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# A modified method for drought identification

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**Abstract** Water management under drought conditions is a challenging task to irrigation and agricultural engineers. The parameters of interest in identifying drought include onset, termination and severity. In this paper, a methodology to identify those parameters from the available historic data on streamflow and rainfall having seasonal pattern is proposed. The methodology follows and modifies a procedure by Herbst *et al.* (1966) suggested for the analysis of drought. This modified methodology is applied to the streamflow series of the Bhadra river and the mean areal rainfall series for the catchment of the Bhadra reservoir in Karnataka State, India. The droughts identified by the proposed methodology are concurrent with the historically realized droughts, thus proving the viability and applicability of the methodology in the identification of drought conditions.

## Methode améliorée pour l'identification des sécheresses

**Résumé** La gestion des eaux dans des conditions de sécheresse est un veritable défi pour les ingenieurs responsables des irrigations et de l'agriculture. Les paramètres concernant l'identification des sécheresses comprennent la date de début, celle de la fin et sa sévérité. Dans le présent article on propose un méthodologie pour identifier ces paramètres à partir des données historiques disponibles concernant les débits des rivières et les précipitations dans le cas où celles ci présentent un caractère saisonnier. On suit pour celà une méthodologie améliorée donnée par Herbst *et al.* (1966) proposée pour l'analyse des sécheresses. Cette méthodologie améliorée a été appliquée à des séries de débits de la rivière Bhadra et au moyennes spatiales de précipitations sur le bassin du réservoir Bhadra dans l'état de Karnataka, Inde. Les sécheresses identifiées par la méthodologie proposée sont en accord avec les sécheresses historiques connues ce qui prouve la valeur et la facilité d'application de cette méthodologie pour l'identification des conditions de sécheresses.

## INTRODUCTION

With increasing population and ever-increasing demand for an additional

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water supply, be it for municipal use or for irrigated agriculture, the key to the successful operation of any water resource system lies in the management of the system under uncertain supply such as in droughts. Droughts are manifestations of meteorological, hydrological and agroclimatological variations over space and time. In order to manage a drought one needs to know the characteristics of droughts such as onset, duration, areal extent and severity.

Many kinds of drought definitions and indices have been developed and documented by a variety of disciplines as reported by WMO (1975). Most of the drought indices developed in the past are *ad hoc* and work in isolation. An operational definition of drought based on the availability of water would be needed for the assessment and the management of droughts (Yevjevich, 1967).

This paper focusses on an analytical procedure to study the phenomenon of drought. The proposed method is a modification of the methodology proposed by Herbst *et al.* (1966) for the identification of droughts. The proposed methodology has been tested to analyse droughts based on monthly streamflow as well as on rainfall series, and found to be most satisfactory.

## IDENTIFICATION OF DROUGHT

Drought can be quantified using the following factors:

(a) initiation and termination i.e. location in absolute time;
(b) duration; and
(c) severity.

Dracup *et al.* (1980) proposed that the following steps are required in drought analysis at a single site:

(a) **Determination of nature of water deficit** The first step is to determine the nature of the water deficit. Thus one has to select the basic phenomenon or phenomena for the definition of drought. In this study, streamflow and rainfall are considered as the basic phenomena.

(b) **Identification of the variable** In this step, the variable (or variables) describing the phenomenon must be determined, such as whether to use a point measurement or a total area value or whether to use discharge or a similar variable. The volume of streamflow at a particular site and the total depth of rainfall in the catchment are taken as the variables in this study.

(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 hydrological data are averaged or totalled in the drought analysis. The 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 the mean monthly flow/rainfall 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 a drought, yet if sustained for a period of time, can result in a drought.

The present study aims at identifying hydrological droughts, and thus soil moisture deficit accounting, which is needed for identification of agricultural droughts, has not been considered. Also, the characteristics of droughts like onset, duration, and severity have been analysed from an operational standpoint.

The following procedure has been adopted in the present study. The procedure is explained for streamflow and the same procedure has been used with rainfall data for the identification of droughts.

The main problem in analysing droughts is separating their occurrence in the record, i.e. defining their occurrence.

The procedure for determining the onset of a drought is as follows. First, the carry-over from month to month was determined by subtracting 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 was termed effective flow. If $T(t)$ denotes the truncated flow (i.e. monthly mean flow) for time period $t$, $Q(t)$ denotes the actual flow in time period $t$, $E(t)$ denotes effective flow in period $t$ and $D(t)$ denotes the difference (either positive or negative) in time period $t$, then:

$$E(t) = Q(t) + D(t-1) * W(t) \tag{1}$$

and $D(t) = Q(t) - T(t)$ (2)

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

$$W(t) = 0.1\left[1 + T(t) \Big/ \textstyle\sum_{t=1}^{12} T(t)/12\right] \tag{3}$$

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

There are a few parameters that are required for testing the onset and termination of drought. The first parameter, mean monthly deficit, was calculated for each of the twelve months 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 twelve 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 flow, the sum of the three highest values of mean monthly flow, and so on up to the sum of the twelve highest values of mean monthly flow, which is equivalent to the mean annual flow.

The test for the onset of a 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 of the mean monthly flows (*MMMI*) and the mean annual deficit (*MAD*). A monthly increment $X$ is thus obtained from the formula:

$$X = \frac{MAD - MMMI}{11} \quad (4)$$

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*.

The test for the onset of a 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, and if it was positive, the start of a potential drought was not signified. The differences 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 a 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 negative differences occurring from the first month over a 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 $n$th month exceeded the value $MMMI + (n - 1)X$, a drought was deemed to have started from the first month.

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.

The test to check whether a drought had terminated has to be applied to the month following the first month with a positive difference occurring after the start of drought. A precondition to be satisfied was that at least 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 for termination of drought without further testing.

Provided this precondition was satisfied, two further tests were applied simultaneously. The first test was designed to identify a temporary termination of drought in the sense that the period above the truncation level of the flow merely constituted an interruption or suspension of the drought rather than its termination. This first test entailed adding all the differences algebraically from the first to the *n*th 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.

The second test comprised ten sequential tests and consisted first of summation of the actual inflows from the first to the third months of testing and comparison 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 the 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, up to 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 the 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.

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

## APPLICATION

A computer program was developed for the methodology of drought analysis explained in the previous section. The program was run on a SIEMENS-7580 E system with the 52 years (1937–1988) of monthly streamflow data and 28 years (1956–1983) of monthly rainfall data in the catchment of the Bhadra Reservoir in the State of Karnataka, India.

Examination of the results for the identified drought periods and their duration reveals that they do not correspond to the historical droughts reported by Rebello *et al.* (1975), Chakraborthy & Roy (1979) and Rama Prasad (1987). The reasons for the failure of the drought identification by the procedure suggested by Herbst *et al.* (1966) may be:

(a) the methodology is only applicable to the series for which the standard deviation is not high, i.e., the monthly values should not vary too much from year to year. This is true if one looks at equation (2). If data are of highly varying nature then $T(t)$ will always be at a somewhat higher level than the truncated level flow for a series which has less monthly variability from year to year. Moreover, when the truncated level is high the drought duration that will be identified by the methodology will be somewhat longer;

(b) the methodology is applicable only to trend free 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 either to the higher or to the lower side of the present trend, thus making the drought identification deviate from the historical record; and

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

In the light of the points discussed above, a modified form of the procedure for drought analysis has been studied to account for high variability in the monthly streamflow or rainfall series.

Table 1 shows the statistics of the monthly streamflow series for the Bhadra river. It can be seen that the variability of the monthly streamflows is quite large. Figure 1 shows the plot of annual flows for 52 years. The mean annual flow is 2998 $Mm^3$ and the standard deviation is 850 $Mm^3$. Thus it is evident that the streamflow data considered have not only high variability in the annual series but also have high variability in the monthly series. The monthly statistics of rainfall over the catchment are listed in Table 2 and the plot of the annual rainfall is shown in Fig. 2. The monthly statistics of rainfall series also have high variability. For series having these kinds of characteristics, modification in the calculation of the monthly truncated flow has been found more appropriate since drought identification mainly depends on the truncated flow for each month. Thus a new formula for computing truncated flow is suggested which takes into account the monthly variability, and is given by:

$$T(t) = \bar{Q}(t) - \sigma_t^2 / \bar{Q}(t) \tag{5}$$

where:

$\bar{Q}(t)$ = mean monthly flow or rainfall for the month $t$; and
$\sigma_t$ = standard deviation of flow or rainfall for the month $t$.

***Table 1*** *Statistics of streamflow series*

| *Month* | *Mean* | *Standard deviation* | $C_v$(%) |
|---|---|---|---|
| *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* |
| *Year* | *2997.5* | | |

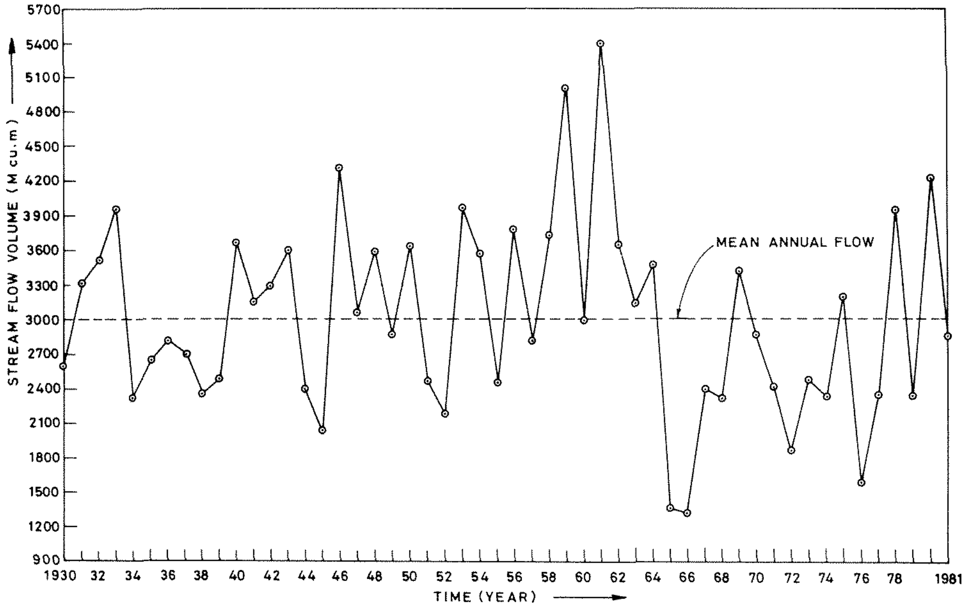



*Fig. 1* *Annual streamflow series.*

Equation (5) reduces to $T(t) = \bar{Q}(t)$ as suggested by Herbst *et al.* (1966) for the series which has negligibly small monthly standard deviations. Table 3 gives the mean monthly deficits and the values in the sliding scale that are to be compared for determination of the onset of a drought for each month. With these parameters and the modified formula for the truncated flow (equation (5)) along with the other formulae (equations (1)-(4)) the run was repeated for the same series. The results on drought initiation, drought duration and other drought characteristics are found to be quite similar to the historical droughts.

***Table 2*** *Statistics of monthly rainfall series*

| *Month* | *Mean* | *Standard deviation* | $C_v$*(%)* |
|---|---|---|---|
| *Jun.* | *413.2* | *192.1* | *47* |
| *Jul.* | *793.7* | *277.3* | *35* |
| *Aug.* | *476.7* | *244.7* | *51* |
| *Sep.* | *171.0* | *75.9* | *44* |
| *Oct.* | *158.8* | *81.5* | *51* |
| *Nov.* | *64.2* | *60.3* | *94* |
| *Dec.* | *9.4* | *15.5* | *166* |
| *Jan.* | *0.6* | *1.6* | *259* |
| *Feb.* | *3.0* | *4.5* | *150* |
| *Mar.* | *11.9* | *11.2* | *94* |
| *Apr.* | *80.8* | *40.1* | *50* |
| *May* | *139.1* | *80.2* | *58* |
| *Year* | *2322.4* | | |

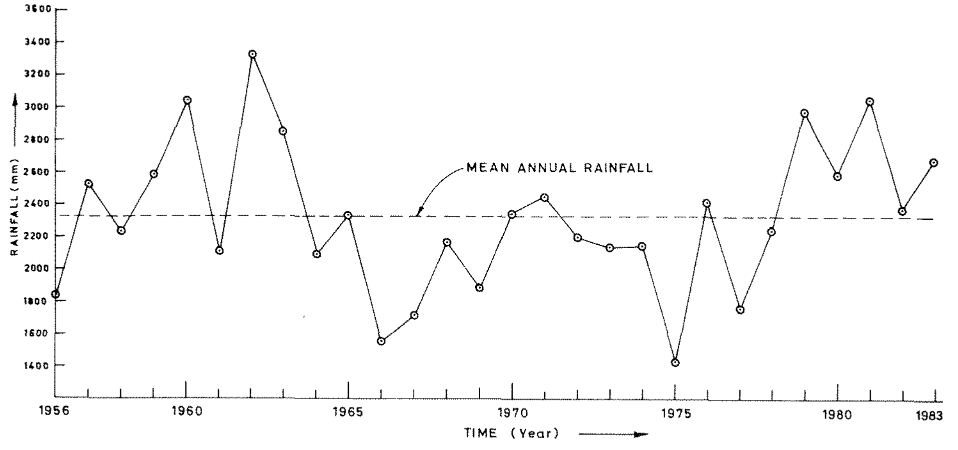



***Fig. 2*** *Annual rainfall series.*

***Table 3*** *Parameters used in drought identification*

| *Month* | *With streamflows* | | | *With rainfall* | | |
|---|---|---|---|---|---|---|
| | *Truncated flow ($Mm^3$)* | *MMD ($Mm^3$)* | *Sliding scale* | *Truncated rainfall (mm)* | *MMD (mm)* | *Sliding scale* |
| *Jun.* | *165.40* | *17.09* | *829.28* | *323.81* | *40.36* | *462.26* |
| *Jul.* | *829.28* | *70.66* | *774.69* | *696.83* | *56.65* | *415.35* |
| *Aug.* | *699.02* | *4.30* | *720.10* | *351.13* | *39.49* | *368.43* |
| *Sep.* | *287.28* | *35.97* | *665.51* | *137.36* | *14.02* | *321.52* |
| *Oct.* | *207.43* | *24.19* | *610.92* | *116.94* | *12.50* | *274.61* |
| *Nov.* | *23.34* | *0.12* | *556.33* | *7.61* | *0.97* | *227.69* |
| *Dec.* | *35.35* | *0.61* | *501.74* | *16.48* | *0.0* | *180.78* |
| *Jan.* | *28.26* | *1.77* | *447.15* | *3.49* | *0.0* | *696.83* |
| *Feb.* | *16.02* | *1.72* | *392.55* | *3.73* | *0.0* | *649.91* |
| *Mar.* | *10.72* | *1.15* | *337.96* | *1.45* | *0.15* | *603.00* |
| *Apr.* | *11.34* | *1.20* | *283.37* | *60.96* | *8.57* | *556.09* |
| *May* | *0.83* | *0.00* | *228.78* | *92.87* | *8.07* | *509.17* |

*MMD = mean monthly deficit.*

Tables 4 and 5 list the details of onset and termination and severity of the identified droughts using the streamflow series and the rainfall series respectively. Examination of the results in Tables 4 and 5 reveals that the identified droughts are almost the same except that the drought during the period February 1979–October 1979 is identified only in the streamflow series. These droughts have coincided with reported historical droughts except for the short period droughts (duration of less than three months. A look at the severity indicates that the longest period (17 months) drought occurred during June 1965–October 1966 and had the highest severity. The July 1971–October 1972 drought, even though it had a duration of 16 months, had a severity of only about one third when compared to the June 1965–October 1966 drought. In the same manner, the droughts during August 1944–October 1945 (duration of 15 months) and August 1951–September 1952 (duration of

***Table 4*** *Characteristics of identified droughts using streamflow series*

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

***Table 5*** *Characteristics of identified droughts using rainfall series*

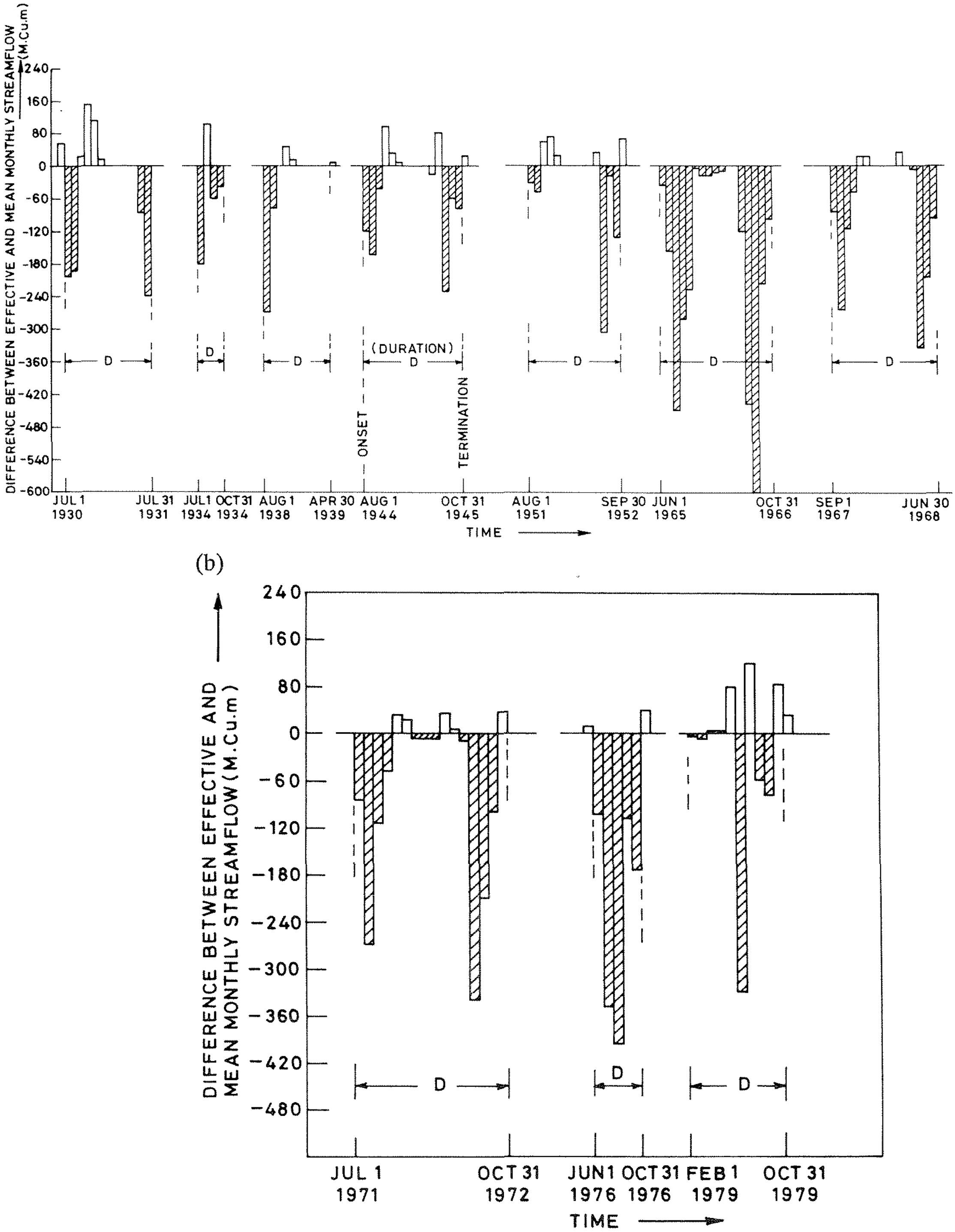
| *Series no.* | *Onset* | *Termination* | *Duration (months)* | *Severity* |
|---|---|---|---|---|
| *1* | *1 Apr. 1965* | *30 Sep. 1966* | *10* | *95* |
| *2* | *1 Sep. 1967* | *31 Jul. 1960* | *11* | *10* |
| *3* | *1 Sep. 1971* | *31 Dec. 1972* | *16* | *34* |
| *4* | *1 May 1975* | *31 Oct. 1976* | *6* | *17* |

14 months) were only about one fifth and one eighth of the highest severe drought (July 1965–October 1966). The details of the onset, termination and the monthly distribution of the identified droughts using streamflows are shown in Fig. 3 (those results using rainfall are not shown as they have almost the same pattern). It is seen from the Figure that the highest severity occurred in the June 1965–October 1966 (17 months) drought and was due to the fact that during this entire period all the monthly streamflows were less than their corresponding truncated flows. On the other hand, the June 1971–October 1972 drought (which had almost the same duration) had three months with excess flows, thus resulting in a less severe drought (Fig. 3(b)).

The effect of the choice of starting month in the identification of droughts has also been studied by running the program for different starting months, namely January, April, June, August, October (which represent the starting months of different seasons) for both the rainfall and the streamflow sequence. It was found that the starting month has a bearing only on the first drought identified and does not have any influence on subsequent droughts. This may be due to the fact that once surplus water was available to nullify the first identified drought, the suggested procedure for identification of the next onset does not depend on past values.

The properties of droughts identified by this methodology are useful in the planning and the management of drought situations in the reservoir system command area. A study of this kind for the real-time control of the operation of the Bhadra reservoir system is under way.

(a)




(b)



*Fig. 3 Characteristics of identified droughts: (a) 1930–1968; and (b) 1971–1979.*

## CONCLUSIONS

A methodology for the identification of droughts has been postulated, in accordance with the methodology suggested by Herbst *et al.* (1966), mainly for drought analysis using rainfall data, with some modifications. The suggested methodology in this study is applicable for all types of streamflow or rainfall series such as series with high monthly variability, series with some trend etc.. The methodology has been applied to streamflow data of the Bhadra reservoir system and the rainfall data of its catchment and found to have performed well in the identification and characterization of droughts.

## REFERENCES

Chakraborthy, A. K., & Roy, P. S. (1979) Influence of droughts on ecosystem as observed from Landsat. *Proc. Int. Symp. on Hydrological Aspects of Drought,* 3-7 December 1979, New Delhi, Vol. I, 47-66.

Dracup, J. A., Lee, K. S. & Paulson, E. G. (1980) On the statistical characterisation of drought events. *Wat. Resour. Res.* **16**(2), 289-296.

Herbst, P. H., Bredenkamp, D. B. & Barker, H. M. G. (1966) A technique for the evaluation of drought from rainfall data. *J. Hydrol.* **4**(4), 264-272.

Rama Prasad (1987) Drought hydrology in Karnataka. Chapter III of *Karnataka State Environment Report, 1985-86,* ed. C. J. Saldanha, Government of Karnataka, Bangalore, India.

Rebello, N. S. P., Havanagi, G. V. & Nagaraja, S. (1975) *A Comprehensive Co-ordinated Plan for the Development of Drought Prone Areas in Karnataka.* Univ. of Agricultural Sciences, Bangalore, India, Vols. I & II.

WMO (1975) *Drought and Agriculture.* Technical Report no. 138, World Meteorological Organization, Switzerland.

Yevjevich, V. (1967) An objective approach to definition and investigations of continental hydrological droughts. *Hydrology paper* no. 23, Colorado State Univ., Fort Collins, Colorado, USA.

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