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A rainfall index for hydrological floods/droughts over India

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सार — इस शोधपत्र में, भारत के विभिन्न भागों में जल विज्ञान सम्बन्धी बाढ़/सूखा के वर्ष का पता लगाने के लिए जून से सितम्बर की कुल मौसमी वर्षा तथा इसके समय वितरण को देखते हुए सूचकांक तैयार किया गया है। सामान्य वर्षों के लिए माध्य सूचकांक मूल्य को $\pm 25\%$ की सीमा देने के पश्चात् बाढ़/सूखा के वर्षों की बारम्बारता का परिकलन किया गया है। सामान्य रूप से, जल विज्ञान सम्बन्धी बाढ़ और सूखा दोनों के वर्षों की बारम्बारता, उच्च वर्षा क्षेत्रों की तुलना में निम्न वर्षा के क्षेत्रों में अधिक होती है। इनकी क्रमशः मौसम विज्ञान सम्बन्धी अधिक और न्यून वर्षा के वर्षों की बारम्बारता के साथ निकटता से तुलना की गयी है। किन्तु कुछ विशेष वर्षों का वर्गीकरण मौसम विज्ञान और जल मौसम विज्ञान सम्बन्धी दृष्टिकोण के बीच भिन्नता पाई जाती है। फिर भी इन विभिन्नताओं का स्वरूप सभी स्टेशनों पर समान नहीं होता है।

ABSTRACT. In this paper, considering total seasonal rainfall of June through September as well as its time distribution, an index has been evolved for identifying a year as hydrologically flood/drought in different parts of India. After giving a margin of $\pm 25\%$ to the mean index value for normal years, frequencies of flood/drought years have been calculated. In general, frequencies of both hydrological flood and drought years are more in low rainfall areas as compared to high rainfall areas. They compared quite closely with the frequencies of meteorological excessive and deficient rainfall years respectively. But the categorization of some individual years is found to differ between meteorological and hydrological points of view. The nature of these differences is, however, not uniform at all the stations.

1. Introduction

In view of immense practical value, drought has been extensively studied in major scientific disciplines of meteorology, hydrology, agriculture and economics. Presently, we are concerned with hydrological drought and the purpose is to study the phenomena using rainfall data. Generally, hydrological drought is defined in terms of *"severe shortage in the surface and ground waters and river and stream flows"* (Yevjevich 1967, WMO 1975, Dracup *et al.* 1980, Ben-Zvi 1987). Modelling drought characteristics faces a serious problem because of non-availability of long-term records of these hydrological parameters. To a large extent this can be overcome by defining hydrological drought in terms of rainfall data which are readily available for longer periods, for a large number of stations.

Over India, rainfall is a seasonal phenomenon and over most parts it is due to the southwest monsoon, from June through September. Hydrological parameters in this area are thus highly dependent upon the amount and distribution of rainfall processes. The main objectives of this study are :

(*i*) To evolve an index considering total seasonal (June through September) rainfall as well as its time distribution for identifying a year as hydrologically flood/drought and

(*ii*) To compute the frequencies of hydrological floods/droughts in different parts of India.

2. Data used

Fig. 1 shows the location of 362 well distributed raingauge stations over the country whose daily rainfall data for the period June through September, from 1901 to 1980 are used in the study. For individual stations, the length of record varies from 40 to 80 years. The geographical distribution of normal southwest monsoon rainfall is also given in Fig. 1.

3. Seasonal rainfall amounts and meteorological excessive/deficient years

In India for an area, a year is declared as drought when annual rainfall deficiency exceeds 25% of its normal (India Meteorological Department 1971, Govt. of India 1976). Applying this criteria of $\pm 25\%$ departure on southwest monsoon rainfall, Parthasarathy *et al.* (1984) have computed empirical probabilities of flood/drought years in different parts of India. In order to facilitate comparison with other results of this study, we also applied the same criteria to the present data set and computed probabilities of excessive (flood) and deficient (drought) years. The results are presented in Fig. 2 which are in close agreement with those of Parthasarathy *et al.* (1984). In general, the frequencies are more in low rainfall areas as compared to high rainfall areas.

4. Development of a rainfall index for hydrological purposes

The process of evolving the rainfall index is covered in two parts. Firstly, to quantify the time distribution

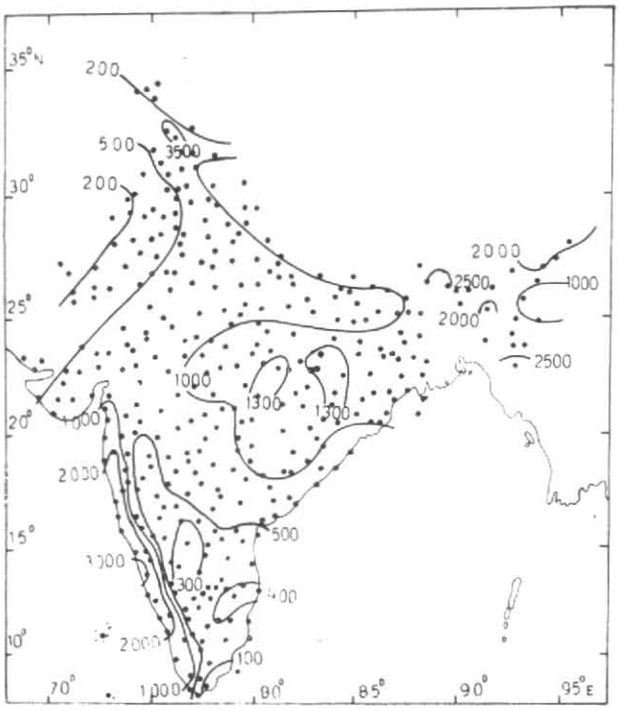

Fig. 1. Location of 362 raingauge stations. The lines indicate the normal southwest monsoon rainfall distribution (in mm)

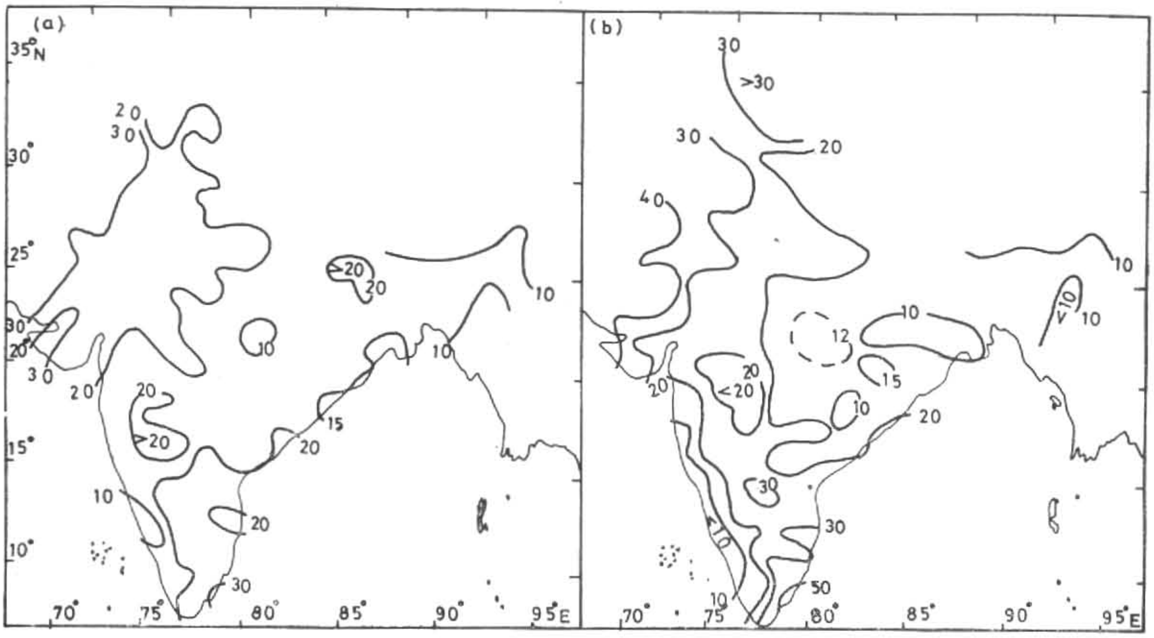

Fig. 2. Empirical probabilities (in %) of frequency of meteorological (a) excessive and (b) deficient rainfall years

of southwest monsoon rainfall and secondly, to compbine it suitably with total monsoon rainfall to get an index. The details in brief are described below.

4.1. *Quantification of time distribution of southwest monsoon rainfall* — Here the time distribution of southwest monsoon rainfall has been quantified by computing Oliver's Precipitation Concentration Index (PCI), which is defined as follows (Sato *et al.* 1985) :

$$\mathrm{PCI}_j = \frac{\sum_{i=1}^{M} X_{ij}^2}{\left(\sum_{i=1}^{M} X_{ij}\right)^2} * 100 \qquad (1)$$

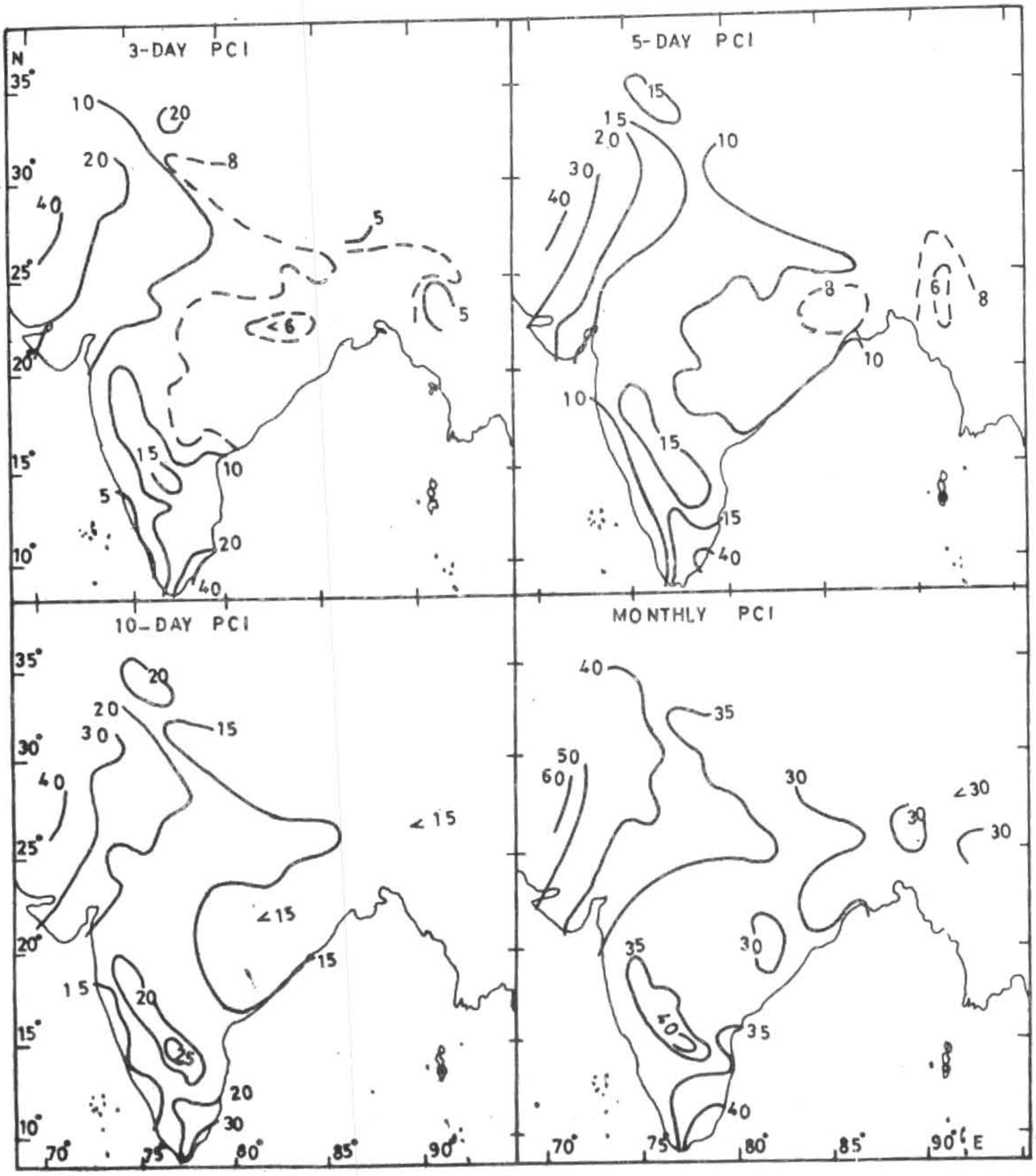

Fig. 3. Distribution of the mean precipitation concentration index (in %) computed using 3-day (triad), 5-day (pentad), 10-day (decade) and monthly rainfall totals

where j indicates the particular year, *i.e.*, $j=1, 2, \ldots,$ 80. For the present purpose triad (3-day) rainfall totals of the southwest monsoon period is used as X $(M=41)$ to compute PCI.

The choice of triad rainfall totals for PCI computation has been made after an experimental analysis with daily, triad, pentad, weekly, decadal and monthly rainfall totals. The distribution of mean PCI over India with rainfall totals of chosen periods of triad, pentad, decade and month is presented in Fig. 3. Though the period of reliable rainfall (or rainy season) over India varies from about 20 days in northwestern India to about 200 days in extreme Peninsular and northeastern India (Singh 1986), the monthly PCI exhibited a limited variation of 30 to 60 per cent and decadal PCI 15 to 40 per cent. But triad and pentad PCIs have exhibited variation from about 6 per cent to 40 per cent. Therefore, triad and pentad PCIs are better capable of reflecting the nature of time distribution of rainfall in different parts of India. Considering panted rainfall totals may sometimes yield high PCIs value because of pooling of smaller rainfall amounts which might not have produced enough surplus water. On the other hand, consideration of rainfall totals shorter than 3 days duration may split the rainstorms, which are generally of 2 to 3 days in duration (Abbi 1972), resulting in low PCI values. Hence, triad rainfall total is considered appropriate for PCI computation for hydrological purposes.

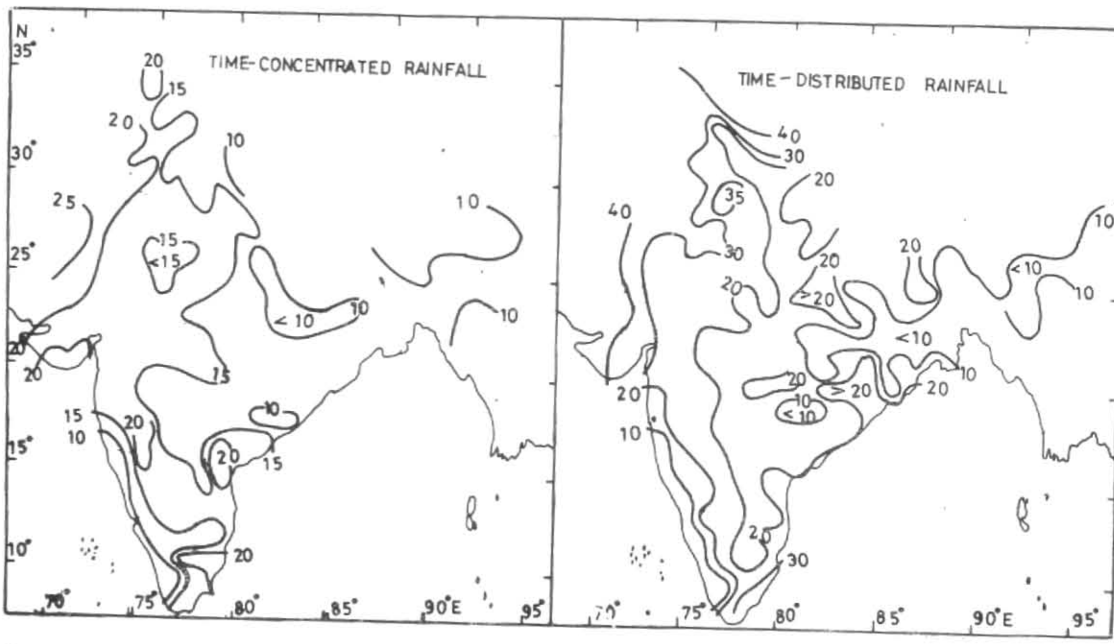

Fig. 4. Empirical probabilities (in %) of frequency of time-concentrated and time-distributed rainfall years

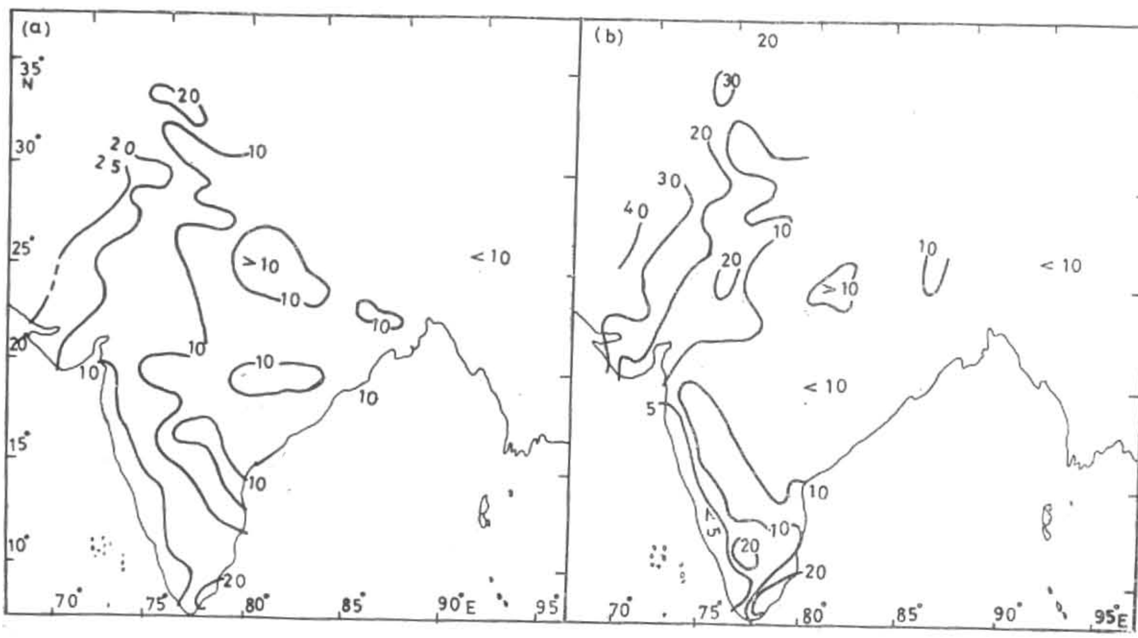

Fig. 5. Empirical probabilities (in %) of frequency of hydrological (a) flood and (b) drought years

4.2. *Variations in the triad rainfall PCI* — In order to know the nature of yearly variations of triad rainfall PCI in different parts of India, frequencies of time-concentrated rainfall years (PCI exceeded 125 per cent of normal) and time-distributed rainfall years (PCI not exceeded 75 per cent of normal) have been calculated for each of 362 stations in terms of empirical probabilities. The isopleths of these frequencies are presented in Fig. 4. The occurrence frequency of time-distributed rainfall years in different parts of the country is between 10 and 15 per cent except in west Rajasthan (25 per cent), southeast Tamil Nadu (20 per cent), parts of central Peninsula and Jammu & Kashmir (20 per cent each). Similarly, occurrence frequency of time-distributed rainfall years is also high in low rainfall areas (30 to 40 per cent) and low (10 to 20 per cent) in high rainfall areas. Hence PCI exhibits large variation in low rainfall areas as compared to high rainfall areas.

4.3. *Evolution of the final rainfall index* — Eqn. (1) gives an account of only time distribution of rainfall during June through September. In order to have the features of seasonal rainfall amount as well as its time-distribution collectively, the total seasonal rainfall and PCI have been combined suitably to produce an index. The two terms are combined in such a way that both of them are equally effective in controlling variations in the index value. Computation of coefficient of variation of monsoon rainfall and PCI has shown that for different stations variability of PCI was more than that of monsoon rainfall. Therefore, a higher weightage was given to the rainfall term than the PCI term. The weighting factor W has been calculated in the following manner :

$$W = \frac{1}{N} \sum_{j=1}^{N} \{(\mathrm{PCI}_j / \overline{\mathrm{PCI}}) / (R_j / \bar{R})\} \qquad (2)$$

where PCI_j and $\overline{\mathrm{PCI}}$ are the actual and mean values respectively, of the triad rainfall PCI series; and R_j and $\bar{R}$ that of rainfall series.

For most stations W varied between 1. 01 and 1.5, but for stations in low rainfall areas of extreme northwest India and southeast Tamil Nadu it varied between 2 and 6. After involving W the final index, designated as rainfall index for hydrological purposes (RIH) is evaluated as follows :

$$\mathrm{RIH}_j = \frac{1}{(1+W)} (\mathrm{PCI}_j / \overline{\mathrm{PCI}} + W^* R_j / \bar{R}) \qquad (3)$$

j takes values from 1 to 80 for different years from 1901 to 1980.

5. Frequency of hydrological floods/droughts over India

RIH has been computed yearwise for different stations. For a particular station, choosing mean RIH as the truncation level and giving a margin of $\pm 25\%$ to the mean RIH for normal condition, a year with RIH exceeding 125% the mean is identified as hydrological flood year and that with RIH less than 75% the mean as drought year. The empirical probabilities of frequency of flood and drought years have been worked out for different stations and their isopleth charts prepared as shown in Fig. 5. In major parts of the country, the occurrence frequency of hydrological flood years is between 10% and 20% but in northwest India and some parts of Tamil Nadu it is more than 25%. Barring some isolated pockets, the occurrence frequency of flood years is more in low rainfall areas and less in high rainfall areas. Similarly, the occurrence frequency of drought years is more in low rainfall areas (more than 20%) and less in high rainfall areas of northeast India and the west coast.

6. Discussion

Following a uniform criterion, the triad rainfall totals have been used for PCI computation to quantify the time distribution of seasonal rainfall. However, shorter/longer time-scale rainfall totals can be used for this purpose if rain-spells over an area are generally of shorter/longer durations. The PCI and the seasonal rainfall amounts are inversely related. For different stations the linear correlation coefficient is found to vary between —0.24 and — 0.40 (statistically significant at 10% to 1% level), which indicates that during high/low rainfall years, rainfall will be distributed/concentrated in large/few number of rainspells.

The correlation between seasonal rainfall amount and RIH is also high. It varies between 0.5 and 0.79 (statistically significant at 1% to 0.1% level) for different stations. This shows that large number of years which can be identified as meteorological excessive/deficient rainfall years will be hydrological flood/drought years. But there were years which were in different categories from meteorological and hydrological points of view. An examination of such years indicated that there were differences in them for different stations. As such, generalisation of these differences is not possible.

It may look somewhat unrealistic that occurrence frequency of flood years is also more in low rainfall areas, but it is bound to be until different standards are followed for flood/drought year identification in different rainfall regimes. There does not seem to exist such flexible criterion at present.

7. Conclusions

The main conclusions are as follows :

(*i*) Quantification of time distribution of the seasonal rainfall using the precipitation concentration index (PCI) has been found useful to evolve an index for identifying a year as hydrologically flood/drought in different parts of the country,

(*ii*) Over India, the occurrence frequency of hydrological floods varies between 10 and 25 per cent. and that of droughts between 10 and 40 per cent.

(*iii*) In general, frequencies of hydrological floods/droughts are more in low rainfall areas as compared to high rainfall areas, and they are in good agreement with the frequencies of meteorological excessive/deficient years. But there were some years which were identified as hydrological flood/drought were not meteorological excessive/deficient years or other way round.

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