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PROBABILITIES OF HISTORIC DROUGHTS FOR SOUTH WESTERN ORISSA IN INDIA

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ABSTRACT

The statistical experimental method has been applied to compute frequency distribution of longest duration and largest deficit of drought using annual rainfail series of four stations in south west Orissa (India). The validity of the method was established by comparing the distribution of longest negative runlength of drough with the theoretical distribution obtained from independent normal process. Lognormal distribution was sucessfully fitted to describe the distribution of longest duration and largest deficit of drought. Regression models have been proposed to estimate representative sample size and parameters of lognormal distribution for longterm management of drought in the region.

INTRODUCTION

Drought is a major factor of uncertainty that continues to haunt Indian agriculture and economy. The year 1987 reminds us of one of the worst drought spells in recent times affecting two-third geographical area of India and costing the national exchequer equivalent of US $ 500 million in drought relief measures alone (Upadhyaya and Gupta, 1989). The estimation and prediction of extreme cases of drought or flood thus becomes essential to optimise the management of water resources under wide range of possible future demands and hydrological conditions. Droughts could be defined in terms of different hydrological indicators. Dracup et al. (1980) defined droughts in terms of their impact and found water deficit, averaging period, truncation level and regionalisation to be critical in drought analysis. The exact probability distribution of particular drought descriptor, say for example the longest negative runlength, to be or not to be exceeded in a sample size 'N' may be derived for an independent normal process (Feller, 1957). However, many hydrologic phenomena are dependent: either normal dependent or nonnormal independent or dependent processes for which available probability distributions are not applicable. Millan and Yevjevich (1971) generated large number of samples of hydrologic variable (streamflow) to derive probability distribtuion of longest negative runlength or largest deficit of drought as descriptors of largest historical droughts for normal, nonnormal, independent and dependent stationary processes which follow the first order linear autoregressive models.

The analysis of drought using streamflow series has several advantages since it interprets the effects of topography, geomorphology, soil and landuse pattern. However, detailed records of streamflow are not generally available in river planes for want of reliable monitoring. Under such situations, description of drought based rainfall data offers useful alternative. The evidences of such exercises are scarce in literatures. In the present study annual precipitation series of four stations representing a homogeneous region of 5.85 million hectares in south west Orissa in India have been employed to characterise the drought features of the area. The approach can be usefully employed for the management and planning of water and crop resources using conveniently available rainfall data.

METHODOLOGY

Experimental statistical method (Millan and Yevjevich, 1971) was applied to compute recurrence interval of droughts at four stations in South West. Orissa (India) using longest duration and largest deficit of drought as basic parameters corresponding to a given sample size and a defined probability of truncation level. Auto regressive and skewness coefficients, estimated from 26 year historical(1961-1987) annual rainfall series for each of four stations in Orissa (Fig. 1), were utilised in a first order autoregressive model to generate synthetic rainfall series for future (Matalas, 1967). In the model, normal random numbers were generated using Box and Muller's (1958) method. The skewness of historical data was combined with the random component of generated numbers following the procedure of Thomas and Fiering (Millan and Yevjevich. 1971) and the theory of run (Yevjevich, 1967) was applied to investigate drought events from generated data. The synthetic rainfall data was divided into different segments; different sample sizes (duration of segment), number of samples to be generated and truncation levels (i.e. the probabilities relating to crossing levels useful in defining droughts) were selected based on guidelines given by Millan and Yevjevich (1971).

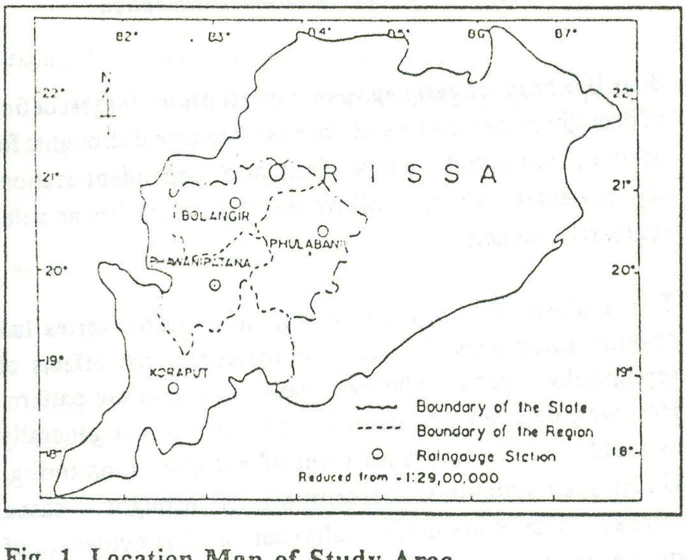

Fig. 1. Location Map of Study Area

Experimental statistical method (Millan and Yevjevich, 1971) and theoretical approach of Feller (1957) were employed to compute cumulative frequency distributions of longest duration of drought and for validating it for independent normal process. Four truncation levels (q=0.5, 0.4, 0.3, 0.2) and five sample sizes (N=25,50,100,200 and 500 years) were used to compute the frequency distributions. The Kolmogorov Smirnov test (Haan, 1977) was used to check the goodness of fit of theoretically derived distribution to the one obtained by experimental statistical method. The expected value (mean) of theoretical distribution was also compared with sample mean of experimental distribution. After satisfying the criteria of these tests, the cumulative frequency distribution of largest deficit and longest duration of drought were determined for individual stations corresponding to different sample sizes and truncation levels. The distributions were transformed into lognormal probability distribution and their validity was also checked with Kolmogorov Smirnov test. The mean, coefficient of variation as well as mean of logarithms and standard deviation of logarithms of largest deficit and longest duration of drought were determined and regression equations were developed in the following form:

$$u = a + b\,(q) + c\,(N) + d\,(\epsilon) + e\,(\tau) \qquad (1)$$

where N is sample size, q is the truncation level, ϵ is the auto-regressive coefficient and τ is the skewness coefficient. In equation (I), u represents the mean, coefficient of variation, mean of logarithms or the standard deviation of logarithms, while a, b, c, d and e are regression coefficients. The regression models for representative sample size (N), developed assuming that the longest duration or largest deficit of representative sample size equals the mean of respective variables, were of the following form

$$Nr = a + b\,(\mu_l) + c\,(q) + d\,(\epsilon) + e\,(\tau) \qquad (2)$$

$$Nr = a + b\,(\mu_g) + c\,(q) + d\,(\epsilon) + e\,(\tau) \qquad (3)$$

where

μ_l = mean of longest duration of drought.
μ_g = mean of largest deficit of drought.

RESULTS AND DISCUSSION

Since simulated sequences must bear resemblance to historical sequences. Characteristics of available sample series (Table 1) were used as estimates of population for generation of data by first order autoregressive model.

Table 1 : Statistical Characteristics of Annual Precipipation Series at Four Stations.

Station	Mean (cm)	Standard Deviation	Coefficient of Variation	Skewness Coeffi-cient	First Serial Correlation Coefficient
Bhawani--patana	111.80	22.37	0.20	0.89	-0.15
Bolangir	117.58	23.74	0.20	0.63	0.01
Koraput	121.98	23.68	0.19	-0.07	0.07
Phulabani	121.53	26.35	0.22	0.63	0.12

It is seen from Table 1 that four stations have identical coefficient of variation indicating the homogeneity of region in respect of precipitation. However, the wide range of skewness and first serial correlation coefficients signifies that the precipitation series of four stations are not independent normal. This justified the use of experimental statistical method rather than theoretical approach. The cumulative frequency distribution of longest duration of drought obtained by experimental statistical and theoretical approaches for independent normal process are illustrated in Fig. 2, while the sample and expected means of distribution obtained from these approaches are given in Table 2.

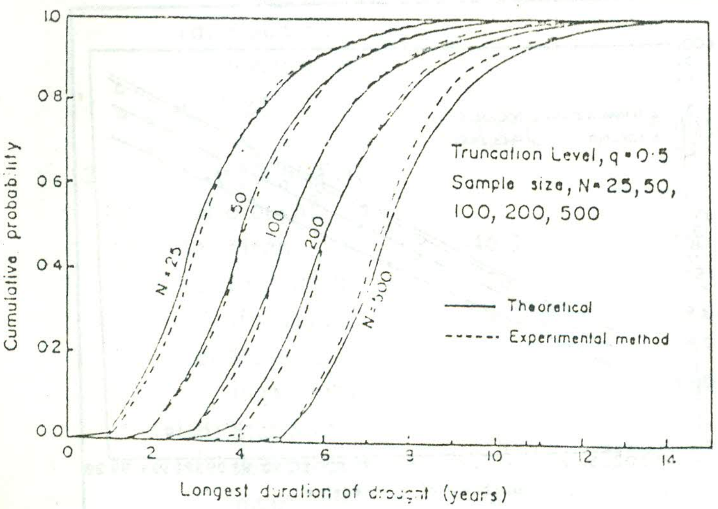

Fig. 2 : Comparison of Distribution of Longest Duration of Drought

Table 2: Expected Mean of Theoretical and Sample Mean of Experimental Distribution

Sample Size	25	50	100	200	500
Expected mean	3.99	4.99	5.99	6.98	8.30
Sample mean	4.00	4.97	5.96	6.98	8.11
Difference	0.01	0.02	0.03	0.00	0.19

Figure 2 shows identical nature of distribution curves of the two methods. The deviation between the curves increased as the number of generated samples decreased from 3800 to 192 (with increase in sample size from 25 to 500). The maximum deviation between the distribution curves was less than critical values of Kolmogorov test statistic at 1% level of significance. The differences between the expected and sample means were very small (Table 2) ranging from 0.05% to 2.28% of expected mean. The results confirmed validity of experimental statistical method for estimating distribution of longest duration and largest deficit of drought for four raingauge stations. The cumulative distributions of these parameters corresponding to a specific truncation level (q=0.5) for Bhawanipatana station are shown in Fig. 3. The values of cumulative probability for different longest durations of drought and values of largest deficits at various cumulative probability levels for sample size of 25 and mean as truncation level for all raingauge statons are given in Table 3 and Table 4 respectively.

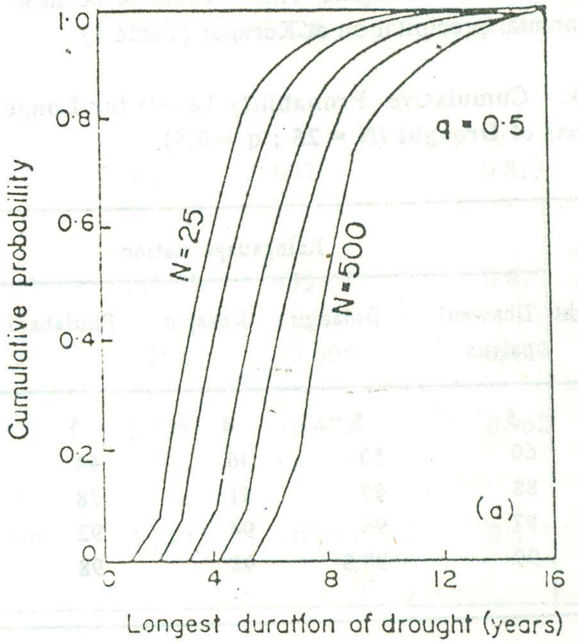

Fig. 3a. Longest Duration of Drought (year)

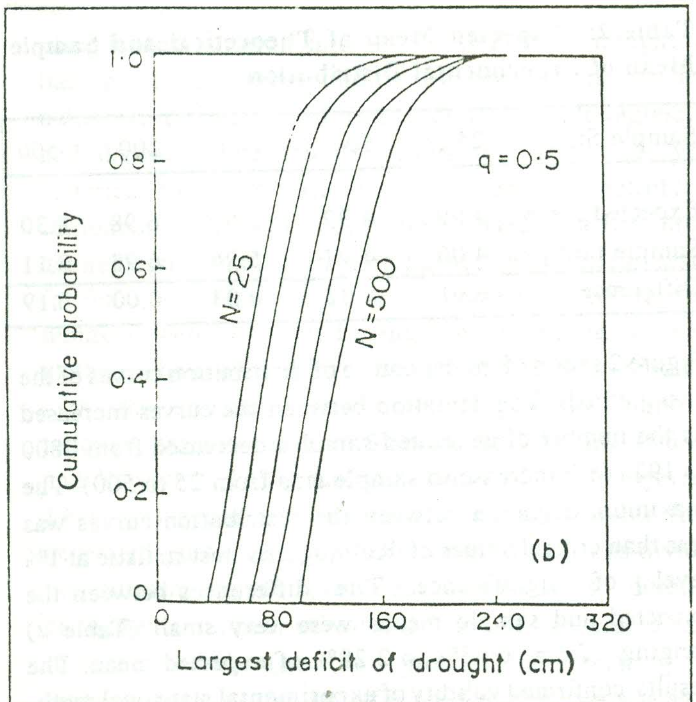

Fig. 3 b. Largest Deficit of Drought (cm)

Fig. 3. Comulative Frequency Distribution of Bhawanipatana (a) Longest Duration of Drougth, (b) Largest Deficit of Drougth.

It is observed from Table 3 that in comparison to other stations Bhawanipatana is more prone to longest duration droughts of smaller lengths. Table 4 indicates that almost at all probability levels Koraput has higher values of largest deficits of droughts. This could be because of higher annual precipitation at Koraput (Table 1).

Table 3: Cumulative Probability Levels for Longest Durations of Drought (N = 25 ; q = 0.5)

Longest Duration of Drought (yrs)	Raingauage station			
	Bhawani patana	Bolangir	Koraput	Phulabani
2	5	5	4	5
4	60	50	46	44
6	88	85	81	78
8	97	96	94	92
10	99	98.8	98	98

Table 4: Largest Deficits (cm) at Various Cumulative Probability Levels (N = 25; q = 0.5)

Commulative Probability Levels	Raingauage Station			
	Bhawani patana	Bolangir	Koraput	Phulabani
10	40	50	55	60
30	56	68	80	80
50	68	86	107	104
70	81	109	135	130
90	104	145	187	180

Cumulative distribution of largest deficit of drought for four stations were computed by experimental methods and were plotted on lognormal paper (Fig. 4a). Kolmogorov Smirnov test showed good fitting of lognormal distribution to largest deficit of drought at 10% and 1% levels of significance. Further, the fittings of lognormal distribution for the case of longest duration of drought (Fig. 4b) shows that a continuous distribution can be adequately represented by discrete variables. This provided good evidence of the validity of lognormal distribution for the two drought variables in question. The parameters required to define the lognormal distribution can be estimated by regression models represented by eq. (1). The regression and multiple correlation coefficients were estimated for the entire region and are presented in Table 5.

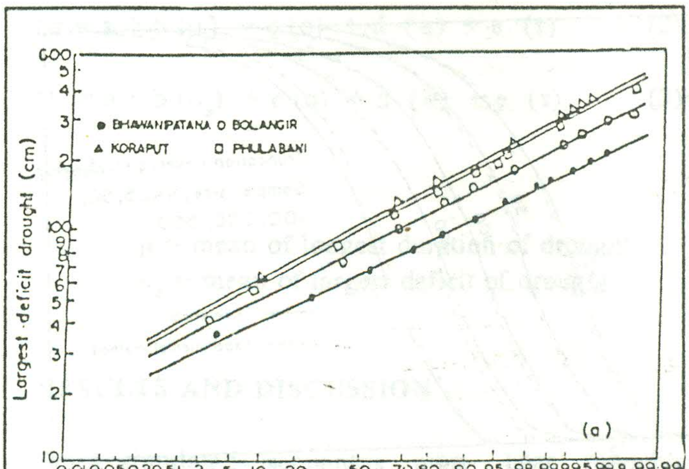

Fig. 4 a. Largest Deficit

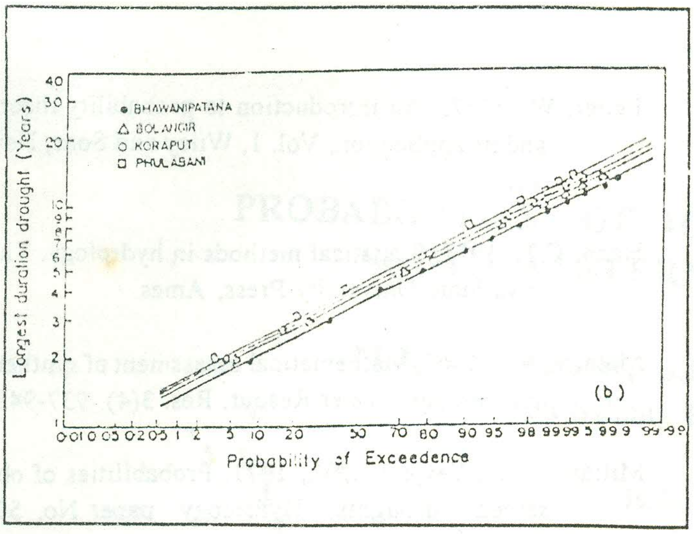

Fig. 4b . Longest Duration of Drought (N=25)

Fig. 4 : Fitting the Lognormal Distribution to Cumulative Distribution of (a) Largest Deficit and (b) Longest Duration of Drought (N=25)

Higher multiple correlation coefficients for the dependent variable (in range of 0.83 to 0.96) establishes that regression models can be used to estimate the parameters of lognormal distribution. Multiple regression models for representative sample size of longest duration and largest deficit of drought (Eq. 2 and 3) of south west orrisa are given below:

$$Nr = 167.82 + 107.214(\mu) - 1534.33(q) - 312.56(\epsilon) + 59.75(\tau)$$

$$Nr = 245.23 + 4.14(\mu_s) - 1438.25(q) - 486.10(\epsilon) + 16.89(\tau)$$

The multiple correlation coefficients for these two equations were 0.822 and 0.70 respectively indicating reasonable validity of the estimates for use in longterm planning of water resources for drought management in south west Orissa in India.

Table 5: Estimated Regression Coefficients and Multiple Correlation Coefficients.

Sr. No.	Statistical Parameters	Regression Coefficient a	b	c	d	e	Multiple Correlation Coefficient
1.	Longest duration of drought						
	(a) Mean	-1.036	14.307	0.006	2.912	-0.558	0.935
	(b) coefficient of variation	0.0405	-0.101	0.000	0.067	0.002	0.834
	(c) Mean of of logarithms	0.191	3.022	0.001	0.615	-0.126	0.946
	(d) Standard deviation of logarithms	-0.391	-0.093	0.000	0.061	0.002	0.839
2.	Largest deficit of drought						
	(a) Mean	-46.31	366.43	0.143	140.39	-35.02	0.891
	(b) Coefficient of variation	0.418	-0.089	0.000	0.263	-0.006	0.829
	(c) Mean of logarithms	2.753	4.180	0.001	1.525	-0.477	0.962
	(d) Standard deviation of logarithms	0.400	-0.079	0.000	0.240	-0.006	0.837

SUMMARY AND CONCLUSIONS

The south west region of Orissa (India) faces severe drought recurringly. The experimental statistical method was applied to determine cumulative probability distribution of longest duration and largest deficit of drought for four rainguage stations of the region using annual rainfall series. Lognormal distribution was found to adquately describe the features of these variables. It was found that one of the stations (Bhawanipatana) is likely to experience longest duration droughts of small length more frequently than the other stations. Regression models described to estimate the parameters of lognormal distribution can be applied with confidence to characterise the drought in longterm prespective of water resource planning and crop management for the region.

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