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DROUGHT IDENTIFICATION USING STREAMFLOWS

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SYNOPSIS

Water management under drought conditions is a subject of great relevance to our country. In order to manage the drought one needs to know the characteristics of the drought, its duration, areal extent and its severity. In this paper a methodology to identify these parameters from the available historic/forecasted flow data is proposed following a modified procedure of Herbest et al.(1966) originally suggested for analysis of drought using rainfall data. This modified methodology is applied to 52 years streamflow series (1930-31 to 1981-82) of Bhadra river in Karnataka. The identified droughts by the proposed methodology are concurrent with the historically realised droughts, thus proving the viability and applicability of the methodology in identification of drought conditions.

1.0 INTRODUCTION

1.1 The economic uplift of our country mainly depends on sound and stable agricultural base, since about 70% of the working population is engaged in agriculture. Nearly one third of the total cropped area is chronically affected by drought. Thus water management under drought conditions is a subject of great relevance to our country. In order to manage the drought one needs to know the characteristics of drought suchas its onset, duration, areal extent and its severity.

1.2. Many kinds of drought definitions and indices have been developed and documented by a variety of disciplines as reported by WMO [8]. Most of the drought indices developed in past are adhoc and work in isolation. Rainfall analysis alone has been the main criteria in many of the earlier studies. However, rainfall in itself is not an adequate index of drought condition as drought is a relative measure and is resulted due to many other interacting variables representing hydrological process. Thus an operational definition of drought could best be one that based on availability of water in the form of streamflow which is the resultant of rainfall, topographical and soil characteristics.

1.3 This paper focuses on an analytic procedure to study the phenomena of drought. It deals with the hydrological aspect of drought and the approaches for the analysis of streamflows which is an important hydrological variable, in order to quantify the various parameters related to drought characteristics. However, these approaches can also be extended to study the drought using other hydrological variables such as soil moisture, groundwater etc.

2.0 CONCEPTS OF DROUGHT

2.1 One of the first steps in the investigation of any problem is the definition of the problem itself.

2.2 Drought is generally viewed as a sustained regionally extensive occurrence of below normal water availability. However, the determination of drought characteristics mainly depends on the interaction between the natural occurrence of water (hydrometeorological factors) and the particular water user or interest. A geophysicist may view drought as a combination of certain climatological, meteorological and geohydrological factors. An engineer may view drought as conditions brought about by the vagaries of rainfall affecting normal crop production due to uncertainties in streamflows and irrigation supplies. From the meteorologist point of view, the drought is due to deficiency in precipitation below its normal value in a region. The perception of drought from an agriculturist point of view is soil moisture deficit during the growing season. The hydrologist views drought as below normal water availability in streams, reservoirs, tanks and aquifers. An economist may view drought as the cause by which normal developmental activities are being affected. Even within each of these discipline, the perception of drought varies. These views centre around the basic concept of uncertainty in the factors affecting the supply of water for whatever purpose it may be put to. Thus the concept of drought in this study is decided to be based on streamflows after critical examination.

3.0 ANALYSIS OF HYDROLOGICAL DROUGHT

3.1 According to Yevjevich [9], hydrological drought is the deficiency in water supply on earth's surface, or the deficiency in precipitation, effective precipitation, runoff or in accumulated water in various storage capacities. Linsley et al. [4] defined hydrological drought as a "period during which streamflows are inadequate to supply established uses under a given management system". In short, a hydrological drought means a deficit of water supply in time, in area or both. Parameters involved and factors influencing the hydrological drought are numerous. In the context of reservoir storage, the hydrological drought can be defined considering the inflow into the reservoir. Drought can be quantified using the following factors.

i. Initiation (or) Termination i.e.location in absolute time
ii. Duration and
iii. Severity

3.2 Dracup et. al. [2] proposed that the following steps are required in drought analysis at a single site.

a) Nature of water deficit

The first step is to determine the nature of water deficit. Thus one has to select the basic phenomenon or phenomena for the definition of droughts. In this study, the streamflow is considered as the basic phenomenon.

b) Identification of the variable

In this step, the variable or variables that describes the phenomenon must be determined, such as whether to use a point measured or a total area value or whether discharge or similar variable. The volume of streamflow at a particular site is taken as the variable.

c) Identification of the integral period of time

The integral period of time is the time increment, i.e. hour, day, month, season, year etc., over which the hydrologic data is averaged or totalled in the drought analysis. Month is taken as the integral period of time in this study.

d) Choice of truncation level

The fourth step is to establish the truncation level which is employed to distinguish droughts from other events in the historic record. In this study, the truncation level is defined for each month as mean monthly flow of that month. It is to be noted that the truncation level may be a misnomer as a value less than this indicates a deficit which need not necessarily cause drought and however, if this deficit sustains for a period of time it can result in drought.

3.3 In this work, the onset and the termination of drought is identified and tested following the method suggested by Herbest et al. [3] for the analysis of drought using rainfall data, with some modifications.

3.4 Determination of onset of drought:

The main problem in analysing drought is separating their occurrence from the hydrologic record i.e. defining their occurence.

3.5 The procedure for determining the onset of drought is as follows. First, the carry-over from month to month was determined by substracting the mean flow for a particular month, for example, June, from the actual flow for the same month so that a deficit or excess for that month was obtained. This amount was multiplied by a weighting factor for the next month (in this case, July) and the product, whether negative or positive was added algebraically to the streamflow amount of that month (July) and this sum is termed as effective flow. Let T(t) denote the truncated flow for time period t, Q(t) denote the actual flow in time period t, E(t) denote effective flow in period t and D(t) denote the difference (either positive or negative) in time period t. Then,

$$E(t) = Q(t) + D(t-1) \times W(t) \qquad \text{--- [1]}$$

and $D(t) = E(t) - T(t)$ --- [2]

where $W(t)$ = weighting factor for month (t) and is given by

$$W(t) = 0.1 \times \left(1 + \frac{T(t)}{\sum_t T(t)/12}\right) \qquad \text{--- [3]}$$

3.6 Using equations (1), (2) and (3), the effective flow for each month of record was calculated by allowing for the carry-over effect of a surplus or deficit of streamflow in the preceding month; for the first month of record the carry-over was taken as zero so that effective flow was equal to the actual flow. This process was continued to obtain the effective monthly flow for the full period of record.

3.7 There are few parameters that are required for testing the onset and termination of drought. The first parameter, mean monthly deficit, for each of the twelve months was calculated from the differences that were determined, from equation (2) for the entire record. The mean monthly deficits were based not only on those months in which a negative difference occurred, for positive differences (i.e. negative deficits) were taken as zero and thus also included in the calculation. In this way the mean monthly deficit (MMD) for each of the twleve months was calculated, summation yielding the mean annual deficit (MAD). The other parameters necessary were the highest mean monthly flow, the sum of the two highest values of mean monthly flows, the sum of the three highest values of mean monthly flow, and so on upto the sum of the twelve highest values of mean monthly flow which is equivalent to the mean annual flow.

3.8 The test for onset of drought is based on a comparison of the sum of negative differences from the point in time at which the test begins, with a sliding scale of twelve values calculated by linear interpolation between the maximum value of mean monthly flow (MMMI) and the mean annual deficit (MAD). A monthly increment x is thus obtained from the formula

$$x = \frac{MAD - MMMI}{11} \qquad \text{--- [4]}$$

The first value on the sliding scale is equal to MMMI, being the maximum deficit that can occur in a single month (when no flow comes in the month which normally receives high flow). The second value in the sliding scale is obtained by adding 1x to MMMI, the third by adding 2x and so on up to MMMI+11x which is equivalent to MAD.

3.9 The test for onset of drought was conducted as follows. Firstly it was assumed that no drought prevailed prior to the start of the available record. The difference for the first month of record was inspected; if it was positive, the start of a potential drought was not signified so the difference of the succeeding months were inspected until a month with a negative difference was found, such a month representing the possible month for the start of drought. The absolute value of the negative difference was compared with the first value of the sliding scale, namely MMMI, and if the latter was equalled then a drought was deemed to have started. If MMMI was not equalled the difference of the next month was inspected and, if negative, was added to the negative difference of the first month and compared with the second value on the sliding scale, MMMI+x; if this criterion was exceeded by the absolute value of the two deficits combined, a drought was deemed to have started from the first month. In this manner the absolute value of the sum of all negetive differences occurring from the first month over a period of year was tested sequentially against the twelve values of the sliding scale. If at any time the summed value of negative differences from the first to the nth month exceeded the value MMMI+(n-1)x, a drought deemed to have started from the first month.

3.10 Simultaneously with this sequential testing, the algebraic sum of all differences was found from the first month of test, and if at any time during the eleven tests, the sum became positive the potential drought was deemed to have ended. Testing for the onset of drought was then to be carried out at the next month with a negative difference following that month the preceding test was carried out.

3.11 **Determination of the termination of drought:**

The test to check whether the drought was terminated has to be applied to the month following the month with a positive difference occurring after the start of a drought. A precondition to be satisfied was that atleast one of the two months following the initial month with a positive difference should also have a positive difference. If this condition was met then the initial month qualified of further testing for termination of drought.

3.12 Provided this precondition was satisfied, two further tests were applied simultaneously. The first test was designed for temporary termination in the sense that whether the spell above the truncation level of flow merely constituted an interruption or suspension of drought rather than its termination. The first test entailed adding all the differences algebraically from the first to the nth month of the test inclusive; if the sum became negative before a termination condition had been satisfied by the second test, then the drought was considered only to have been temporarily interrupted.

3.13 The second test comprised ten sequential tests and consisted first of summing actual inflow from the first to third months of testing and comparing with the sum of the three highest values of mean monthly truncated flows. If the actual inflow was higher, the drought was considered to have terminated, but if not, then the sum of first four months was compared with the four highest values of mean monthly truncated flows, and so on should the drought not yet have been terminated upto a comparison of the sum of flows of the twelve months following and including the month from which the test commenced, with the mean annual truncated flow (sum of all twelve monthly truncated flows). By this stage, either the drought had been terminated, in which case it was deemed to have ended in the month in which the multiple test had been initiated, or drought conditions had been resumed after a temporary interruption, so that algebraic sum of the differences would have become negative. Once the termination had occurred, testing for the start of the next drought began at the first month with a negative difference following the month in which the drought ended.

3.14 Determination of drought severity:

An index for drought severity is estimated by calculating average monthly drought intensity (DI), that is, the total deficits beyond the monthly mean deficits for the period of drought (D) divided by the sum of the mean monthly deficits for the same period, the product (DI x D) being the weighted index of drought severity.

4.0 APPLICATION

4.1 A computer program has been developed for the methodology of drought analysis explained in the previous section (Sec. 3). The program was run in SIEMENS-7580 E system available at IIT Madras with the 52 years monthly streamflow data of Bhadra river (Karnataka).

4.2 A look at the results on the identified drought periods and their duration reveals that they do not correspond to the historical droughts [1,5,6,7]. The reasons for the failure of the drought identification by the procedure suggested by Herbest et al. [3] may be

a) The methodology is only applicable to the streamflow data where the standard deviation of the monthly flows are not high ie., the monthly flows should not vary too much from year to year. This is true if one look at the equation [2]. If monthly streamflow data are of very high varying nature then the T(t) will be always at somewhat higher level rather than the truncated flow for the series which has less monthly variability from year to year. Moreso, being the truncated level is high the drought duration that will be identified by the methodology will be some what longer.

b) The methodology is applicable to only the trend free streamflow series. That is, for any month if the magnitude of the first half of the series is higher or lower than the second half of the series, then the mean will be brought down either to the higher/lower side of the present trend, thus making the drought identifications be deviated from the historical record.

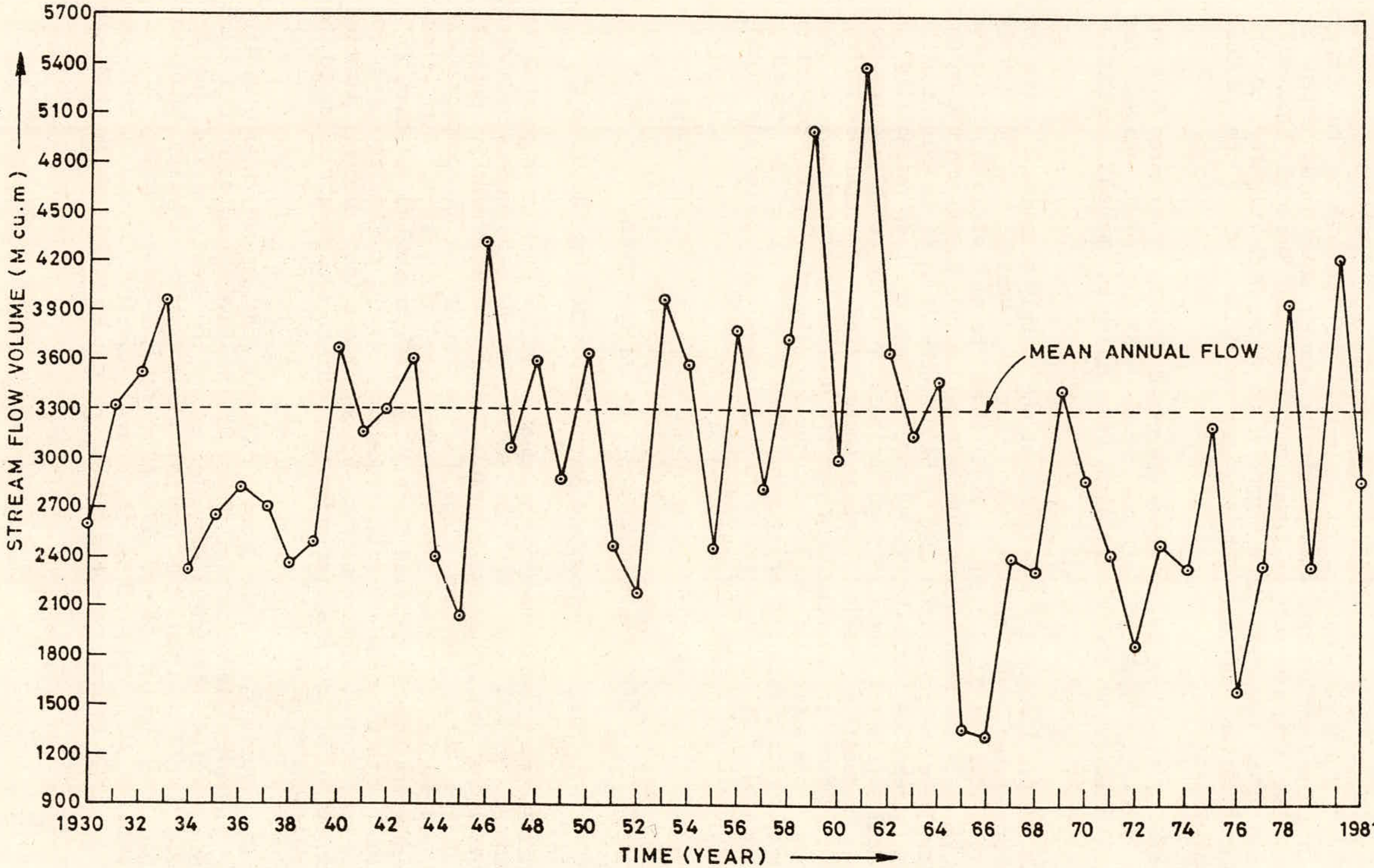

Fig.1 Annual streamflow series of Bhadra river.

c) The methodology is not suitable for application to either rainfall/streamflow data of a particular station which is subjected to both the extremes such as floods and droughts. The high flow will bring down the mean to a higher value which when compared to the identification of drought may not coincide with the actual realisations.

4.4 In the light of the above discussed points, a modified form of the procedure suggested by Herbest et al. [3] for drought analysis has been studied to account for high variability in monthly streamflow series.

4.5 Table 1 shows the statistics of the monthly streamflow series of Bhadra river. It can be seen that the variability of monthly streamflows is quite large. Fig.1 shows the plot of annual flows for 52 years. The mean annual flow is equal to 2998 M.CuM. and the annual flows have the range from 1300 to 5400 M.CuM. Thus it is evident that the streamflow data considered have not only the high variability in annual series but also have high variability in the monthly series. For the streamflow series having these kind of characteristics, modification in the calculation of the monthly truncated flow has been found more appropriate as the drought identification mainly depends on the truncated flow for each month. Thus a new formula for computing truncated flow has been suggested which takes into account the monthly variability of streamflow series, and is given by

$$T(t) = \bar{Q}(t) - \sigma_t^2/\bar{Q}(t) \qquad \text{---[5]}$$

Where

$\bar{Q}(t)$ = Mean monthly flow for the month t

σ_t = Standard deviation of flow for the month t

This formula boils down to the equation $T(t) = \bar{Q}(t)$ as suggested by Herbest et al. [3] for the series which has monthly standard deviations negligibly small. Table 2 gives the mean monthly deficits and the values in the sliding scale that are to be compared for determination of onset of drought, for each month. With these parameters and the modified formula for the truncated flow (equation 5) along with the other formulae (equation 1-4) the run was repeated for the same series. The results on drought initiation, drought duration and other drought charateristics are found to be almost similar to the historical drought.

4.6 Table 3 lists the details of onset and termination and severity of the identified droughts. These drought have almost coincided with the reported historical droughts except the small period droughts (duration of less than four months). A look at the severity indicates that the longest period (17 months) drought occured during Jun 1., 1965- Oct 31., 1966 and has the highest severity. The Jul 1, 1971- Oct 31., 1972 drought eventhough has a duration of 16 months has the

Table 1. Statistics of streamflows of Bhadra river

Month	Mean M.CuM.	Std.deviation M.CuM.	C_v (%)
Jun	267.5	165.5	62
Jul	960.1	355.7	37
Aug	835.6	337.8	40
Sep	359.9	161.1	45
Oct	264.5	122.9	47
Nov	128.8	72.5	56
Dec	73.5	53.0	72
Jan	35.4	15.5	44
Feb	18.8	7.2	38
Mar	13.1	5.6	42
Apr	13.8	5.8	42
May	26.5	26.1	98

Table 2. Parameters used in drought identification.

Month	Truncated flow M.Cu.m	MMD M.Cu.m	Sliding scale M.Cu.m
Jun	165.40	17.09	829.28
Jul	829.28	70.66	774.69
Aug	699.02	4.30	720.10
Sep	287.28	35.97	665.51
Oct	207.43	24.19	610.92
Nov	23.34	0.12	556.33
Dec	35.35	0.61	501.74
Jan	28.26	1.77	447.15
Feb	16.02	1.72	392.55
Mar	10.72	1.15	337.96
Apr	11.34	1.20	283.37
May	0.83	0.00	228.78

Table 3. Characteristics of identified droughts

S.No	Onset	Termination	Duration (Months)	Severity
1	Jul 1, 1930	Jul 31, 1931	13	6349
2	Jul 1, 1934	Oct 31, 1934	4	561
3	Aug 1, 1938	Apr 30, 1939	9	2102
4	Aug 1, 1944	Oct 31, 1945	15	7202
5	Aug 1, 1951	Sep 30, 1952	14	4805
6	Jun 1, 1965	Oct 31, 1966	17	37875
7	Sep 1, 1967	Jun 30, 1968	10	1680
8	Jul 1, 1971	Oct 31, 1972	16	13225
9	Jun 1, 1976	Oct 31, 1976	5	4522
10	Feb 1, 1979	Oct 31, 1979	9	2996

severity of only about one third when compared to the Jun 1., 1965-Oct 31.,1966 drought. In the same manner the drought resulted during Aug 1., 1944- Oct 31., 1945 (duration of 15 months) and Aug 1., 1951-Sept 30., 1952 (duration of 14 months) are only about one fifth and one eighth of the highest severe drought (Jul 1., 1965- Oct 31., 1966). Fig.2 shows the details of the onset, termination and the monthly distribution of the identified droughts. It is seen from the figure that the highest severity has occurred in the Jun 1., 1965 - Oct 31., 1966 (17 months) drought and is due to the fact that during this entire period all the monthly streamflows are less than their corresponding truncated flows. On the other hand, the Jun 1., 1971 - Oct 31., 1972 drought (which has almost equal duration) has 3 months with excess flows thus resulting in a less severe drought.

5.0 CONCLUSIONS

5.1 A methodology for identification of droughts using streamflow data has been postulated, in accordance with the methodology suggested by Herbest et al.(3) mainly for drought analysis using rainfall data, with some modifications. The suggested methodology in this study is applicable for all types of streamflow/rainfall series like series with high monthly variability, series with some trend etc. The methodology has been applied to Bhadra river streamflow data and found to have performed well in identification and characterization of droughts.

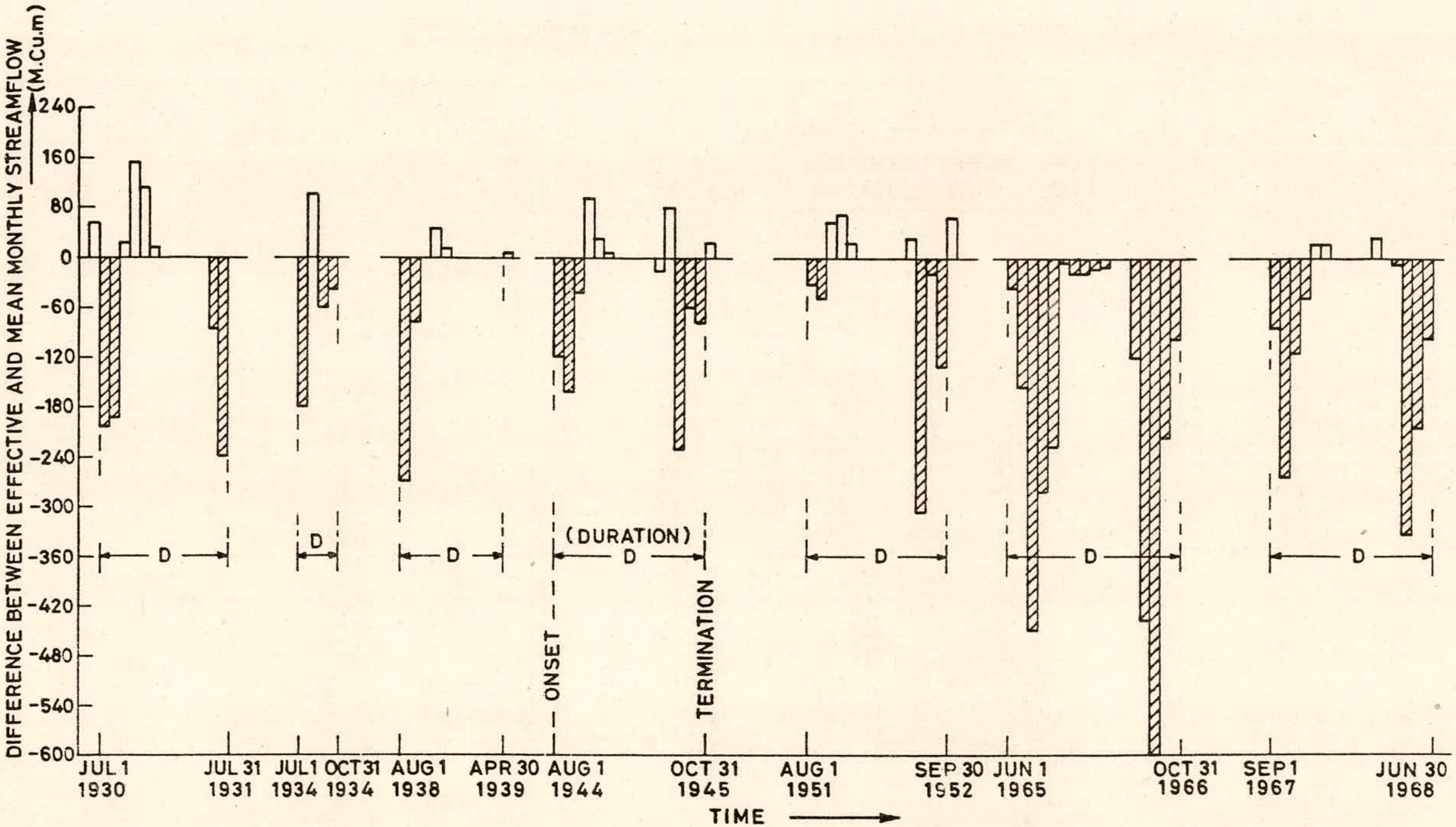

Fig.2 Characteristics of identified droughts.

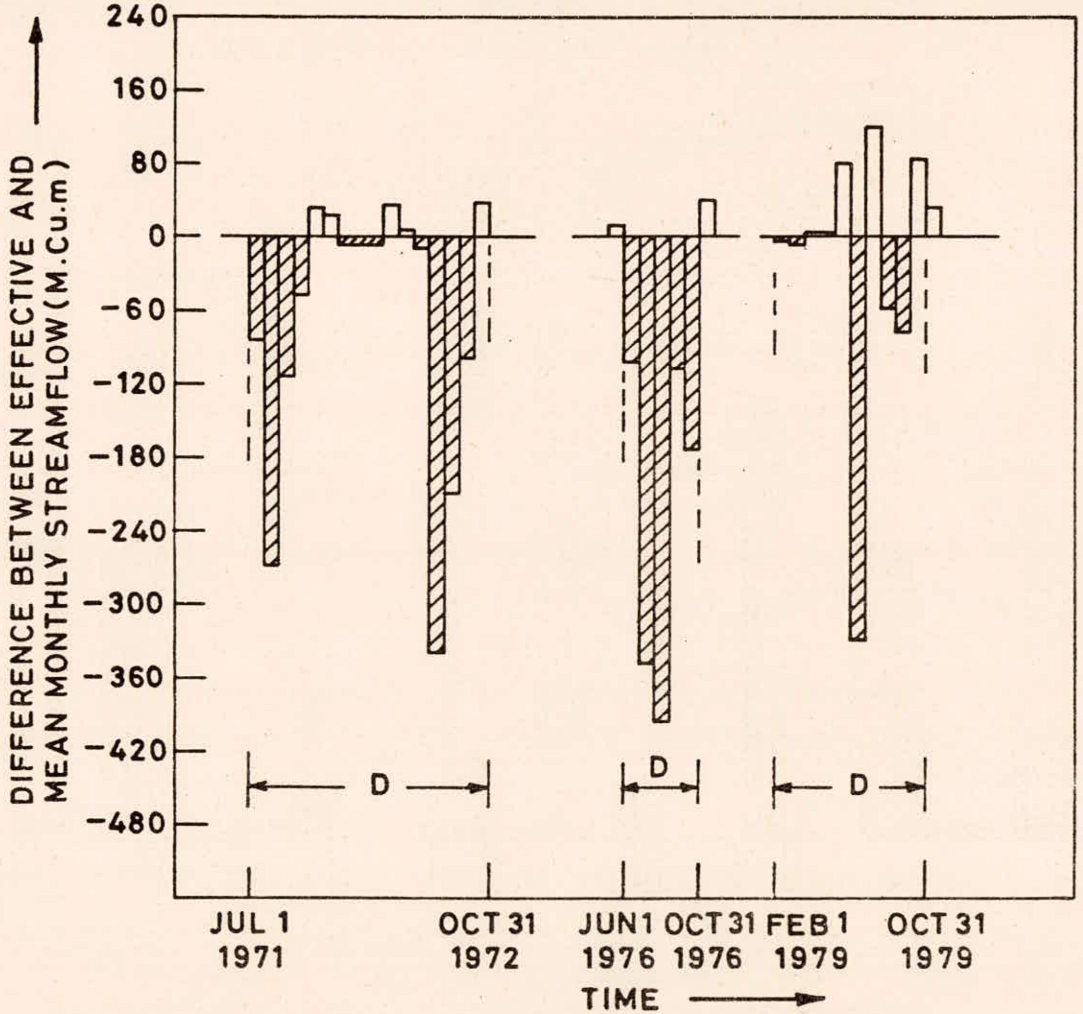

Fig.2 Characteristics of identified droughts (contd.)

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