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Variability in drought incidence over India — A statistical approach

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सार — 113 वर्षों (1875–1987) की अवधि की मानसून वर्षा के आधार पर सम्पूर्ण देश के लिए सूखे के परिमाण को निश्चित करने और सूखा सूचकांक को विकसित करके उसके द्वारा सूखा वर्षों को अभिनिर्धारित करने का प्रयास किया गया है। इस उद्देश्य के लिए प्रत्येक 113 वर्षों में प्रत्येक वर्ष मानसून ऋतु में सामान्य स 75 प्रतिशत तक कम वर्षा प्राप्त करने वाले भारत के कुल क्षेत्र को लिया गया है। इससे माध्य सूखा प्रभावी क्षेत्र और इसके मानक विचलन को निकाला गया है। किसी भी वर्ष में सूखा द्वारा प्रभावित क्षेत्र और 113 वर्षों के माध्य सूखा क्षेत्र को मानक विचलन द्वारा विभाजित करके जो अंतर मिला उसे सूखा सूचकांक के रूप में परिभाषित किया गया। उत्तरोत्तर सूखा वर्षों के मध्य समय अन्तराल का सांख्यिकीय विश्लेषण किया गया है और वितरण को यादृच्छिकता के लिए निश्चित किया गया है तथा इसकी जांच की गई है। सूखा वर्षों की श्रृंखला को आवर्ती अवधि विश्लेषण का विषय बनाया गया है।

विश्लेषित समय ढांचे के अंतर्गत यह देखा गया कि भारत में सबसे भयंकर सूखा 1918 में पड़ा था। यह प्रेक्षण किया गया कि भारत में कभी-कभी उत्तरोत्तर तीन वर्षों तक सूखा पड़ सकता है जिसकी तीव्रता तथा सीमा अलग अलग हो सकती है। उत्तरोत्तर सूखा वर्षों के मध्य समय अन्तराल को पॉयसन वितरण द्वारा अनुमानित रूप में व्यक्त किया जा सकता है।

ABSTRACT. Based on the monsoon rainfall for 113 years (1875-1987), an attempt has been made to quantify drought for the country as a whole and identify drought years by developing a drought index. For this purpose total area of India receiving monsoon rainfall less than 75% of the normal was obtained for each of the 113 years. From this, mean drought affected area and its standard deviation were worked out. The difference between area affected by drought in any year and the 113 years' mean drought area divided by the standard deviation was defined as drought index. Time interval between successive drought years has been subjected to statistical analysis and the distribution determined and tested for randomness. The series of drought years, was also subjected to return period analysis.

Within the analysed time frame, 1918 is found to be the worst drought in India. It is observed that India can sometimes even experience spells of three successive years of drought of varying intensity and extent. The time interval between successive drought years can be approximately described by Poisson's distribution.

1. Introduction

Study of rainfall deficiency in India has attracted the attention of Indian meteorologists towards the beginning of the present century. Pioneering work in this field was done by Sir Gilbert Walker in 1919, who worked out rainfall departures from long-term means and identified bad monsoon years. Subsequently until 1950, there was hardly any attempt to study droughts in India. Interest in drought studies revived after 1950, and particularly after 1970, when drought incidence became a frequently recurrent feature of Indian rainfall.

Walker (1919) used seasonal rainfall data during the period 1841 to 1908 in his study; however, he had some doubts about the degree of accuracy of the data. Drought concept was applied, perhaps, for the first time to agriculture by Ramdas (1950) who defined drought to have occurred if the weekly rainfall is less than twice the mean deviation. He identified 1877, 1899 and 1913 as years of outstanding agricultural drought, while in 1920 the drought was only partial, affecting northwest and central parts. Ramdas and Mallik (1948) defined drought to have occurred when the actual rainfall during a week was less than or equal to half the normal rainfall. Using this definition, Mallik (1958) examined the occurrence of droughts in Bihar and Uttar Pradesh. Surprisingly, he could not identify 1918 as a drought year in east Uttar Pradesh and Bihar, from the point of view of shortening of wet season. Williams (1958) studied the frequency of drought in south India and concluded that Karnataka has the least and Andhra Pradesh highest liability to drought. Mallik (1966) presented district-wise incidence of dry periods in west Rajasthan on weekly basis and developed a drought index based on number of dry spells and their duration. He found that either good or deficient rainfall conditions tend to occur simultaneously in many districts, lending support to the idea that west Rajasthan is a homogeneous climatic area.

During the past decade a number of studies have been reported on the identification of drought and its characteristics. Chowdhury *et al.* (1979) applied logarithmic distribution to dry spells in Maharashtra and found the core of drought prone area situated over Ahmednagar district and adjoining regions. Bhalme and Mooley (1980) quantified the Indian droughts by developing a drought area index. Years of marked annual rainwater deficiency over India were identified by Mooley *et al.* (1981) on the basis of the area under rainwater deficiency. To assess monsoon deficiency in India, Mooley and Parthasarathy (1982) developed an index called Monsoon Deficiency Index. From this index they identified the four worst years of monsoon failures as 1899, 1918, 1877 and 1972 in the order of decreasing monsoon rainwater deficiency and reported that consecutive occurrence of drought years is a rare event. Chowdhury and Abhyankar (1984) determined the recurrence period of drought in 31 meteorological sub-divisions of India by computing simple probability of occurrence of droughts.

Very few studies have been undertaken to statistically examine the interval between successive drought years, which is a very important aspect of drought incidence. Rao (1958) studied interval between deficient rains, but only for one station. Studies on the application of return period technique to drought incidence in India are also not available. Studies of drought from these angles would bring out many diagnostic features which could be useful in drought prediction.

In the present investigation, we propose an index on the basis of the area of the country affected by drought and its interannual variability. The distribution of time interval between successive droughts has been determined and discussed. Areas liable to be affected by drought for different return periods have also been delineated.

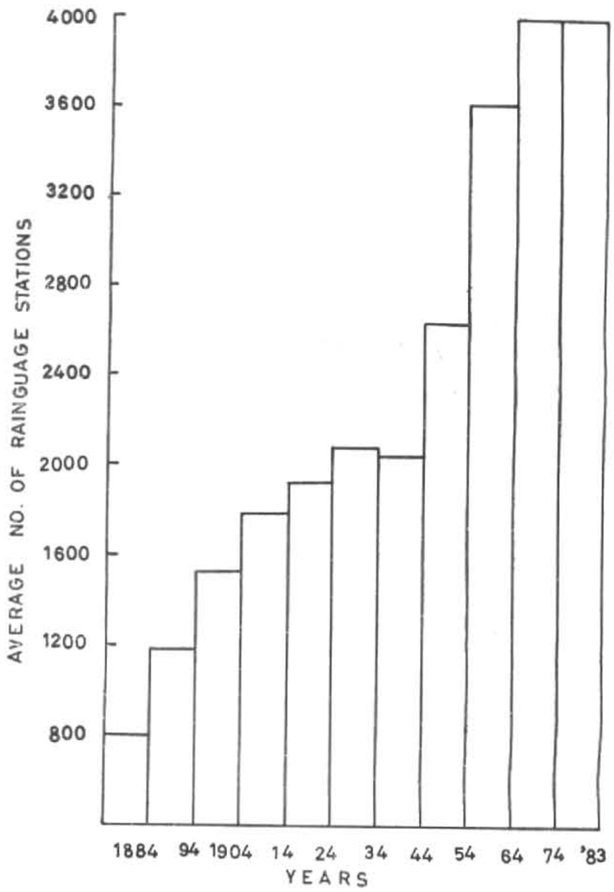

Fig. 1. Average number of raingauge stations

2. Data used

The present study utilised 113 years data (1875-1987) of rainfall from the available network of raingauges. Though this data set has its own problems due to variations in the raingauge network density and missing data, it provides an adequate representation of the rainfall variations. The number of stations for which the data have been used and its variation till 1983 is shown in Fig. 1. Between 1983 and 1987 the number of raingauge stations remained nearly constant. The number of raingauges increased steadily from about 800 in 1875 to nearly 2100 in 1945. Subsequently their number increased conspicuously and after 1965 they were about 5 times that at the beginning of the period under study. The sub-divisional mean rainfall is obtained for each month of the summer monsoon season (June to September) as the arithmetic mean of rainfall of all available stations for that month. Summation of the sub-divisional mean rainfall of all the four months in a year is taken as the mean seasonal rainfall in that year for the sub-division.

3. Review of different drought criteria

Drought means many things to many disciplines. What may be a drought for a hydrologist need not be the same to an agriculturist or a meteorologist. Ramdas (1953) defines drought as an occasion when the weekly rainfall is half of the normal or less, provided the normal rainfall itself is 5 mm or more. Agricultural drought is considered to be experienced when four such consecutive weeks occur during the kharif crop season. Subrahmanyam and Sastry (1969) define an agricultural drought when the weekly aridity anomaly is more than 25% of the normal. Their approach is an improvement on earlier methods as it takes into account the soil factors and the evapotranspirative demand.

The decile method of Gibbs and Mather (1967) as also the technique given by Van Rooy (1969) were applied in India (George and Kalyanasundaram 1969, Kalyanasundaram and Ramasastry 1969, etc). In these techniques, drought is examined purely from rainfall deficiency point of view. These are basically useful for hydrological or meteorological drought but cannot be applied to agriculture. Palmer's (1965) drought index, adopted by George *et al.* (1973) considers all components of hydrologic cycle. Palmer's index is an important contribution to the drought studies. However, its major lacuna is that it emphasises more on antecedent moisture conditions and thus represents neither an agricultural nor hydrological drought. Drought Area Index (DAI) developed by Bhalme and Mooley (1980) is also based on Palmer's technique but the coefficients determined are not uniform and vary spatially.

Percentile method was used by Mooley *et al.* (1981). They considered a year as drought when the rainwater deficiency was below the tenth percentile of the normal distribution.

Based on monthly rainfall Bhalme and Mooley (1980) developed an equation, by adopting procedure given by Palmer (1965), for computing monthly and seasonal drought/flood indices for each year, for each of the meteorological sub-divisions. They then defined a Drought Area Index as the percentage area of India having mean monsoon index $\leqslant -2$. For the first time, an objective attempt was made to quantitatively defined drought for the whole country. This method suffered from two limitations, *viz.,*

(*a*) neglecting areas like west Rajasthan, Saurashtra & Kutch, Punjab, Haryana etc having highest degree of drought proneness in India and

(*b*) interannual variability was not taken into account while developing DAI.

With a view to assessing deficiency in the monsoon rainfall over India, an index termed as Monsoon Deficiency Index (MDI) was developed by Mooley and Parthasarathy (1982). This index was obtained by expressing the area of the country receiving rainfall less than 81% of the normal seasonal rainfall as a fraction of total area of the country. The most important aspect of their data series was that they considered a fixed number of 306 stations throughout the data period (*i.e.*, 1871-1978) and thus, assured homogeneity of the rainfall series. They were also able to identify some of the years of worst monsoon failures in India. They had in their methodology, however, ignored the year to year variations in the area affected.

Mooley and Parthasarathy (1983) proposed a criterion based on rainfall expressed as a standard deviate $y_i = (x_i - \bar{x})/\sigma$ where x_i is the rainfall in the i^{th} year, $\bar{x}$, the normal rainfall and σ the standard deviation. Drought is presumed to have occurred when $y_i < -1.28$, the value 1.28 being the 10% value of the Gaussian distribution. They used district as a basic unit and as such, this approach gives a better representation of sub-normal rainfall for an area comprising of a number of districts like a State or meteorological sub-division. But data of mere 306 stations appears rather inadequate to represent a vast country like India, which according to Ministry of Information and Broadcasting Publication entitled *India 1986* has 439 districts (including 4 union territories).

One of the shortcomings in some of the above studies is the assumption that rainfall is normally distributed. As is well known rainfall over India is not normally distributed in many parts.

Chowdhury and Abhyankar (1984) used seasonal rainfall deficiency of more than 25% for identifying drought over various sub-divisions of India. Percentage area of the country affected by drought were classified into various categories. Their approach is solely based on areas receiving less than 75% of the normal rainfall without taking into account the interannual variability.

Most of the drought studies used rainfall deficiency in different ranges or some derived parameter like aridity (George and Ramasastry 1973, Chowdhury *et al.* 1977 etc) to represent drought situation. Many of the authors, have devised objective criteria in developing drought indices using long series of data. They had, however, not included the interannual variability in these indices. The criterion evolved in the present study takes into account (*i*) a rainfall deficiency of 25% or more, which generally is widely assumed to lead to drought conditions and (*ii*) year to year variations by computing standard deviate of the area affected by drought.

4. Technique used

In this study 31 meteorological sub-divisions (Fig. 2) have been considered. They cover nearly the whole of the country except hills of west Uttar Pradesh. If any sub-division in a year received less than 75% of normal seasonal (June to September) rainfall, it was deemed to have been affected by drought and its area noted. Total area of India affected by drought during each of the 113 years was thus obtained. From this, the mean area of the country affected by drought and its standard deviation were worked out. These two statistical parameters were suitably combined to yield the drought index.

5. Results and discussion

5.1. *The Drought Index (DI)*

More than 80% of the annual rainfall in India occurs in the monsoon months (June–September) except in Jammu & Kashmir, Tamilnadu, Kerala and northeast India (India Met. Dep. 1971). Being a tropical country many a time, one part of India receives abundant rainfall while other areas go dry. A desirable condition for drought index is that it should be a dimensionless number and should take into account the year to year variability. The drought index proposed in the present study fulfils this requirement.

For the 113 year series, the mean drought affected area is 0.41×10^6 sq. km or 13.1% of the total area of the country. The standard deviation σ of the series is 0.48×10^6 sq. km. In a year the country as a whole is considered as drought affected when the total drought affected area in that year, x, exceeded $\bar{x}$. The Drought Index (DI) has been defined as : $DI = [(x - \bar{x})/\sigma]$.

The drought would be severest if the whole country is affected. The DI in such a case would be 5.69. The index would be positive when $x > \bar{x}$ and assumed as zero for $x \leqslant \bar{x}$. The following table describes the DI ranges and its intensity.

Area affected	*DI range*	*Drought intensity*
$\bar{x} < x \leqslant \bar{x} + \sigma$	0.1–1.0	Slight
$\bar{x} + \sigma \leqslant x \leqslant \bar{x} + 2\sigma$	1.1–2.0	Moderate
$\bar{x} + 2\sigma \leqslant x \leqslant \bar{x} + 3\sigma$	2.1–3.0	Severe
$x > \bar{x} + 3\sigma$	>3.0	Calamitous

5.1.1. *Statistical properties of the index*

Before applying any statistical test to a series it is necessary to ensure the homogeneity of the data. For this purpose the DI series was divided into two parts, *viz.*, 1875-1931 and 1932-1987 and subjected to Student's *t* test. The *t* value obtained was 0.7 which was not significant. It was, as such, considered that the two sub-periods do not significantly differ from each other and so the DI series of 113 years was taken to be homogeneous.

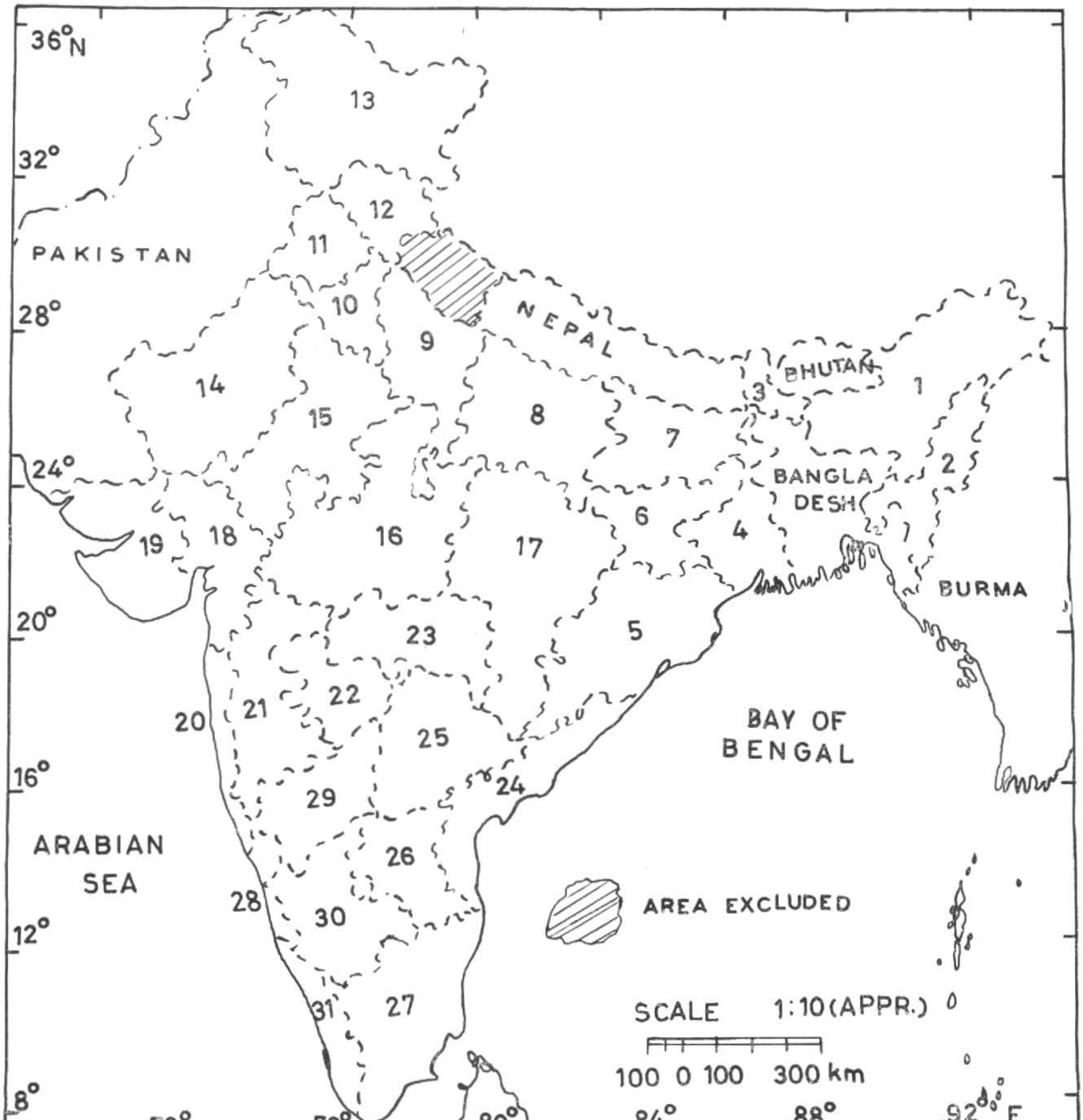

Fig. 2. Meteorological sub-divisions

(1) North Assam; (2) South Assam; (3) Sub-Himalayan West Bengal & Sikkim; (4) Gangetic West Bengal; (5) Orissa; (6) Bihar Plateau; (7) Bihar Plains; (8) East Uttar Pradesh; (9) Plains of West Uttar Pradesh; (10) Haryana, Chandigarh & Delhi; (11) Punjab; (12) Himachal Pradesh; (13) Jammu & Kashmir; (14) West Rajasthan; (15) East Rajasthan; (16) West Madhya Pradesh; (17) East Madhya Pradesh; (18) Gujarat Region, Daman, Dadra & Nagar Haveli; (19) Saurashtra, Kutch & Diu; (20) Konkan & Goa; (21) Madhya Maharashtra; (22) Marathwada; (23) Vidarbha; (24) Coastal Andhra Pradesh; (25) Telangana; (26) Rayalaseema; (27) Tamil Nadu & Pondicherry; (28) Coastal Karnataka; (29) North Interior Karnataka; (30) South Interior Karnataka and (31) Kerala

For testing year to year persistence in the time series the serial correlation was computed (WMO 1966) and tested for significance. None of the serial correlations was found significant and, therefore, it was concluded that statistically, droughts in India do not persist from year to year.

Among the basic statistical properties of the index, the mean and standard deviation are 0.38 and 0.75 respectively, yielding a coefficient of variation of 197%. The DI series is thus characterised by a high variability. The probability of DI being zero is as large as 68%. If g_1 and g_2 are Fisher's coefficients of skewness and kurtosis respectively, than for a series to be normally distributed. $g_1/SE(g_1)$ and $g_2/SE(g_2)$ should not exceed 1.96 at 5% level of significance and 2.58 at 1% level. The values of these statistics are found as 9.47 and 14.07 respectively. The DI series does not, as such, follow a normal distribution. The distribution of drought incidence is found to be positively skewed and leptokurtic.

5.2. *The drought years*

The drought years along with their intensities and ranking according to the DI magnitude are given in Table 1. The values of DI for the individual years are depicted in Fig. 3. Years which experienced drought of severe or higher intensity were 1877, 1899, 1918, 1972, and 1987. 1918 appears to be the worst affected year when nearly 69% of the area of the country($\simeq \bar{x}+4\sigma$) was reeling under water stress and scarcity conditions.

Another noteworthy observation from Table 1 is that, contrary to earlier belief, drought as categorised by the present study, could occur in India even for three consecutive years, as it happened from 1883 to 1885 and 1985 to 1987. Occurrence of drought in two consecutive years was observed on seven occasions, *viz.*, 1876-77, 1901-02, 1904-05, 1951-52, 1965-66, 1968-69 and 1971-72.

Recently, Parthasarathy *et al.* (1987) studied year-by-year drought affected area (expressed as percentage area of the country) based on data from 1871 to 1984. Three hundred and six raingauge stations, one from each district in the plains of India were selected for the study. The extreme years of drought found in that work, agree in nearly all cases identified in the present study. However, some difference was found in the ranks which may be due to the difference in the number of raingauge stations used in two studies.

TABLE 1

Years of drought in India

Year	Area affected ($\times 10^6$ sq. km)	% area of the country affected	DI value	Category	Ranking
1876	0.49	15.8	0.98	Slight	34
1877	2.03	64.7	3.38	Calamitous	2
1883	1.03	32. 8	1.29	Moderate	13
1884	0.70	22.2	0.60	Slight	26
1885	0.48	15.4	0.15	Do.	35
1891	1.15	36.7	1.54	Moderate	9
1896	0.68	21.7	0.57	Slight	27
1899	1.99	63.4	3.31	Calamitous	3
1901	0.89	28.5	1.01	Moderate	20
1902	0.54	17.1	0.27	Slight	33
1904	0.98	31.1	1.18	Moderate	16
1905	1.09	34.7	1.41	Do.	10
1907	0.85	27.2	0.93	Slight	22
1911	0.97	30.8	1.16	Moderate	17
1913	0.70	22.3	0.60	Slight	25
1915	0.63	20.2	0.47	Do.	30
1918	2.16	68.7	3.64	Calamitous	1
1920	1.22	38.8	1.69	Moderate	8
1925	0.80	25.5	0.81	Slight	24
1928	0.67	21.4	0.55	Do.	28
1936	0.86	27.6	0.95	Do.	21
1941	1.01	32.3	1.26	Moderate	15
1951	1.04	33.2	1.32	Do.	11
1952	0.81	25.8	0.83	Slight	23
1965	1.35	42.9	1.95	Moderate	6
1966	1.01	32.3	1.26	Do.	14
1968	0.65	20.6	0.50	Slight	29
1969	0.62	19.9	0.45	Do.	31
1971	0.42	13.3	0.02	Do.	36
1972	1.39	44.4	2.05	Severe	5
1974	0.92	29.3	1.06	Moderate	19
1979	1.24	39.4	1.72	Do.	7
1982	1.04	33.1	1.31	Moderate	12
1985	0.95	30.1	1.12	Do.	18
1986	0.60	19.0	0.39	Slight	32
1987	1.55	49.2	2.37	Severe	4

5.3. *The time interval between successive droughts*

Many research workers have used different statistical methods to study frequency distribution of drought occurrences in a fixed interval of time. In section 5.1 we have obtained the basic data of drought sequence, separated by drought-free intervals of varying lengths. Present section introduces some of the statistical techniques in the analysis of such time intervals.

(a) *The distribution function of time intervals*

The frequency distribution of time interval between the occurrence of successive droughts is illustrated in Fig. 4. It is clear that the distribution of time intervals is exponential. The data were fitted to the Poisson's distribution and the goodness fit tested by applying χ^2 test. The computed value of χ^2 was not found significant at 1% level. We, therefore, accepted the null hypothesis, *viz.*, there is no significant difference between the observed and theoretical values of the time intervals. Therefore, the data can be considered to follow a Poisson's distribution. The probability density function of the time intervals t can be written as $f(t) = Ee^{-Et}$, where E is the expectation of drought intervals for unit of time. If the expectation of drought is expressed per unit of time then, for this distribution, both the mean and standard deviation equals $1/E$.

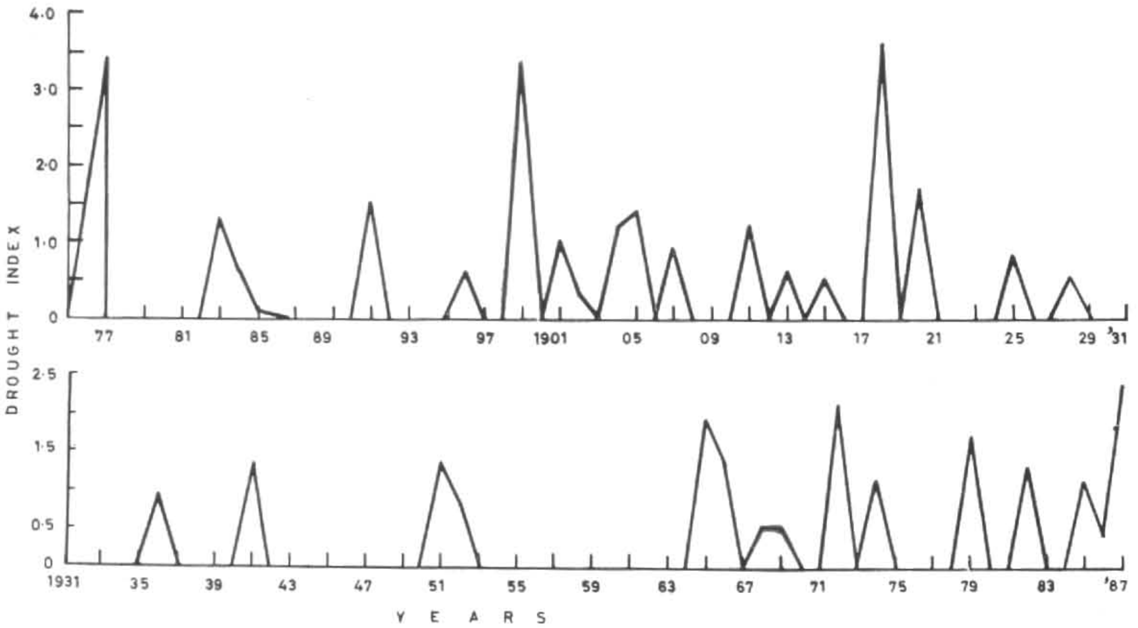

Fig. 3. Drought index (1877-1987)

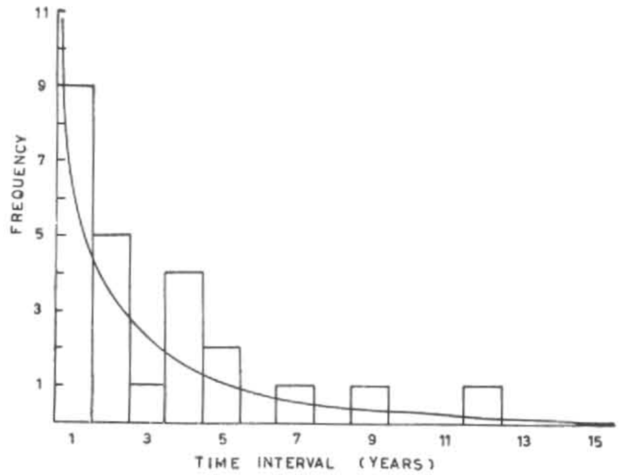

Fig. 4. Drought time intervals against frequency

The probability of occurrence of r drought intervals in a time period of τ years, is given by (*cf.* Maguire *et al.* 1952) :

$$P(r) = \frac{e^{-E\tau}\,(E\tau)^r}{r\,!}$$

The time interval between successive occurrence of drought in India could be more than 7 years and as large as 12 years. But such cases of drought incidence appear to be a rare phenomenon. With decreased time interval, instances of drought event has been observed to increase. When the time interval is of 1-2 years, largest number of cases of drought seems to occur. In other words, there is greater possibility for the drought to recur after one or two years (*cf.* Bhalme and Mooley 1980) than for intervals larger than three or more years. Frequent occurrences of large scale monsoon failures and scarcity conditions during past two decades, particularly in 1978-87 period, bear testimony to this conclusion.

In this study probability of drought intervals in a 5-year period have been obtained by taking $\tau = 5$ and putting $r = 1, 2$ etc. The approximate probability (%) of drought incidence in 1, 2, 3, 4 and 5 years were 35, 24, 11, 4 and 1 respectively. This basic information may, perhaps, be useful to evolve a strategy to meet drought conditions and outlining drought proofing.

(b) *Distribution of the largest interval*

Fisher (1929) defines a statistic g as the ratio of the largest interval between occurrence of an event to the sum of such intervals. If t_L is the largest among n independent time intervals, $\bar{t}$ the mean of the intervals than it may be shown that :

$$g = t_L / n\,\bar{t}$$

For testing significance of the largest interval, it is assumed that each of the n intervals contributes a certain fraction to the total sum of square, and g is taken to be the largest of these fractions. The probability of g exceeding any given value has been worked out by Fisher. If the value at 5% level of significance is $g_{0\cdot05}$ then the largest interval t_L is significant if :

$$t_L \geqslant g_{0\cdot05}\, n\,\bar{t}$$

TABLE 2

Return period of drought

Time interval (once in years)	Estimate (%) of area affected by	
	Ordinary least square method	Method of moments
5 years	27.4	23.7
10 years	36.7	32.6
25 years	48.4	43.8
50 years	57.1	52.1
75 years	62.1	56.8
100 years	65.8	60.3

The significant test described above is based on the following assumption, namely, the probability that the largest of the n intervals should exceed g, is $\simeq n\,(1-g)^{n-1}$

In the study $n=24$, $\bar{t}=3.16$, $t_L = 12$ and $g_{0\cdot05}=.23534$

The computed value of t_L obtained is 17.85 years which is greater than the observed interval of 12 years. Hence, the largest drought interval in not significant.

5.4. *Return period analysis*

As mentioned above, some part of the country or the other in each year gets deficient rainfall because of the convective nature of tropical rainfall. The maximum area affected by drought in each year, thus forms a series analogous to the maximum rainfall series and can be subjected to the return period analysis.

Extreme event theory was used by Gregory and Parthasarathy (1986) to analyse the return periods of extreme rainfall deficits for 32 meteorological subdivisions of India, using log-Pearson type III frequency distribution. They concluded that drought of a given magnitude could occur more frequently than assumed earlier.

In the present study, both the ordinary least square (OLS) method and the method of moments of the Gumbel's system were adopted. The results of the analysis are presented in Table 2. Basically, the probabilities by both these methods are found to be not much different from each other. The method of moments appeared to yield lower values compared to the least square method. It appears that once in 5 years, a fifth of the area of the country can be expected to experience drought conditions. The drought area may be about 35% once in 10 years, 45% once in 25 years and 55% once in 50 years. This information together with information given in section 5.3 may be helpful for planners and administrators for developing long term plans to combat harmful economic and social effects of droughts.

6. Conclusions

Drought, though being a physical phenomenon, is very difficult to be defined and quantified. An attempt has been made in this paper to define drought in quantitative terms. This has been done by subtracting long term mean of drought affected area from the area affected in a year and dividing the difference by the standard deviation of the drought area. Years of large scale monsoon failures in India have been identified in the study. The interval between successive occurrence of drought has been subjected to statistical analysis.

The study revealed that:

(*i*) The year 1918 was the worst drought year since the rainfall observations have started to be recorded in India.

(*ii*) Though drought has occurred successively for two consecutive years, on a few occasions, contrary to popular belief, drought has also been observed in three consecutive years.

(*iii*) The occurrence of drought appeared to be a random phenomenon. However, the time interval between successive years of drought appears to follow a Poisson distribution, and

(*iv*) From the return period analysis drought can cover 1/5th of the area of the country once in 5 years, nearly a third of the area once in 10 years and affect half of India once in 50 years. Occurrence of drought affecting more than 65% of the total area of the country is an extremely rare event.

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