Drought Analysis of Southern Part of Chhattisgarh Agro-Climatic Plain Zone: A Case Study of Bilaspur District

Vijay Singh[1,*] and R. K. Isaac[1]
[1,*]Department of Soil and Water Conservation Engineering
Allahabad Agricultural Institute-Deemed University, Allahabad

Rainfall data of 20 years (1982-2001) based on standard weeks was analyzed for Bilaspur District of Chattisgarh State. The earliest dates of monsoon periods were determined along with their deviations from the mean value. The frequency of dry and wet weeks was calculated by using the concept developed by Pandarinath by considering 20mm rainfall in a week as a demarcation line. Dry and wet spells in pre monsoon, monsoon, and post monsoon periods were estimated by using Markov Chain Model. The monthly maximum rainfall at different probability levels was calculated by using Gumble Probability Method. It was observed that there were 23 dry weeks in pre monsoon and 19 wet spells in monsoon at 0.75 probability density, which was found in close proximity with the observed rainfall for the year 2001. The estimation of deficit periods showed that there was a need of irrigation water especially in the 20th to 23rd weeks and 30th to 33rd weeks after transplanting of paddy crop. Moisture deficit periods were calculated by comparing the mean monthly evapo-transpiration values with the mean monthly rainfall values of Chhattisgarh.

Keywords: Drought Analysis, Paddy Cultivation in Chhattisgarh, Probability Analysis, Markov Chain Model, Gumble Probability Method

1. INTRODUCTION

Though the state of Chhattisgarh (a newly carved state out of Madhya Pradesh) receives 1200-1600 mm of rainfall annually yet, it is one of the most drought-prone regions of the eastern India. In this area, droughts of varying intensities occur once in 2-3 years causing huge losses to paddy crop (its main crop) and migration of rural poor in other parts of the country in search of livelihood. In a span of 4 years (2000-2004), Chhattisgarh experienced 3 droughts.

According to the Indian Metrological Department, a metrological drought in an area is defined as a situation when the seasonal rainfall received in that area is less than 75% of its long term average value. It is further classified as moderate drought if the rainfall deficit is between 26-50% and severe drought when the deficit exceeds 59% of the normal. Since the year 1875, India experienced 25 drought years; the worst being in the year 1918 when nearly 70% of the country was affected by the drought. The latest drought occurred in the year 1987 in which 47% area of the country was affected. The estimation and prediction of extreme cases of drought and flood thus become essential to optimize the management of water resources under wide range of possible future demands and hydrological conditions. The information of drought is of great importance to the planners for designing storage capacity of reservoirs to tide over the water requirement for protective irrigation during drought periods.

Sharma *et al*[1,2,3] analyzed the drought using the definition of 'drought month' (a month in which actual rainfall is less than 50 per cent of the average monthly rainfall) and 'Drought year' (the year receiving rainfall less than or equal to average rainfall minus the standard deviation of the series). The rainfall data of 15 years (1972-1986) of Allahabad district Uttar Pradesh were analyzed at the probability densities of 0.99 to 0.01 for the return periods of 1.0101 to 100 years for each month by using Gumble Distribution Method[4].

The one day maximum, average weekly, average monthly and cumulative seasonal rainfall data were analyzed using rainfall data of 30 years (1974-2003) from TNAU, Coimbatore by fitting different probability distribution like Normal, Log-normal, Gumble, Log-Pearson Type III, Gamma and Exponential with the reference to minimum dryness index. The rainfall data were fitted in the above distributions and their corresponding rainfall events were estimated at 20, 40, 60 and 80 percent probabilities of exceedence. From the rainfall analysis, it was inferred that the best fit for one day maximum rainfall was with the Gumble Method followed by Normal Distribution. Gumble Method followed by Exponential, and Normal distribution were identified as the best fit for the average weekly rainfall; whereas Gumble Method followed by Normal, Exponential and Log-Pearson type III distribution were identified to best fit for average monthly rainfall. In case of cumulative seasonal rainfall, it was observed that Gumbel Method followed by Log-normal, Log-Pearson type III and Normal distribution best fitted for the chosen area in the respective sequence [5].

In the present study, daily precipitation series of Bilaspur District in the southern part of Chhattisgarh State were used to characterize the drought features. The approach can be gainfully used for the management and planning of water and crop resources using conveniently available rainfall data and to work out the objectives successfully. Therefore, the present study was undertaken to cater the needs of farmers in order to improve water user efficiency.

2. MATERIALS AND METHODS

The study area is located at 22° 9' 12" N latitude, 82° 12' 12" E longitude and at an altitude of 292.3 m above mean sea level. The climate of Bilashpur is sub-humid and the temperature varies 460°C to 50°C from May to January. The relative humidity varies from 90 to 20 %. The daily rainfall data for the period of 20 years (1982 to 2001) was collected from the Observatory of College of Agriculture and Research Station, Indra Gandhi Agricultural University, Sarkanda, Bilashpur which is recognized by the Indian Metrological Department. In this study, the rainfall data was analyzed according to standard metrological weeks (52), months (12, January to December), season (3; July to October as monsoon season, November to February as post monsoon season and March to June as summer season) and yearly. Weeks of onset and offset of monsoon were select for a period of 20 years by taking 20 mm rainfall as demarcation line based on the concept of Pandarinath[6].

The average and mean period of monsoon was selected as 24th June to 30th September by using the following equation:

$$\text{Average period of begining of monsoon} = \frac{\text{Date of begining of monsoon 1 to 20 years}}{\text{n}}$$

$$\text{Average period of end of monsoon} = \frac{\text{Date of end of monsoon 1 to 20 years}}{\text{n}}$$

$$\text{Mean period of monsoon} = \frac{\text{Ave. period of begining of monsoon - Ave. period of end of monsoon}}{2}$$

The earliest and delayed dates of onset and onset of monsoon and their deviation from their mean were calculated by finding the difference between the observed and the estimated dates.

2.1. Markov Chain Model

The Markov chain probability model was applied to find out the long term frequency behaviour of dry and wet weather spell. The concept of Pandarinath[6] has considered and event having less than 20 mm of rainfall was taken as a dry week and more than 20 mm was considered as a wet week. Based on the experience, Pandarinath has followed different notations in this method.

Probability of the week being dry:

$$P(d) = F(d)/N \qquad -(1)$$

where, $P(d)$ = probability of the week being dry,
$F(d)$ = frequency of dry weeks,
N = total number of years of data being used.

Initial probability of week being wet is:

$$P(w) = F(w)/N \qquad -(2)$$

where, $P(w)$ = probability of the week being wet,
$F(w)$ = frequency of wet weeks,
N = total number of years of data being used..

The transitional probability of a week being dry preceded by another dry week is:

$$P(dd) = F(dd)/F(d) \qquad -(3)$$

where, $P(dd)$ = probability of the week being dry preceded by another dry week,
$F(dd)$ = frequency of dry weeks preceded by another dry week..

Probability of two consecutive dry weeks is:

$$P(2D) = P(dw1) \times P(ddw2) \qquad -(4)$$

where, $P(2D)$ = probability of two consecutive dry weeks;
$P(dw1)$ = probability of the first week being dry,
$P(ddw2)$ = probability of the 2nd consecutive dry week given the preceding week being dry,

The transitional probability of a week being wet preceded by another wet week is:

$$P(ww)=F(ww)/F(w) \qquad -(5)$$

where, $P(ww)$ = probability of the week being wet preceded by another wet week,
$F(ww)$ = frequency of wet weeks preceded by another wet week.
Probability of two consecutive wet weeks is:

$$P(2W) = P(ww1) \times P(www2) \quad \text{-(6)}$$

where, $P(2W)$ = probability of two consecutive wet weeks;
$P(ww1)$ = probability of the first week being wet;
$P(www2)$ = probability of the 2nd consecutive wet week given the preceding week being wet,

2.2. Gumbel Distribution Method

For the computation of the monthly rainfall Gumble's Distribution Method (most widely used probability-distribution function for extreme value in hydrologic studies for prediction of max. rainfall) was used. For analyzing the rainfall date for probability distribution, the mean of rainfall for sample size 'n' is

$$\bar{x} = \frac{\sum x}{n} \quad \text{-(7)}$$

and standard deviation, $\sigma_x = \sqrt{\frac{\sum (x-\bar{x})^2}{n}}$ -(8)

Considering the probability level as 0.99, 0.95, 0.85, 0.75, 0.65, 0.50 to compute the recurrence interval by $T = 1/P$, with the help of T, frequency factor K is calculated by:

$$K = \sqrt{\frac{6}{\pi}} \left(Y + \ln\left(\ln \frac{T}{T-1} \right) \right) \quad \text{-(9)}$$

where, Y = 0.57721.
Then expected rainfall is calculated by

$$x_T = \bar{x} + K\sigma_x \quad \text{-(10)}$$

where, x_T = value of the variate x with recurrence interval T.

2.3. The Deficit Period

The deficit period monsoon was computed with the help of rainfall and Evapo-transpiration (ETp) at probability level 0.99, 0.95, 0.85, 0.75, 0.65, 0.50. When the magnitude of ETp is greater than the predicted rainfall, the week was considered as a dry week and vice-versa.

3. RESULTS AND DISCUSSION

Analysis of daily rainfall data of southern Chhatisgarh area showed that the rainfall is highly variable from June to December. The most of the rainfall was occurring from June to October; the maximum in the month of July (391.6 mm).

3.1. Assessment of Dry and Wet Spells

The probability of occurrence of the dry weeks was calculated by using Markovs Chain model (Table 1) which was higher (0.50 to 1.00) in the first 24 weeks of the year and it fell in subsequent weeks and maintained an average of 0.15 probability level up to 37th week of the year and again increased rapidly from 38th week to 52nd weeks (0.6 to 1.0 probability level) of the year. The conditional probability of dry week proceeded by another dry week was high up to 24th week but the probability of occurrence of two consecutive dry week was high (1 probability level) up to 23rd week. The probability of occurrence also increased from 39th to 52nd week and the probability of occurrence of two consecutive dry and wet weeks (first week being dry or wet respectively). The probability of occurrence of wet week was very low up to 53rd week and then started to increase gradually up to 37th week (0.4 to 0.9 probability level) after that it started to decrease gradually till 44th week (0.9 to 0.05 probability level after which it reduced to the level of 0.1). The conditional probability of occurrence of wet week proceeded by another wet weeks was moderate in the 5th and 6th week of the year but it actually increased substantially from 25th to 37th week and then decreased gradually. The probability of occurrence of two consecutive wet week was significant in 25th week (0.57 probability level) and increased up to 0.83 probability level (39th week) in successive weeks but it started to decrease suddenly from 38th week.

Table 1: Probability of different Dry and Wet Spells

Weeks	*P(d)*	*P(w)*	*P(dd)*	*P(ww)*	*P(2D)*	*P(2W)*
1	0.90	0.10	0.88	0.00	0.83	0.00
2	0.85	0.15	0.93	0.00	0.71	0.00
3	0.95	0.05	0.84	0.00	0.89	0.00
4	0.90	0.10	0.94	0.00	0.84	0.50
5	0.90	0.10	0.94	0.50	0.84	0.10
6	0.95	0.05	0.94	1.00	0.89	0.00
7	0.90	0.10	0.94	0.00	0.81	0.00
8	1.00	0.00	0.90	0.00	1.00	0.00
9	0.95	0.05	1.00	0.00	0.95	0.02
10	0.85	0.15	1.00	0.33	0.72	0.00
11	1.00	0.00	0.85	0.00	1.00	0.00
12	1.00	0.00	1.00	0.00	1.00	0.00
13	1.00	0.00	1.00	0.00	1.00	0.00
14	0.90	0.10	1.00	0.00	0.80	0.00
15	1.00	0.00	0.90	0.00	1.00	0.00
16	1.00	0.00	1.00	0.00	1.00	0.00
17	1.00	0.00	1.00	0.00	1.00	0.00
18	0.90	0.10	1.00	0.00	0.84	0.10
19	0.95	0.05	0.94	1.00	0.95	0.05
20	0.95	0.05	1.00	1.00	0.95	0.03
21	0.90	0.10	1.00	0.50	0.80	0.00

Weeks	*P(d)*	*P(w)*	*P(dd)*	*P(ww)*	*P(2D)*	*P(2W)*
22	0.95	0.10	0.89	0.00	0.89	0.00
23	0.85	0.15	0.94	0.00	0.70	0.02
24	0.60	0.40	0.83	0.13	0.48	0.18
25	0.25	0.75	0.80	0.46	0.13	0.58
26	0.10	0.90	0.50	0.77	0.00	0.79
27	0.15	0.85	0.00	0.88	0.03	0.69
28	0.20	0.80	0.25	0.81	0.00	0.61
29	0.10	0.90	0.00	0.77	0.00	0.79
30	0.10	0.90	0.00	0.88	0.03	0.83
31	0.20	0.80	0.25	0.93	0.13	0.70
32	0.15	0.85	0.66	0.88	0.08	0.74
33	0.10	0.90	0.50	0.88	0.00	0.78
34	0.20	0.80	0.00	0.87	0.00	0.60
35	0.20	0.80	0.00	0.75	0.06	0.67
36	0.35	0.65	0.28	0.84	0.14	0.43
37	0.25	0.75	0.40	0.66	0.08	0.65
38	0.60	0.40	0.33	0.87	0.38	0.20
39	0.70	0.30	0.64	0.50	0.52	0.11
40	0.60	0.40	0.75	0.37	0.83	0.26
41	0.85	0.15	0.65	0.67	0.84	0.25
42	0.85	0.15	0.80	0.00	0.70	0.00
43	0.95	0.05	0.90	1.00	0.75	0.15
44	0.95	0.05	1.00	1.00	0.96	0.05
45	1.00	0.00	0.95	0.00	0.90	0.00
46	0.95	0.05	1.00	0.00	1.00	0.00
47	0.95	0.05	1.00	1.00	0.95	0.05
48	0.90	0.10	1.00	0.50	0.95	0.03
49	1.00	0.00	0.91	0.00	0.80	0.00
50	0.95	0.05	1.00	0.00	1.00	0.00
51	0.95	0.05	1.00	1.00	0.95	0.05
52	0.90	0.10	0.92	0.00	0.90	0.00

3.2. Prediction of Monthly Probability of Occurrence of Rainfall

Probability analysis of various rainfall by using Gumble distribution method (Table 2) showed the probability of occurrence of monthly maximum rainfall from January to December at probable rainfall density of 0.99, 0.95,0.85,0.75,0.65 and 0.50 for the return period of 1.01,1.05,1.176,1.33,1.538 and 2 years respectively. Table 2 shows that the occurrence of rainfall in December by using Gumble distribution method varied from

83.97mm at 0.99 probability level to 20.54mm at 0.50 probability level. The average expected rainfall of July month was found to be high as 576.26 mm.

Table 2: Occurrence of Rainfall (mm) at different Probability Levels

Months	Rainfall (mm)					
	P(0.99)	*P*(0.95)	*P*(0.85)	*P*(0.75)	*P*(0.65)	*P*(0.50)
November	105.10	87.49	67.53	55.29	42.48	24.90
December	83.97	70.03	54.25	44.57	34.44	20.54
January	108.40	91.30	72.30	60.50	48.24	31.35
February	129.31	108.24	84.86	70.38	55.23	34.43
March	80.68	67.99	53.91	45.19	36.07	23.54
April	58.83	49.81	39.80	33.60	27.11	18.21
May	110.81	93.70	74.70	62.94	50.64	33.75
June	480.79	421.89	356.52	316.04	273.69	215.55
July	797.34	718.31	630.58	576.26	519.44	441.43
August	578.78	527.03	468.39	432.43	394.81	343.16
September	512.81	448.79	376.26	371.78	285.25	221.37
October	177.98	152.36	123.33	105.54	86.91	61.35

3.3. Assessment of Moisture Deficit Periods during Monsoon, Pre-Monsoon and Post-Monsoon and Drought Alleviation Strategies

Table 3 shows the comparison between different occurrence of monthly maximum predicted an observed value of rainfall at different probability level and 1.33 return periods for year 2001. By using Gumble distribution method, it was found that the expected rainfall in July was found to be the highest (576.26 mm) which is in close proximity to the observed value for the year 2001. It is also clear that the rainfall at probability level of 0.95 was higher than the observed values for the year 2001 and the rainfall at 0.75 probability level was nearly similar to the observed value of the year 2001.

Table 3 shows moisture deficit period from the January to June and from mid of September to December. During these periods the evapo-transpiration was higher than the average monthly rainfall. But during the period of July to September the rainfall was adequate and the evapo-transpiration was lower meaning thereby that the irrigation requirement during moisture deficit period was necessary.

Table 3: Occurrence of Rainfall (mm) at different Probability Levels in Post-Monsoon, Pre-Monsoon & Monsoon Periods

Months	Rainfall (mm)							ETp
	P(0.95)	*P*(0.85)	*P*(0.75)	*P*(0.65)	*P*(0.50)	Actual 2011	Rainfall	
November	448.79	376.26	55.29	285.25	221.37	9.80	15.10	85.20
December	152.36	123.33	44.57	86.91	61.35	0.00	12.80	64.20
January	87.49	67.53	60.54	42.48	24.90	24.80	20.50	52.80
February	70.03	54.25	70.38	34.44	20.54	0.00	21.50	94.68
March	91.30	72.30	45.19	48.24	31.35	45.50	15.50	143.88
April	108.24	84.86	33.60	55.23	34.43	29.20	12.40	142.77
May	67.99	53.91	62.94	36.07	23.54	16.20	22.70	174.00
June	49.81	39.80	316.04	27.11	18.21	323.40	168.50	152.10
July	93.70	74.70	576.26	50.64	33.75	616.20	375.10	121.80
August	421.89	356.52	432.43	273.69	215.55	281.20	307.20	115.20
September	718.31	630.58	371.78	519.44	441.43	381.40	180.60	121.11
October	527.03	468.39	105.53	394.81	343.16	49.20	45.80	113.70

Drought analysis shows that the study area is drought prone at two stages, firstly at the beginning of season (which can cause delay in transplanting operation of paddy) and secondly at the beginning of the ripening of the crop (which can drastically decrease the yield of the crop). Mitigation of drought at the beginning of the season is possible by switching from the traditional transplanting method of crop establishment to dry seeding (in which rice seeds are sown on dry tilled unsaturated field early in the season) which subsequently may become flooded with the onset of the monsoon. It also showed that the yield of dry seeded paddy will not be affected because the earlier established crop would be near to harvesting stage by the time drought sets in.

4. CONCLUSION

The study revealed that on an average, there are 32 dry weeks and 20 wet weeks in the year. The monthly rainfall analysis by Gumble Distribution showed that the 0.75 probability density is in close proximity to the observed rainfall in the year 2001 and can be selected for crop planning. The rainfall deficit analysis shows that the two periods namely- January to June and October to December have higher water requirements so the application of irrigation water is necessary during these periods. From the drought analysis, it was observed that the study area becomes drought prone at two stages; firstly, at the beginning of the season (which can cause delay in transplanting operation of paddy) and secondly, at the beginning of the grain ripening stage (which can drastically reduce the crop yield).

Mitigation of drought at the beginning of the season is possible by switching from the traditional transplanting method of crop establishment to dry seeding of paddy (in which rice seeds are sown on dry tilled unsaturated fields early in the season, which subsequently may become flooded with the onset of the monsoon rains).

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