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Variations in meteorological floods during summer monsoon over India

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सार — इस अध्ययन में भारत के 113 वर्षों (1875-1987) के लिए भारत के 31 मौसम विज्ञान संबंधी उप-खण्डों के वर्षा के आंकड़ों का बाढ़ सूचकांक को विकसित करने के लिए प्रयोग किया गया है और सूचकांक के साख्यिकीय गुणों का विवेचन किया गया है। मौसमी वर्षा के साथ सूचकांक का संबंध, अवदाबों की संख्या और एल-नीनों की परिघटना का परीक्षण किया गया है।

अध्ययन से यह प्रकट हुआ है कि 1971-80 के दशक में अनावृष्टि वर्षों की अपेक्षा बाढ़ वर्ष अधिक थे। सूचकांक भारत में बाढ़ स्थिति से काफी सम्बद्ध पाया गया। अर्ध-द्विवर्षी दोलनों (क्यू० बी० ओ०) की किसी विशेष प्रावस्था को बाढ़ों के आने की घटना से सम्बद्ध करना कठिन है।

ABSTRACT. In this study, rainfall data of 31 meteorological sub-divisions in India for 113 years (1875-1987) have been used to develop a flood index and statistical properties of the index are discussed. Relationship of the index with the seasonal rainfall, number of depressions and *El-Nino* phenomenon are examined.

The study revealed that 1971-80 decade, had more number of flood years than the drought years. The flood index was found to be significantly related to flood situation over India. It is difficult to associate any particular phase of the quasi-biennial oscillations (QBO) with occurrence of floods.

Key words — Auto-correlation, depressions, quasi-biennial oscillations, red-noise, *El-Nino*, *La-Nina*, power spectrum analysis.

1. Introduction

The Indian monsoon is synonymous with vagaries. Excessive rainfall in some part when other areas face the spectre of drought is not an uncommon feature of the southwest monsoon rainfall. The most recent aberrant behaviour was in 1987 when Bihar and West Bengal experienced the most devastating floods of the century, while major portion of the country concurrently experienced unprecedented drought. Colossal differences in rainfall distribution are thus an inherent part of the monsoon system. In order to alleviate sufferings due to flood and channellising excess water to the drought affected areas, a detailed knowlegde of relevant statistical information is a pre-requisite. It may be mentioned in this connection that meteorological factors which cause floods during monsoon have been well documented in scientific literature. Ramaswamy (1987) found that heavy rainfall is caused by : (*i*) monsoon depression, (*ii*) orographic effects, and (*iii*) during 'breaks' heavy falls are caused over eastern and central Himalayas.

The aim of the present study is to document and analyse years of floods or excessive summer monsoon rainfall over India.

2. Data series

The study utilizes 113 years of rainfall data (1875-1987) for 31 meteorological sub-divisions of India covering most of the country. The number of the stations increased progressively from nearly 370 in 1875 to nearly 2100 in 1945. Between 1945 and 1987 the raingauge stations increased by 2000. The rainfall series was collected from Meteorological Office, Pune.

The hilly areas constitute about 10% of the total area of the India. Though rainfall representation over hilly areas is much less compared to that in the plains and the representative character of station rainfall over a hilly terrain is also less than that over the plain areas, the data was available for a continuous period in respect of all hilly sub-divisions except hills of west Uttar Pradesh. Because of lack of continuous data this hilly sub-divisions which though constitute about 12% of the Indian hill area, could not be included. The study, no doubt includes other hilly areas like Himachal Pradesh and Jammu & Kashmir. It may, however, be mentioned that for the hilly areas the rainfall representation is extremely poor prior to 1901.

3. Past studies

Very few studies on meteorological floods barring hydrometeorological aspects in catchment areas of river basins have been conducted in India. Bhalme and Mooley (1980) computed a Flood Area Index (FAI) from monthly sub-divisional rainfall by adopting procedure enunciated by Palmer (1965). A mean index was calculated for the monsoon season of each year for each of the meteorological sub-divisions. The FAI was then defined as percentage area of the country having monsoon index ≥ 2. Mooley and Parthasarathy (1982) determined worst flood years based on the sub-divisions receiving seasonal rainfall more than

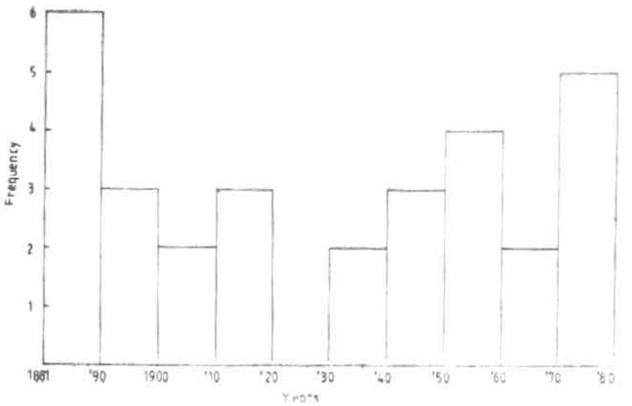

Fig. 1. Occasions of flood years decadal

19% above the normal. The most important aspect of this study was, a data series based on fixed number of 306 rainfall measuring stations throughout the period was considered. Both these studies, however, did not consider interannual variability. Making use of the same network, *i.e.*, 306 constant stations, Parthasarathy *et al.* (1987) identified some of the flood years over India for the period 1871-1984. No other study has come to the knowledge of the authors about quantitative assessment of meteorological floods over India.

4. Definition of meteorological flood

The term "flood" in this study refers to the "meteorological flood". For each of the 113 years the sub-divisions receiving seasonal rainfall $>25\%$ above the normal were determined. Areas of all such sub-divisions in a year were added. Because of the high rainfall variability in northwest India, occasion of floods as defined here may be more as compared to those in northeast India. This series may thus have a bias towards sub-divisions in the northwest India. From the series thus obtained the total area of the country receiving more than 25% normal rainfall was obtained. This series was used to determine mean flood area ($\bar{x}$) and its standard deviation (σ). These two parameters were then used to develop a flood index. If x is the area affected by excess rainfall in a year, the country is assumed to experience meteorological flood when $x > \bar{x}$. The Meteorologcial Flood Index (MFI) for any year is defined as :

$$MFI = (x - \bar{x}) / \sigma$$

All the cases when $x > \bar{x}$ are assumed to have MFI=0. For categorising of the MFI, the non-zero index values were divided into quartile ranges. Values in the first quartile were ignored in the classification. The MFI ranges and the category of flood are given below:

Class	*MFI value*	*Category*
Lower quartile-Median	0.482 to 0.679	Moderate
Median-Upper quartile	0.680 to 1.427	Severe
>Upper quartile	>1.427	Exceptional

5. Results and discussion

5.1. *Flood years*

The different years along with categories of floods (moderate, severe and exceptional) and the corresponding MFI values are given in Table 1. Accordingly, the worst five floods over India in order of decreasing magnitude appear as 1961, 1878, 1917, 1975 and 1884. Dhar *et al.* (1978) utilising mean rainfall departure of the country consider 1917 as the wettest year for the period 1901-1960 chosen for their study. Parthasarathy *et al.* (1987) brought out most widespread droughts/floods over India from 1871 to 1984. Comparison between the years of exceptional floods in this study and the years of most widespread floods in the study of Parthasarathy *et al.* (1987) shows excellent agreement between the two, both of which have the same criterion, *viz.* flood area greater than 90th percentile of the flood area series used, for identification. From Table 1, in 12 cases, flood was observed in consecutive years. Instance of three consecutive years of floods was 1892-1894 and four consecutive years were 1975-1978. The decadewise occasions of flood yeats is shown in Fig. 1 by histograms. In 1891-1900 decade the seasonal rainfall activity appears to be on a high note with floods in six years. The decade 1971-80 though had witnessed severe drought conditions in three years (1972, 1974 and 1979), it is seen that on the whole the monsoon situation was not that bad and in 5 years the country has experienced floods in 1971-1980 decade.

5. 2. *Statistical properties of the index*

Among the other statistical properties of the index, the mean and S. D. were 0.37 and 0.71 respectively, yielding a coefficient of variation as 192. The interannual variability of the index was calculated as

$$\sum_{i=1}^{n-1} \left| x_{i+1} - x_i \right| \Big/ (n-1)$$

where, x_i is the index value for the ith year and n the total number of years. The interannual variability was found as 0.60. The MFI series is thus characterised by a high variability. The probability of MFI being zero was 61%. The distribution of MFI is highly positively skewed.

Auto-correlation of higher lags enable to find out presence of cycles, if any, in the time series. In the present study auto-correlation was calculated for lags 1 to 38. Except for lags 16, 14 and 7 correlation was not found significant for any other lags. To find out if the high correlation for lag 16 remain significant for smaller segments of time series, the MFI series was divided in two parts, 1875-1934 and 1935-1987 and auto-correlations worked out. In this case none of the correlation was found significant. Thus it appears that oscillation of 16 years exists in the flood index though the signal is not intense enough to have any forecasting potential.

TABLE 1

Flood years and their category

S. No.	Year	Area affected ($\times 10^6$ km²)	% of the area affected	MFI value	Category	Ranking
1	1878	1.513	48.185	2.889	Exceptional	2
2	1879	0.690	21.975	0.774	Severe	16
3	1881	0.595	18.949	0.530	Moderate	32
4	1882	0.647	20.605	0.663	Moderate	25
5	1884	1.175	37.420	2.021	Exceptional	5
6	1886	0.685	21.752	0.756	Severe	19
7	1889	0.616	19.618	0.584	Moderate	30
8	1890	0.653	20.796	0.679	Moderate	23
9	1892	1.162	37.006	1.987	Exceptional	6
10	1893	0.688	21.911	0.769	Severe	17
11	1894	0.989	31.497	1.542	Exceptional	11
12	1908	0.691	22.006	0.776	Severe	15
13	1909	0.673	21.433	0.730	Severe	20
14	1914	0.827	26.338	1.126	Severe	14
15	1916	1.025	32.604	1.635	Exceptional	10
16	1917	1.427	45.446	2.668	Exceptional	2
17	1933	1.145	36.465	1.943	Exceptional	7
18	1938	0.944	30.064	1.427	Severe	12
19	1942	0.685	21.815	0.761	Severe	18
20	1944	0.621	19.777	0.596	Moderate	29
21	1945	0.635	20.223	0.632	Moderate	27
22	1955	0.589	18.758	0.514	Moderate	33
23	1956	0.868	27.643	1.231	Severe	13
24	1958	0.637	20.287	0.638	Moderate	26
25	1959	1.135	36.146	1.918	Exceptional	8
26	1961	1.795	57.166	3.614	Exceptional	1
27	1970	0.660	21.019	0.697	Severe	22
28	1973	0.649	20.669	0.668	Moderate	24
29	1975	1.268	40.382	2.260	Exceptional	4
30	1976	0.631	20.096	0.622	Moderate	28
31	1977	0.605	19.268	0.555	Moderate	31
32	1978	0.662	21.083	0.702	Severe	21
33	1983	1.030	32.803	1.648	Exceptional	9

5.3. *Relationship with monsoon depressions*

Monsoon depressions are the low pressure synoptic disturbances. During the northern hemispheric summer monsoon, these depressions form in the Bay of Bengal and while traversing in WNW direction, give copious rains over the country. Normally, 2 to 3 depressions form in each of the months, June to September of the monsoon season (Rao 1976). Dhar *et al.* (1978) from a study of a wettest and driest monsoon believed that number of depressions alone do not control rainfall over India. In the present study, an attempt was made to find out association between the number of depressions in a year and : (*i*) mean rainfall over the country and (*ii*) the MFI. In both the cases the correlation was too low to be of any significance. However, a statistically significant (at 5% level) correlation, *i.e.*, 0.29 was obtained between the mean rainfall over India and the flood index. This confirms the conclusion drawn by Dhar *et al.* (1982) that number of depressions do not have any bearing, whatsoever, with the mean rainfall.

5.4. *Return period analysis*

Because rainfall over most parts of India is convective in nature, every year, some areas receive deficient rainfall while some other may be experiencing excess rainfall and floods. The area experiencing floods as per criterion laid down above thus forms a series which can be subjected to return period analysis. In this study Gumbel's method was used. It appears that every alternate year a tenth of the total area of the country can be affected by excessive rainfall and floods, while once in five years it could be one-fifth. Areas affected once in 10 years and once in 25 years were 28.1 and 37.0% of the total area of the country. Once in 50 years, 43.6% of the area of the country could be affected by floods. Not much difference has been observed between the area affected once in 75 or once in 100 years, in both the cases nearly half of the country could be flood-affected.

5.5. *Power spectrum analysis*

Power spectrum analysis has been applied to study periodicity in the Indian summer monsoon disturbances (Singh and Kripalani 1986, Krishnamurti and Subramanyam 1982 etc). Such a method also enables to examine thermodynamic features like momentum transfers, heat fluxes etc associated with the monsoon disturbances. When the spectral technique was applied to the depression series, the spectrum was found generally to have red-noise type distribution. Statistically significant peaks were observed around 2.5 years and beyond 25 years. The periodicities between 2 to 3 years have been extensively found in the studies of rainfall and other meteorological factors by Koteswaram and Alvi (1969), Jagannathan and Bhalme (1970), Rao *et al.* (1973) etc, Bhalme (1972) studied power spectrum of the depressions based on data from 1891 to 1970 and found major oscillations of about 2.54 years. These are the well known quasi-biennial oscillations.

When the flood index is subjected to the spectrum analysis a white noise type of distribution is seen. Prominent peak of about 2.8 years recognised as QBO is found statistically significant at 95% level. A weak signal of about 20 years cycle is also seen and is probably related to double sunspot cycle (Bhalme and Mooley 1980).

5.6. *Teleconnection with El-Nino*

It is increasingly being recognised that monsoon circulation is a part of global circulation where the latter largely influence the former. Monsoon rainfall over India has been found to be greatly sensitive to the warm sea surface temperature episode over eastern Pacific off Peru coast, popularly known as *El-Nino*. During *El-Nino* situation, the Pacific Walker cell is displaced eastward with the ascending branch in phase with the areas of maximum sea surface temperature and descent occurs over central and west Pacific and the SE Asian region. Such an event in turn should suppress the formation of monsoon disturbances and affect the overall rainfall activity. Sikka (1980) showed a general association between *El-Nino* events and deficient rainfall. Rasmusson and Carpenter (1983) examined the relationship between rainfall over India and *El-Nino* events. According to them, the association between the Indian monsoon and the warm episode has some predictive value.

Mooley and Parthasarathy (1983) found a significant association between monsoon rainfall over India and *El-Nino* events on the basis of data for the period 1871-1978.

The *El-Nino* data available from 1877 as given by Rasmusson and Carpenter (1983) has been used in this analysis. This was supplemented by the information contained in Climate Diagnostic Bulletin, published by U.S. Department of Commerce. Between 1877 to 1987 there were 27 *El-Nino* events while the rest were *non-El-Nino* years also called *La-Nina* by Philander (1985). The normal yearly number of depressions and depression-days in each monsoon season were calculated based on available data from 1877-1987. On an average, the mean number of depressions and depression-days were 6.8 and 30.1 respectively. In about 60% of each of the *El-Nino* and *La-Nina* years the number of depressions were found above normal. This means that, the number of depressions do not have any bearing to these episodes. At the same time, examination of number of depression-days revealed that in 13 out of 27 cases of *El-Nino*, the depression-days were below normal. However, in *La-Nina* years, the below normal cases of the depression-days exceed the above normal ones by nearly 3 : 2, suggesting thereby that chances of below normal depression-days in a *non-El-Nino* episodes are large. Sarker (1988) found that the intense *El-Nino* episodes have concurrent relationship with deficient rainfall on 60% occassions only.

It is, therefore, appears that *El-Nino*, may be modulating the monsoon atmosphere by suppressing formation of the monsoon depressions in some years. However, its influences on the life cycles of these systems is to a limited degree only.

5.7. *The Quasi-Biennial Oscillations (QBO) and the monsoon activity*

The phenomenon of quasi-biennial oscillations (QBO) in the zonal near equatorial stratospheric wind and the reasonable regularity of the phase of the QBO has attracted several research workers in India to relate its phase with weather (Rao and Lakhole 1978, Singh 1985, 1986 etc). In the present study, we have tried to relate the two phases of QBO (*i.e.*, easterly and westerly) with : (*i*) flood/non-flood events as defined in an earlier section, and (*ii*) total number of depression-days during June-September. 30 hPa wind data for Balboa for 1949-1982 as given by Gray (1984) and supplemented with information available in WMO (1987), were used. In year 1952, 1972 and 1982 the wind was in easterly phase but no area had experienced flood while in 1963, 1967 and 1976, the wind was either of variable direction or very weak. It was seen that floods have occurred in India with both easterly and westerly phase. However, area affected by floods are much larger when the stratospheric winds are in westerly phase than in the easterly phase.

An attempt was also made to find out whether the total number of depression-days bear any relationship with a particular phase of equatorial stratospheric zonal wind.

The mean seasonal number of days of depressions based on data from 1877 to 1987 was found as 30. The number of depression-days per season for westerly 30 hPa wind was 26 and for easterly wind was marginally less, *i.e.*, 25 days. It is clear that monsoon depression activity is independent of the temporal changes of the zonal stratospheric wind.

The above studies confirm that it is difficult to associate a particular phase of QBO with occurrence of floods/non-floods or the depression activity in the monsoon season.

6. Conclusions

The following conclusions are drawn from the study :

(*i*) The flood index developed appears to fairly represent the overall flood situation over India.

(*ii*) Flood appears to be a fairly frequent phenomenon over India.

(*iii*) Though the decade 1971-1980 witnessed frequent droughts, there were more flood years in the decade compared to droughts.

(*iv*) It is rather difficult to associate depression activity or floods with any particular phase of stratospheric wind.

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