	0.299	>0.250
29	Jul 16-22	Weibull	1.04	58.14	0.172	>0.250
30	Jul 23-29	Gamma	0.98	78.85	0.264	>0.250
31	Jul 30-Aug 5	Weibull	1.17	68.21	0.407	>0.250
32	Aug 6-12	Weibull	0.97	82.81	0.340	>0.250
33	Aug 13-19	Gamma	1.25	75.92	0.676	0.076
34	Aug 20-2	Weibull	1.08	50.77	0.221	>0.250
35	Aug 27-Sep 2	Weibull	0.94	56.70	0.429	>0.250
36	Sep 3-9	Gamma	0.92	64.78	0.440	>0.250
37	Sep 10-16	Weibull	0.87	42.75	0.329	>0.250
38	Sep 17-23	Weibull	2.53	0.81	0.281	>0.250
39	Sep 24-30	Weibull	2.78	1.73	0.411	>0.250
40	Oct 1-7	Log logistic	2.47	0.62	0.413	>0.250
41	Oct 8-14	Log normal	2.10	1.56	0.197	>0.250
42	Oct 15-21	Log logistic	0.88	16.37	0.234	>0.250

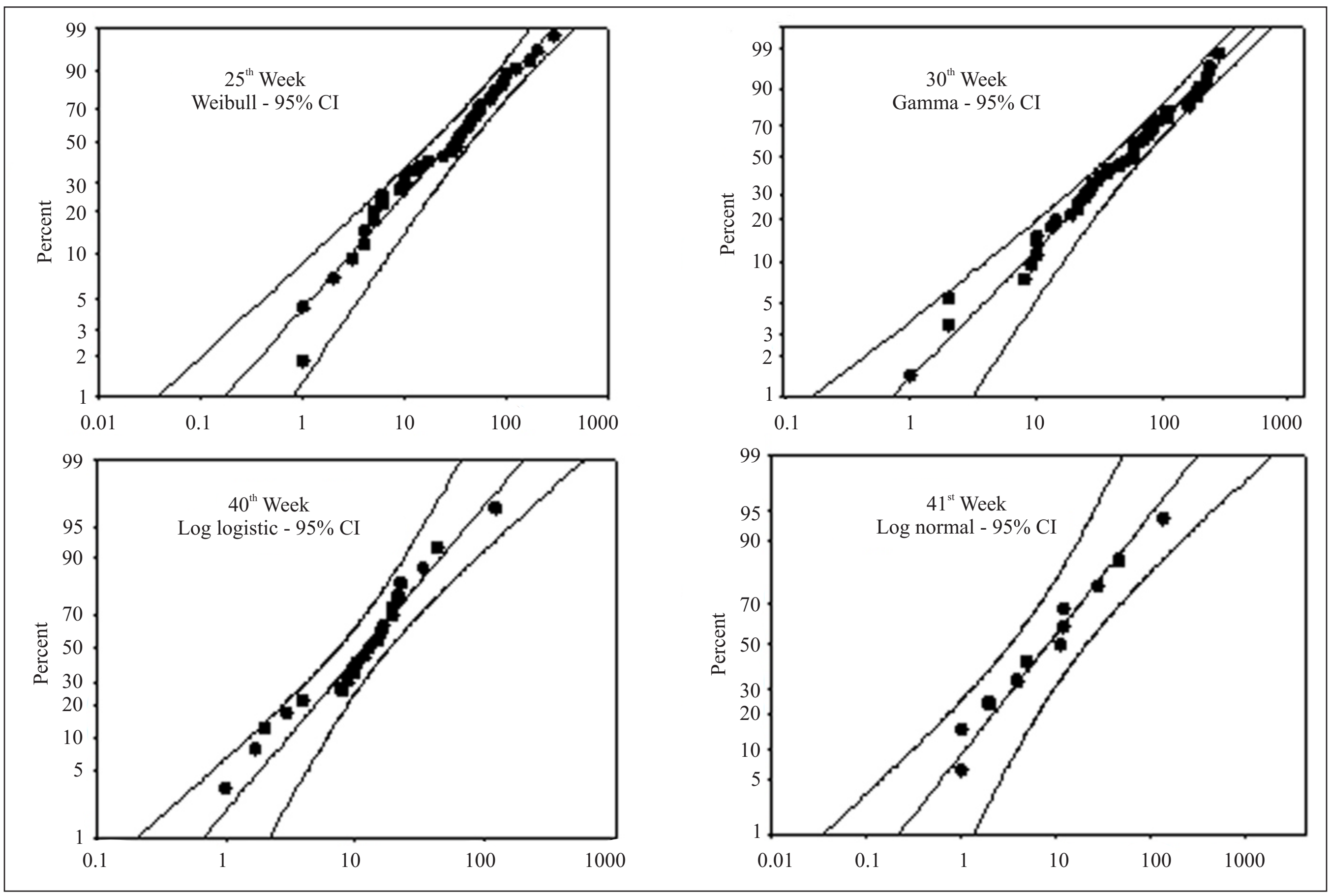

Fig. 4. Best fit Probability plots of two and three parametric tests distributions fitted to the data of different SMW

that the estimated minimum assured weekly rainfall for all SMWs except four SMWs (27, 35, 39 and 40), is in close agreement with the long-term average weekly rainfall at 40 and 50% probability levels.

Crop Planning

In view of highly erratic rainfall distribution, water erosion due to undulating topography, frequent occurrence of early, intermittent and late season droughts, decrease

Table: 3
Minimum assured rainfall (mm) in different SMW at different probability levels

SMW	Probability level									Average rainfall
	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	
22	0.91	1.95	3.14	4.52	6.16	8.18	10.79	14.49	20.84	3.16
23	2.61	4.28	6.11	8.27	10.99	14.60	19.78	28.23	46.23	7.92
24	2.15	5.06	8.65	13.03	18.47	25.41	34.71	48.37	72.82	16.81
25	1.83	4.60	8.18	12.71	18.48	26.03	36.40	51.97	80.67	23.33
26	3.77	9.04	15.52	23.38	33.00	45.11	61.07	84.02	124.02	43.24
27	6.26	12.77	19.93	28.04	37.46	48.83	63.29	83.38	117.15	47.20
28	7.99	15.38	23.26	32.02	42.10	54.19	69.49	90.70	126.40	53.21
29	12.77	23.23	33.77	44.97	57.37	71.67	89.10	112.31	149.43	68.43
30	12.79	23.11	33.69	45.18	58.16	73.50	92.68	119.00	162.76	65.42
31	8.58	16.70	25.32	34.82	45.65	58.47	74.50	96.39	132.45	57.70
32	7.46	15.89	25.48	36.58	49.74	65.88	86.73	116.17	166.61	68.82
33	15.26	25.75	36.07	46.97	59.06	73.11	90.46	113.94	152.51	72.31
34	7.71	15.12	23.02	31.77	41.77	53.65	68.54	88.92	122.61	49.14
35	9.89	18.04	26.28	35.04	44.75	55.96	69.65	87.88	117.09	45.60
36	5.89	13.11	21.57	31.52	43.46	58.23	77.44	104.74	151.79	49.74
37	4.77	10.64	17.56	25.77	35.71	48.12	64.42	87.84	128.80	36.81
38	4.92	8.51	12.63	17.69	24.24	33.22	46.54	69.06	119.37	30.12
39	1.53	2.68	4.01	5.67	7.83	10.82	15.29	22.92	40.18	8.04
40	5.43	8.79	12.43	16.71	22.04	29.08	39.10	55.31	89.46	13.31
41	5.65	9.28	12.89	16.88	21.63	27.71	36.29	50.43	82.75	11.81
42	0.55	1.21	2.14	3.48	5.49	8.65	14.08	24.89	54.85	2.72

trend found in decadal rainfall in Bundelkhand region are the main reasons of low crops productivity than national average (Chand *et al*., 2011). The soils of the region are coarse texture, shallow in depth, poor in organic carbon content and moisture retention capacity, low fertility and high rainfall intensity causing high runoff and severe erosion problems. Rainfall is the main deciding factor for success and failure of crops in this region. Thus, there is a need to plan the cropping pattern in such a way that it can avoid water stress at critical growth stages.

The average rainfall from 22nd to 25th weeks varies from 3.16 to 23.30 mm. This pre-monsoon rainfall may be used for ploughing, seed bed preparation and other pre-sowing agricultural operations. During *kharif* season, it is desirable to complete the sowing operation 12-15 days before the onset of monsoon. However, in rainfed areas, the sowing time should coincide with onset of monsoon. The probability analysis of long-term weekly rainfall data (Table 3) showed that at 70% probability level, assured rainfall of more than 20 mm is expected from SMW 27 onwards. In this condition, sowing of early and short duration crops like groundnut, maize, soybean and jowar can be planned during this week or one week prior to ensure effective utilization of rainwater for enhanced crop production. SMW 27 onwards, the rainfall is more and runoff is likely to occur. This runoff may be harvested and be provided as lifesaving irrigation at critical growth stages of crop growth during lean period. The analysis revealed that total assured rainfall of 299 and 410 mm during the crop-growing period *i.e*., SMW 27-38 at 70 and 60% probability levels, respectively. In the present study, the long-term arithmetic average rainfall during the crop growing period is 644 mm indicating there is hardly any need of irrigation water, which is misleading in view of the fact that total actual rainfall is unlikely to match the total long-term average rainfall in a given year for the crop-growing period. This result is in accordance with the finding of Kumar *et al*. (2007) where it was found that 70% probability level was useful for planning of *kharif* crops and to decide proper time for various agricultural operations for low to mid rainfall areas of western Uttar Pradesh. Minimum assured rainfall at 60-70% probability level was found to be in close agreement with the long-term average weekly rainfall data.

Analysis also revealed that the feasibility of growing recommended and drought tolerant short duration varieties of crops like groundnut (TG 37 A and Kaushal) and sorghum (CSV-13 and 15, Bundela, CSH-23 and SPV 1616) and cowpea with intercropping of pigeon pea by 27 to 28th SMW and in case of late situation sesame (Shekhar, Pragati, Tarun, T-78), black gram (Uttara, PU-31, Azad Urd-3, N. Urd -1), green gram (Samrat, Narendra moong-1), maize (Ganga-1, 2 and 5, Hybrid), pearl millet (BJ-104, Manupur), cowpea, cluster bean in *kharif* season could also be sown between 29 to 30th SMW in this region which can be harvested by 40th SMW.

During *kharif* season, short duration with low water consumption crops may be grown in the event of delay in onset of monsoon. Other major advantage of growing of short duration cereals, pulses and oil seeds in first week of June is that these can be harvested by the mid of September and short duration *rabi* crops can be sown from 38th week onwards as the average weekly rainfall varies from 30.1 to 2.7 mm from 38th to 42nd weeks with supplemental irrigation by harvested rainwater during rainy season. Post monsoon rainfall is highly uncertain and it is risky for growing crops without supplementary irrigation. Moisture conservation techniques such as use of mulching, anti-traspirants, effective control of weeds, adequate plant stands sq m^{-1} which helps in better crop production under moisture stress environment or dry spells periods and to mitigate the effect of drought during active growth period.

4. CONCLUSIONS

As rainfall variability has major implications on country's economic prosperity, it is important to understand the underlying process of rainfall pattern in a given region. Probability distributions are widely used for understanding the rainfall pattern and computation of minimum assured rainfall. A single probability distribution was not adequate to represent the entire data set for the study area. Weibull probability distribution was found to be most appropriate for SMW 24, 25, 27, 29, 31, 32, 34, 35, 37, 38 and 39 whereas for SMW 26, 28, 30, 33 and 36 Gamma distribution was best fitted distribution. Log logistic distribution was found appropriate for SMW 40 and 42 and log normal was best fitted for SMW 41. The long-term average rainfall should not be taken as the criteria for sowing the crops because the total actual rainfall is unlikely to match the total long-term average rainfall in a given year for the crop-growing period. Minimum assured weekly rainfall between 60-70% probability levels was found to be a better representative of long-term average rainfall data. The sowing of early and shortduration crops like groundnut, maize, soybean and jowar can be planned during standard meteorological week 27 to ensure effective utilization of rainwater for enhanced crop production as minimum assured rainfall of more than 20 mm is expected at 70% probability level.

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