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DATA BASE ASPECTS OF TEMPORAL PATTERNS OF CLIMATIC FLUCTUATIONS AN INDIAN CASE STUDY

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ABSTRACT : The paper compares the results obtained by analysing the temporal fluctuations of Indian summer monsoonal rainfall data, 1901–1970, based on (a) 306 District stations (b)29 Meteorological Sub Divisions(c) an "All-India" data set. Significant differences in terms of temporal correlations, overall spatial patterns, and drought occurrences and characteristics, suggest that whereas the "All-India" data set is valuable in terms of causative studies on the macro-scale, it is the local or Sub-Division data that are critical for studies of climatic impacts and climatic hazards.

INTRODUCTION

The temporal patterns of recent climatic fluctuations form a legitimate area of enquiry and definition, but the purposes for which such studies are carried out may vary. In some cases, explanations of the dynamics of the system involved or teleconnection relationships between possible cause and effect are related to such definitions. In other cases they are to facilitate the assessment of the potential impact of such fluctuations on other phenomena, especially the activities of human societies.

The nature and format of the data that are most appropriate for these two different purposes will vary, however, and such differences will also be reflected in the related climatic patterns that are depicted. If this distinction is not remembered, then climatic impact assessments may well be made in relation to inappropriate data and patterns. This is especially so at present when so much of the climatological and meteorological literature focuses on explanation, macro-scale mathematical modelling and improvements in forecasting medium and longer term climatic fluctuations.

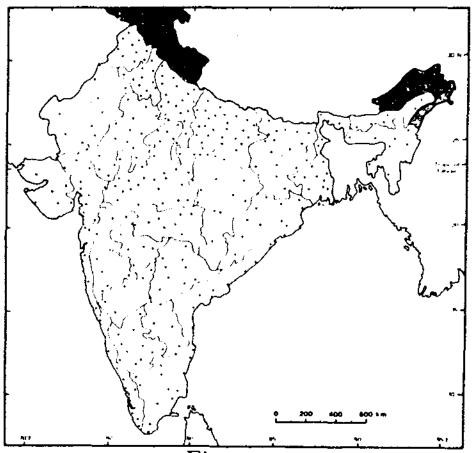

Fig. 1

Figure 1 : The location of the 306 District stations and 29 Meteorological Sub-divisions that form the data base (1901-1970) for this analysis.

The possible conflict of interest can be well illustrated in terms of summer monsoon rainfall conditions in India. Over recent years there has been a growing number of publications on this monsoonal problem using the same basic data. These comprise the rainfall values for 306 District stations (Figure 1), the reliability of which has been established in earlier papers (Mooley et al., 1981, Mooley and Parthasarathy, 1983). By a series of areal weighting procedures these have then been consolidated (Parthasarathy, et al., 1987), into single data sets for each of 29 Metoerological Sub-Divisions (Figure 1) and then from these an "All-India" data set has been generated. In relation to the latter, "All-India" drought and flood conditions have been depicted (Bhalme and Mooley, 1980, Mooley and Parthasarathy, 1983, 1984), and relationships with a variety of possible causative influences have been investigated (Rasmusson and Carpenter, 1983; Bhalme and Jadhav, 1984; Ananthakrishnan and Parthasarathy, 1984; Parthasarathy and Pant, 1985; Bhalme et al., 1986).

However, these characteristics do not necessarily apply to any individual area or climatic station in India, and certainly not to all of them all of the time. Yet it is these more localised circumstances that are critical for any study of climatic impacts or hazards produced by climatic conditions in relation, for example, to water supply, hydrology or agriculture. It is, therefore, necessary to compare the temporal characteristics of these widely-used "All-India" data with both the more regionally relevant Sub-Divisional data sets and the individual station data sets from which both the others have been derived. In addition, the spatial patterns from the two latter data sets, which reflect widely different conditions in different areas of India, must also be considered. In all of these, the summer (June-September) monsoon rainfall values were analysed for the 70 years 1901-1970. Results can be tested in later studies against both earlier (late nineteenth century) and more recent (post-1970) data.

OVERALL TEMPORAL CORRELATION

The succession of wet and dry years reflected in the "All-India" data set does not necessarily apply to all, or even any, of the more regional or local fluctuations across India, for "India as a whole is too large to be treated as a single unit" (Normand, 1953). The overall degree of relationship is displayed by maps expressing the degree of correlation between the "All-India" data and the values for each of the 29 Sub-Divisions (Figure 2a) and the 306 individual stations (Figure 2b) respectively. The basic pattern is consistent between these two figures, as is only to be expected, although the detail and the degree of correlation varies.

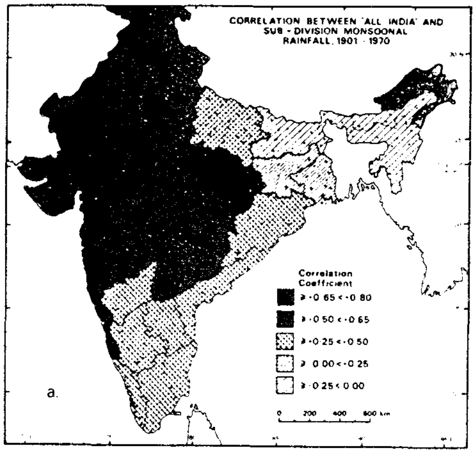

Fig. 2a

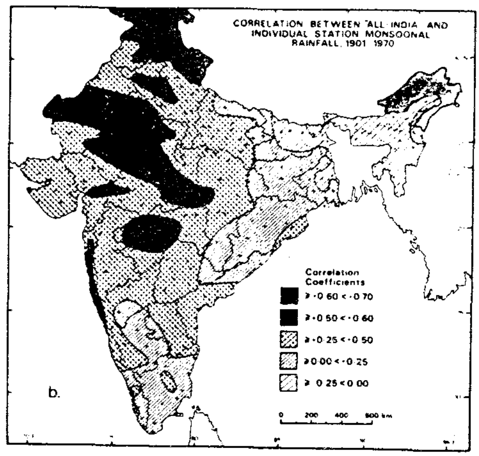

Fig. 2b

Figure 2 : Correlation between "All-India" data and (a) Sub-Division (b) Individual station data for summer monsoonal rainfall, 1901-1970.

In terms of the Sub-Divisions (Parthasarathy et al., 1987) approximately half of the country shows a correlation coefficient of between +0.50 and +0.80 (Figure 2a). Values greater than +0.60 occupy a north-south belt over the western and central parts of the northern two-thirds of the country, with maximum values in Eastern Rajasthan and Western Madhya Pradesh, i.e. the semi-arid areas east of the Rajasthan desert. In contrast, over the Lower Ganges and the Brahmaputra valleys, across Bihar, Bengal and Assam, monsoonal rainfall is essentially uncorrelated with the "All-India" conditions, with coefficients varying between +0.25 and –0.25. In other words, sometimes conditions fluctuate as do the "All-India" conditions and sometimes they may be completely opposite to one another. There is also a transition zone with values between +0.25 and +0.50 extending both westwards and also into Southern India. In Figure 2b, based on the individual 306 stations, the correlation coefficients are lower, the area of higher values is smaller and the area of essentially uncorrelated conditions is larger.

Thus the account of fluctuations of monsoon rainfall based on the "All-India" data set (Mooley and Parthasarathy, 1984) tells what has happened in terms of the total rainfall input on India as a whole, but not what has happened in any specific area. In relation to Sub-Division data, the largest proportion of the variance in one set that can be determined from the other is no more than 64%; it is less than 50% over most of the country, less than 25% over half of the country and not markedly different from zero over the whole of the north-east. Thus the degree of relationship is much less than indicated by Ananthakrishnan and Parthasarathy (1984), when they compared the "All-India" data with macro-scale Northern, Central and Southern Indian conditions. In terms of the individual stations, the highest percentage of the variance determined is only 40%, and for almost half of the country it is no more than 10%. Thus for most climatic impacts, especially those at a regional or local level, the "All-India" data set may provide a misleading base. The pattern of relationships would seem to reflect conditions over that part of India which has the maximum north-south extent. Fluctuations occurring between the 75th and 80th meridians (east) would clearly affect more of the country than would such fluctuations farther east, and would thus be observable in the "All-India" values.

OVERALL SPATIAL PATTERNS

Moreover this pattern is also similar to that of Component I, if a principal components analysis is carried out of the Sub-Division data (Figure 3a). This suggests that the most common spatial pattern (determining just over 30% of the variance) is with wet conditions between meridians 75 and 80 (east) coupled with slightly dry conditions in the north-east and parts of the south, or dry conditions in the former areas and slightly wet conditions in the latter (compare Rasmusson and Carpenter, 1983). Loadings on other components display different patterns, but collectively these contrasting spatial patterns of temporal change necessarily reduce the representativeness of the "All-India" data for most areas of the country.

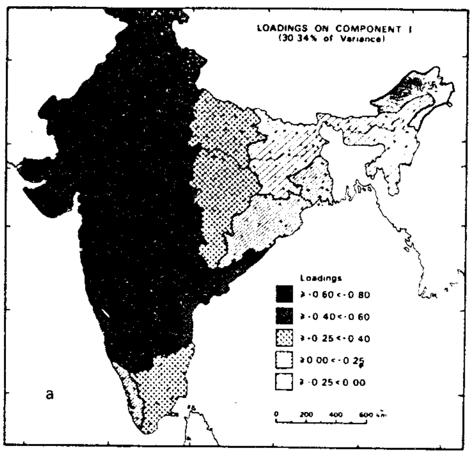

Fig. 3a

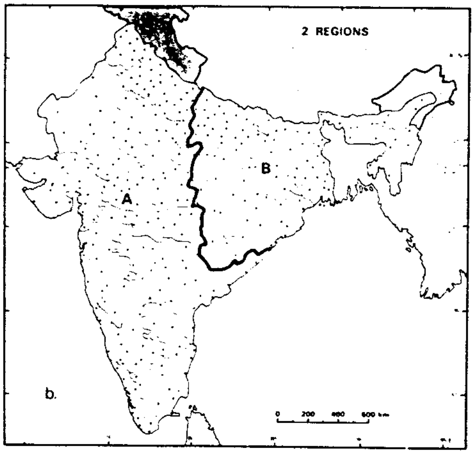

Fig. 3b

Figure 3 : (a) Loadings on the First Component of a Principal Components Analysis of summer monsoonal rainfall for 29 Sub-divisions for 1901-1970. (b) Classification of summer monsoonal rainfall for 29 Sub-Divisions for 1901-1970, using the first 8 components of a Principal Components Analysis : the 2-region solution.

If the results of the first 8 components are used, comprising 76% of the total variance, and Ward's classification algorithm is employed (Ward, 1963), the resultant hierarchical structure permits a range of regional patterns. The simplest 2-region pattern (Figure 3b) replicates the correlation pattern (Figure 2) and the first component (Figure 3a). However, considerable differences are obscured within each of these generalised units, and more detailed structures are shown in Figure 4a (5-regions) and Figure 4b (10-regions). In the 5-region case, this is the scale at which each individual Sub-Division has been grouped with at least one other. The 10-region pattern, however, is the one with the greatest degree of internal coherence within each of the regions, and these probably represent the largest areas that can be safely and sensibly used when considering climatic fluctuations in relation to their role as generators of climatic hazards.

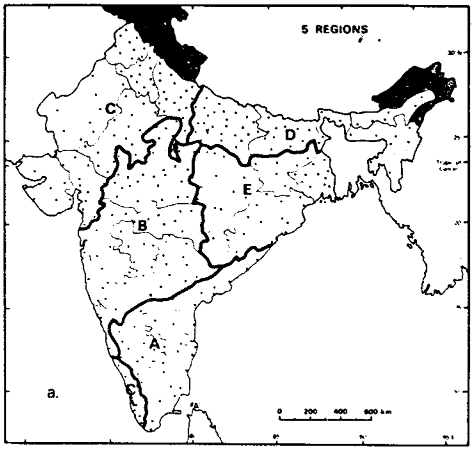

Fig. 4a

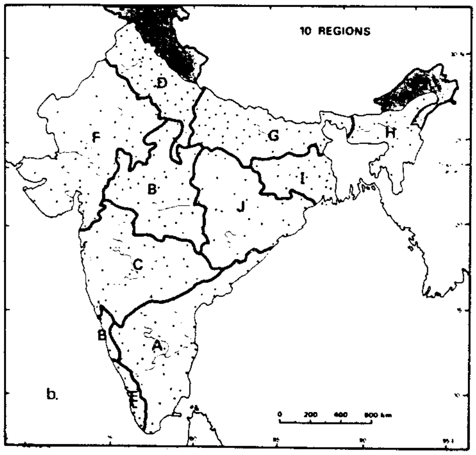

Fig. 4b

Figure 4 : Classification of summer monsoonal rainfall for 29 Sub-Divisions for 1901-1970, using the first 8 components of a Principal Components Analysis :

a) the 5-region solution

b) the 10-region solution.

COMPARISON OF DROUGHT

If the results of Bhalme and Jadhav (1984) are readjusted to the 1901-1970 data base, then their definition of drought over India – years when the "All-India" rainfall is less than 90% of the average – yields 10 such drought years in the period specified (Table 1). From this, as from their own longer full period of study, it can be argued that only once within the record has there been two successive drought years, namely 1904 and 1905. Moreover, six of these drought years were El Nino years (1905, 1911, 1918, 1941, 1951, 1965) and four were not (1901, 1904, 1920, 1966). If, however, the definition by Mooley and Parthasarathy (1983) is used the driest 10% of the years for each Sub-Division being taken, and the percentage of India thus affected in any given year being calculated – then there were 7 years when more than one-third of India was affected by drought in the period 1901-1970. As can be seen (Table 1), these results do not fully coincide with the previous ones, but there is general agreement as is only to be expected.

Year	B+J (% average)	M+P (% India)
1901	87.8	–
1904	88.8	–
1905*	84.3	35.8
1911*	87.3	40.1
1918*	76.9	68.3
1920	83.8	44.4
1941*	86.8	–
1951*	79.8	41.6
1965*	82.8	39.1
1966	88.8	37.3

Table 1. "All-India" drought years in the period 1901-1970, according to B+J (Bhalme and Jadhav, 1984) and M+P (Mooley and Parthasarathy, 1983); * indicates years with a marked El Niño effect.

If Sub-Division and individual station data sets for 1901-1970 are also analysed, then the relative ordering of the years changes again. In Table 2, the most frequently specified drought years are listed in terms of their rank order on four different bases. The first is simply the "All-India" values (Bhalme and Jadhav, 1984). The second is based on Sub-Division values, in terms of the number (not the area) of the 29 Sub-Divisions for which any given year was one of the driest 10% of years (Mooley and Parthasarathy, 1983), i.e. one of the driest seven years. The third column provides a similar ranking in terms of the number of the 306 individual stations for which the year was one of the driest 10% of years. For individual stations, however, it has been argued (India Meteorological Department, 1971; Jaiswal and Kolte, 1981) that monsoon rainfall that is less than 75% of the average value constitutes a drought, and the fourth column in Table 2 therefore ranks the years in terms of the number of stations with a fall that is less than 75% of the average.

Differences of rank occur between these four definitions, but the general picture remains clear. On any criterion and data set, 1918 was the most widespread drought year, and the 1905, 1911 and 1920 droughts were also among the most widely occurring on each definition; 1904, 1941 and 1965 also ranked in the "top ten" on all the criteria used.

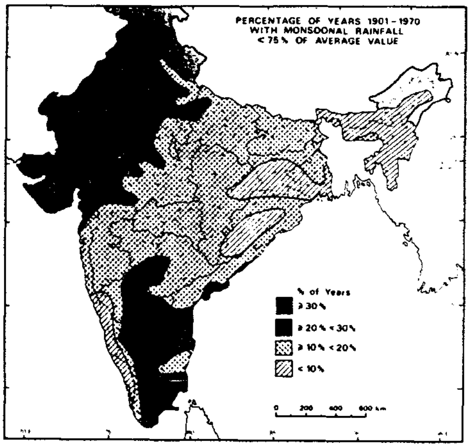

Fig. 5a

Figure 5 : The percentage of years in the period 1901-1970 in which summer monsoonal rainfall at 306 stations was less than 75% of the station's average rainfall.

The number of years in the period 1901-1970 in which monsoon rainfall was less than 75% of the average varied from zero in southern Assam to 32 years in western Rajasthan. As can be seen in Figure 5, in the north-west and the south-east of India more than 20% of the years were drought years by this definition, and in some places more than 30% of the years. In the north-east and south-west, however, some parts experienced droughts according to this definition in less than 10% of the years, whilst in central and central-northern areas values were between 10% and 20% of the years. Another approach to critical frequencies of other percentage-of-average values has recently been presented by Gregory and Parthasarathy (1986).

Table 2. The Rank Number of specific drought years (in the period 1901-1970) on different data units and criteria (rank 1 = driest year)

Year	1	2	3	4
1901	8	11.5	14	9.5
1904	9.5	7	6.5	9.5
1905	5	2.5	2	2
1907	17	20	12	7
1911	7	2.5	5	5.5
1913	11.5	15.5	9	11
1915	17	4.5	6.5	13
1918*	1	1	1	1
1920	4	4.5	3.5	3
1928	15	15.5	8	12
1939*	13.5	11.5	17	14
1941*	6	9.5	3.5	5.5
1951*	2	15.5	11	8
1952	13.5	9.5	15	15.5
1965*	3	7	10	4
1966	9.5	7	13	15.5
1969	11.5	20	16	17
Also				
1902	17			
1922		15.5		
1923*		15.5		
1925*		20		
1959		15.5		

Col. 1 : Rank according to the All-India data

Col. 2 : Rank according to the number of Sub-Divisions where the year was one of the driest 10% of years.

Col. 3 : Rank according to the number of Stations where the year was one of the driest 10% of years.

Col. 4 : Rank according to the number of Stations where the year received less than 75% of the average fall.

Year* : an El Niño year.

In addition the percentage-of-average value below which were the driest 10% of the years (1901-1970) varies markedly across the country as compared to the "All-India" value of 87.5%. For the Sub-Division data (Figure 6a) this critical value was above 80% in the north-east and in Goa on the west coast, falling to between 40% and 50% of the average in West Rajasthan and Kutch. In Gujarat values were between 50% and 60%; in the semi-arid north-west they were between 60% and 70%; whilst there was a broad north-to-south central belt with values between 70% and 80% of the average. As for the pattern based on the individual stations (Figure 6b), values in the north-east and along the west coast were in the 70% to 80% range, rising to above 80% only in eastern Assam. In the south-east they were between 40% and 60% in the main but dropping to less than 40% in the far south-east, whilst in the north-west they ranged from below 60% to below 30%. Along the Ganges valley itself there were lower critical values than immediately to the north and south of the valley line.

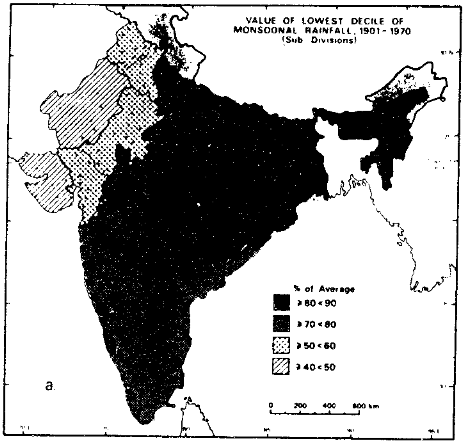

Fig. 6a

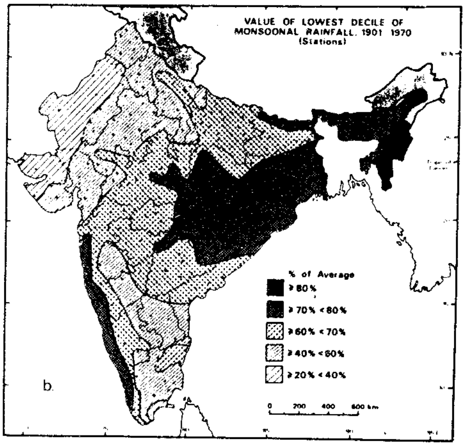

Fig. 6b

Figure 6 : The value of the lowest decile of summer monsoonal rainfall, 1901-1970:

a) based on 29 Sub-Divisons;
b) based on 306 Stations.

Finally, an alternative consideration of the temporal nature of the "All-India" data set can be in terms of the occurrence of decades with an unusual concentration of wet or dry years. This can be effected by the use of the hypergeometric frequency distribution (Gregory, 1979, 1982). Thus if the values of the record are divided into those above and those below the median (i.e. each group having a probability of occurrence of 0.5), then over a 70 year period any decade would require at least 8 out of the 10 years in one category or the other for the frequency to be different from random, at the 5% significance level. On this basis, none of the 61 decades in the period 1901-1970 had, in terms of the "All-India" data set, an unusually high frequency of either dry or wet years.

If one turns to the occurrence of drought years using the definition (Mooley and Parthasarathy, 1983) of the lowest 10% of values i.e. the lowest decile, then 3 or more of these 7 most extreme values must fall in a single decade for the cencentration in time to be significantly different from random. For the "All-India" data the decade 1911-1920 falls into this category, with 1911, 1918 and 1920 being the critical years (Table 1). In contrast, each of the five successive overlapping decades from 1952-1961 to 1956-1965 contained 3 of the 7 wettest years in the "All-India" record, namely 1956, 1959 and 1961 in each case.

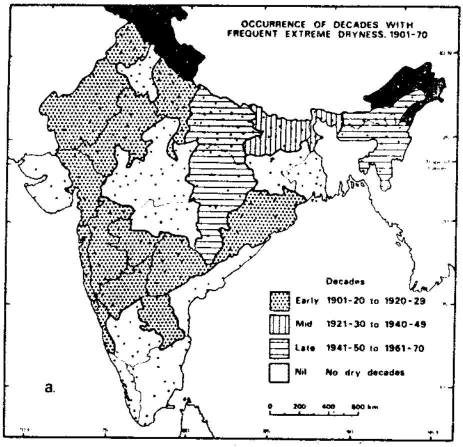

Fig. 7a

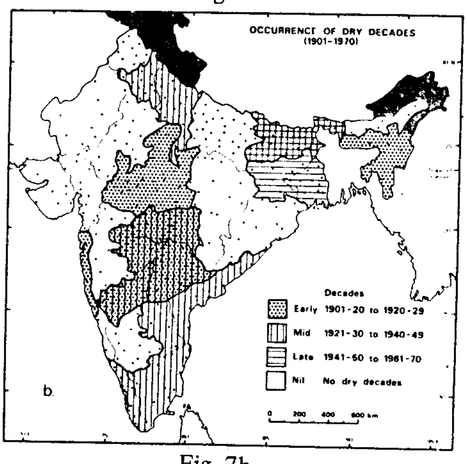

Fig. 7b

Figure 7 : The occurrence of decades within the period 1901-1970 with a significantly non-random high frequency of:

a) the extreme driest 10% of years;
b) years drier than the median value.

If these driest 10% of conditions are specified for each Sub-Division separately, there seem to be some areas in which decades early in the record (1901-1910 to 1920-1929) were critical, some with Middle decades (1921-1930 to 1940-1949) with frequent extreme dryness, some with these characteristics in decades (1941-1950 to 1961-1970), and some where no such concentration of drought years occurred in any decade. From the spatial pattern of these temporal concentrations (Figure 7a) general contrasts between the western, north-eastern and southern areas can be seen. A more complex and confused pattern occurs in Figure 7b, where Early, Middle or Late decadal concentrations of dry (below median) conditions in general are depicted.

CONCLUSIONS

Thus it has been shown that the temporal fluctuations of the widely used "All-India" data set do not necessarily apply to all areas of India, and that even when they do so it is often only in a general way. It is conditions in the western half of the country, excluding the southern areas, that are most reflected in the "All-India" conditions, with the closest relationship being over the semi-arid areas east and south-east of the Rajasthan desert. It is the north-east that has the most distinctively different temporal patterns, whilst large areas in central, southern and south-eastern India are only partially represented by the "All-India" data set. These regional distinctions are repeated on a wide range of criteria, considering rainfall fluctuations in general as well as droughts in particular. It is thus not possible to accept the characteristics of the "All-India" data set as the basis for regional or local climatic impact or hazard studies.

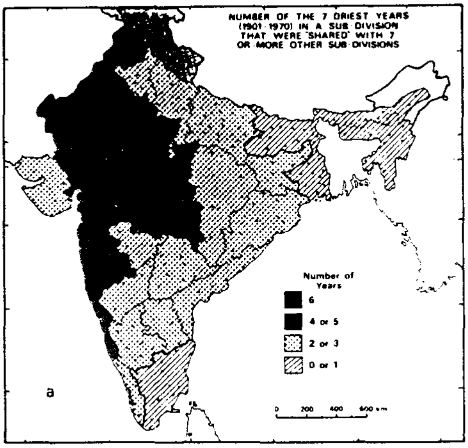

Fig. 8a

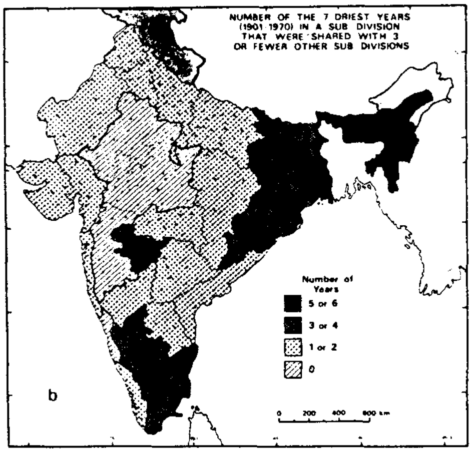

Fig. 8b

Figure 8 : The number of times in the period 1901-1970 that a Sub-Division shared one of its seven driest years with:

a) 7 or more other Sub-Divisions;
b) 3 or fewer other Sub-Divisions.

In terms of droughts, which represent this hazard aspect most critically, the differences between west and east have been repeatedly shown. Moreover, when the "driest 10%" criterion is used on Sub-Division data it can be seen that a drought affecting any Sub-Division in the west or north-west is also likely to affect many other Sub-Divisions at the same time. Thus in Figure 8a can be seen the number of droughts out of 7 (during 1901-1970) in a Sub-Division that also affected 7 or more other Sub-Divisions. In contrast, droughts in the east or north-east tend to be more localised in most cases, and Figure 8b shows the number of droughts out of 7 in a Sub-Division that also affected only 3 or fewer other Sub-Divisions. This spatial distinction must obviously be reflected in the "All-India" data set, so that of the seven worst "All-India" droughts (Tables 1, 2) 5 affected 8 or more Sub-Divisions and none of them affected fewer than 5 Sub-Divisions. The spatially more restricted droughts that affect the north-east and other areas, and which are critical for climate impact and hazard assessment and evaluation in such areas, are thus not reflected in the "All-India" conditions as a whole. The alternative side of the rainfall equation, namely the occurrence of unusually high falls with resultant floods, has not been examined here, but comparable (though not necessarily similar) spatial contrasts are only to be expected.

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