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Droughts and aridity in northeast Brazil

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सार — इस शोधपत्र में, उत्तर-पूर्वी ब्राजील में अकाल और सूखे के संबंध में किए गए अध्ययन से प्राप्त हुए परिणामों की चर्चा की गई है । यह अध्ययन इस क्षेत्र के पन्द्रह स्थानों के वार्षिक जल के स्तरों के विश्लेषण पर आधारित है । इन स्थानों में पड़ने वाले अकाल की उग्रता में पाई गई भिन्नता की इसमें चर्चा की गई है । इन स्थानों के जलवायविक परिवर्तनों का मूल्यांकन आर्द्रता सूचकांक मानों के आधार पर किया गया है । अकाल के अध्ययनों में संचयी विचलन तकनीक के उपयोग का संक्षेप में उल्लेख किया गया है ।

ABSTRACT. Results of a study of droughts and aridity in northeast Brazil are presented in this paper. The study is based on the analysis of yearly water balances at fifteen stations in the region. Incidence of droughts of varying intensities at the stations is discussed. Climatic shifts at the stations are evaluated on the basis of the moisture index values. The use of the cumulative deviation technique in drought studies is briefly mentioned.

Key words — Drought, Aridity, Climatic shifts, Water deficit, Potential evapotranspiration Cumulative deviations technique

1. Introduction

Northeast Brazil, which constitutes the easternmost corner of the south American continent is a vast semi-arid region lying between 4° & 16°S and 33° & 46°W. The coastal parts of this region receive much rainfall (upto 2000 mm) while in the interior parts annual rainfall is as low 400 mm, with a high degree of spatial and temporal variability. The rainy season is centered upon March, April and May with almost no precipitation during the rest of the year.

The frequent droughts affecting northeast Brazil have led to much suffering in the form of rural unemployment, poverty, starvation and subsequent migration from the drought stricken areas.

Numerous attempts have been made to understand the causes of droughts in northeast Brazil (Hastenrath and Heller 1977, Kousky 1979, Namias 1972, Moura and Shukla 1981). The occurrence of droughts and wet spells in the region was investigated by several authors using precipitation data alone (Silva and Marques 1984, Xavier and Xavier 1984). Hargreaves (1973, 1974) discussed the irrigation requirements in the drought zone.

Earlier studies on droughts in northeast Brazil have been based on departures of rainfall from the climatic mean values. The main objective of the present study is to show that classification of droughts in this region cannot be based on rainfall data alone. The stability of the moisture regime in northeast Brazil is of importance to agriculture in the region. This aspect is investigated on the basis of yearly climatic shifts in the moisture regime at selected stations.

2. Methodology

The fundamental cause of all drought situations is water deficiency and the water balance procedure of Thornthwaite (Thornthwaite 1948, Thornthwaite

TABLE 1

Geographical locations and climatic types of the stations

S. No.	Station	Geographical location	Period of study	Climatic type
1.	Umbuzeiro	7° 42′ S, 35° 40′ W	1932-1961	C_1B_4' d a′
2.	Propria	10° 13′ S, 36° 51′ W	1925-1951	D A′ d a′
3.	São Goncalo	6° 45′ S, 38° 13′ W	1943-1980	D A′ d a′
4.	Fortaleza	3° 45′ S, 38° 28′ W	1925-1970	C_1A' w a′
5.	Tapacura	8° 10′ S, 35° 11′ W	1937-1961	C_2A' s_2 a′
6.	Alagoinhas	12° 8′ S, 38° 26′ W	1942-1966	C_1A' d a′
7.	Quixeramobim	5° 12′ S, 39° 18′ W	1925-1963	D A′ d a′
8.	Remanso	9° 41′ S, 42° 4′ W	1925-1955	E A′ d a′
9.	Natal	5° 46′ S, 35° 12′ W	1925-1970	C_1 A′ s a′
10.	Anadia	9° 38′ S, 36° 20′ W	1928-1960	C_1 A′ d a′
11.	Iguatu	6° 22′ S, 39° 18′ W	1925-1972	D A′ d a′
12.	Terezina	5° 5′ S, 42° 49′ W	1925-1957	C_1 A′ w a′
13.	Quixada	4° 58′ S, 39° 1′ W	1925-1950	D A′ d a′
14.	João Pessoa	7° 7′ S, 34° 53′ W	1925-1954	C_2 A′ s_2 a′
15.	Campina Grande	7° 13′ S, 35° 53′ W	1925-1956	D B_4' d a′

*According to Thornthwaite and Mather (1955).

and Mather 1955) which enables a quantitative assessment of water deficiency has found wide application in drought climatology. Water deficiency is an absolute quantity and cannot by itself provide an idea of the extent of water scarcity unless it is compared with the region's water need. Hence the aridity index developed by Thornthwaite (Thornthwaite 1948) which is the ratio of the annual water deficiency to the annual potential evapotranspiration (or water need) can be of much use in the study of drought situations (Sarma 1974, Subrahmanyam *et al.* 1965).

Yearly water balances for 15 stations in northeast Brazil are evaluated based on the procedure of Thornthwaite and Mather (1955). From the monthly mean temperatures monthly heat indices are obtained the sum of which gives the annual heat index at the station. Using the annual heat index and the monthly temperatures the unadjusted daily potential evapotranspiration values are derived. Application of a correction factor, depending on the latitude of the station and month of the year, yields the monthly potential evapotranspiration values. These are used together with the monthly precipitation values to compute the water balances at the stations.

At each station yearly values of aridity index, (I_a), humidity index (I_h) and the moisture index (I_m) have been worked out.

Expressed as percentages these indices are given by :

$$I_a = \frac{100d}{PE} \quad (1)$$

$$I_h = \frac{100s}{PE} \quad (2)$$

$$I_m = I_h - I_a \quad (3)$$

where, PE is the annual potential evapotranspiration and s and d are the annual water surplus and annual water deficiency respectively.

Percentage departures of the yearly aridity index from the median value are obtained and drought years are then classified as of moderate, large, severe or

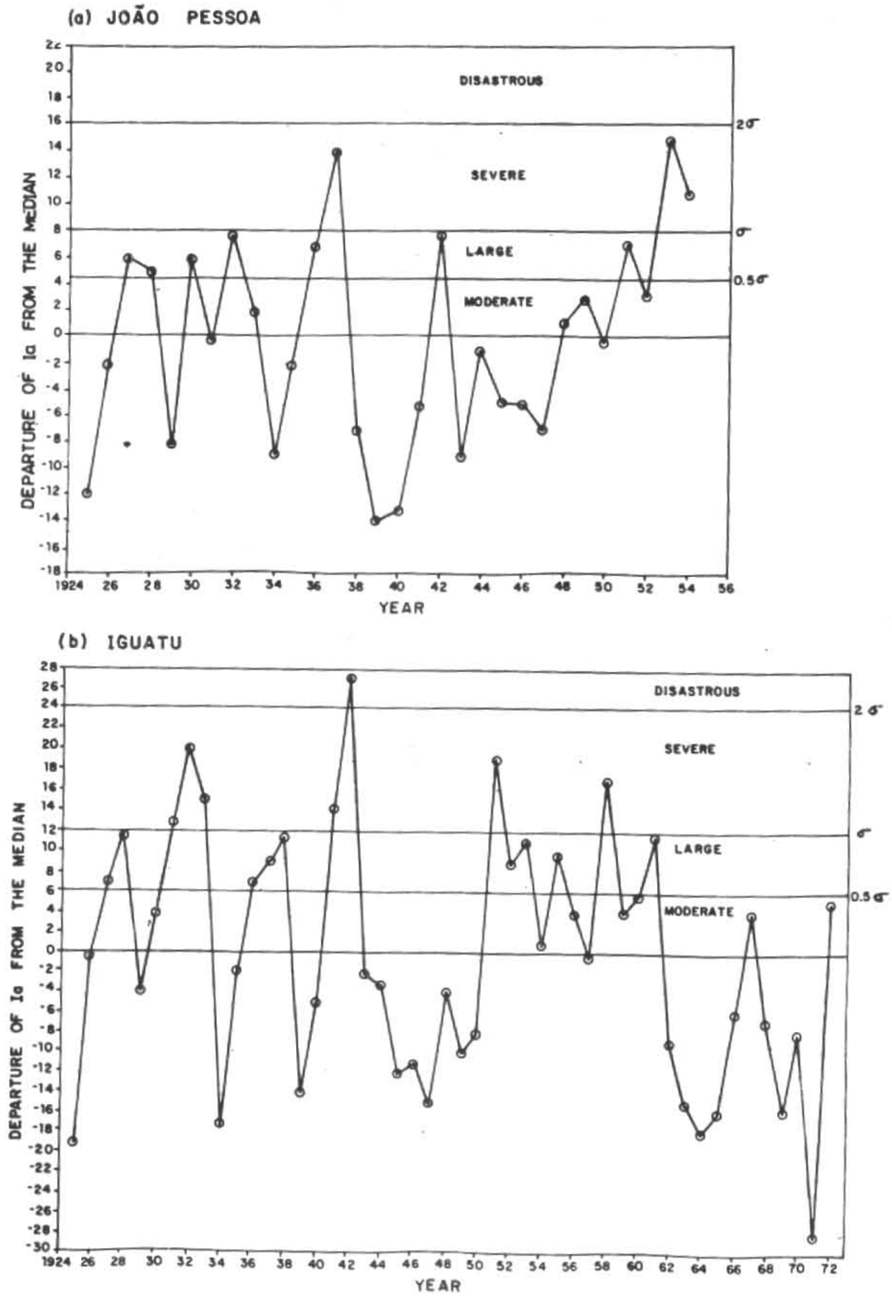

Fig. 1. March of the aridity index

disastrous intensity according as the departures of the aridity index from the median ranged between 0 and 1/2σ, 1/2σ and σ, σ and 2σ and more than 2σ where σ is the standard deviation of aridity index for the period of study. (Subrahmanyam and Subramanyam 1964).

Geographical locations, periods of study and climatic formulae of the stations are given in Table 1.

3. Results and discussion

March of the aridity index and the occurrence of droughts at two stations are shown in Fig.1. Incidence of droughts of different categories at the selected stations is presented in Table 2. Fig. 2 depicts the incidence of various types of droughts at some stations in different periods of time.

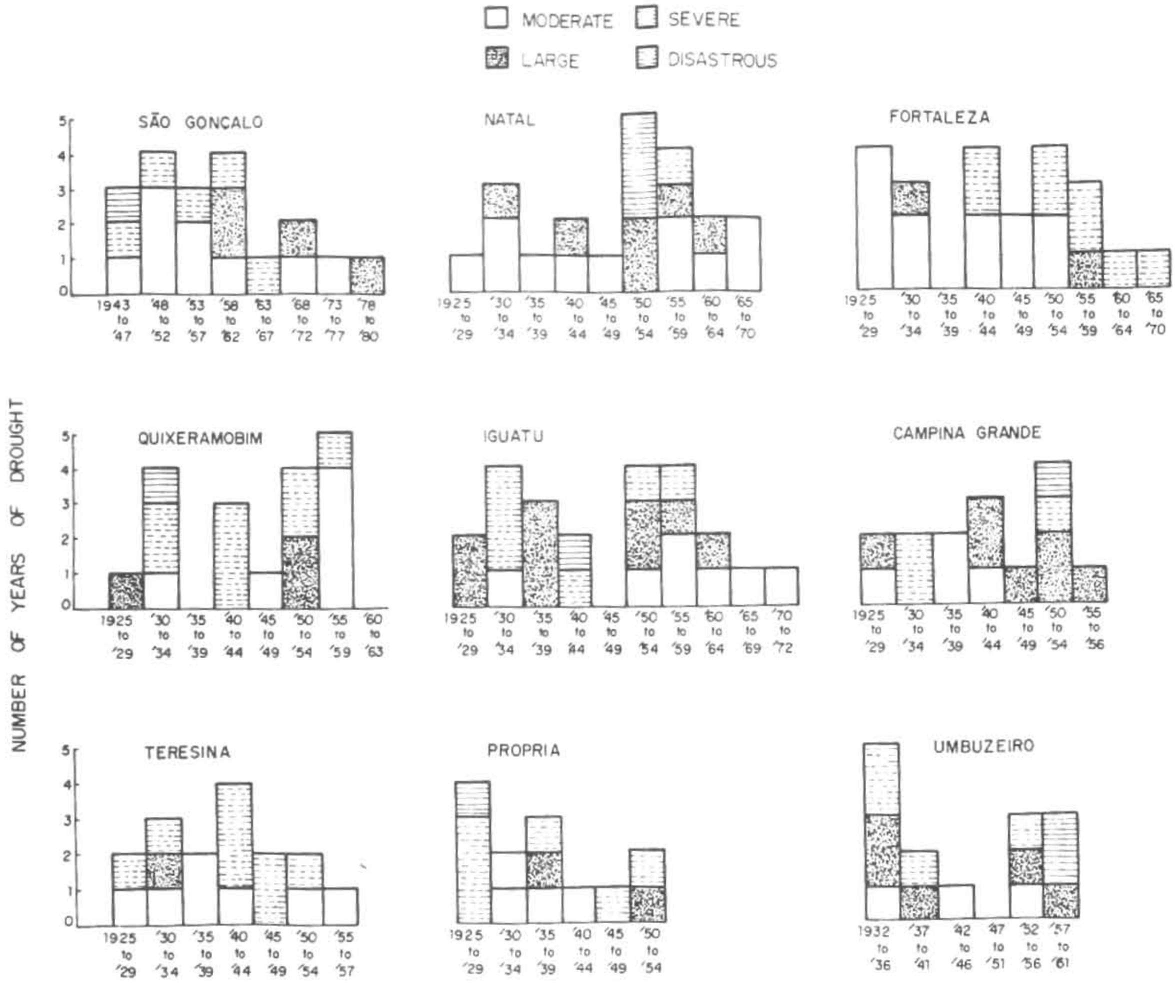

Fig. 2. Frequency of drought years

TABLE 2

Incidence of droughts at the selected stations

S.No.	Station	Period of study (years)	Drought category			
			Moderate	Large	Severe	Disastrous
1.	João Pessoa	30	4	7	3	-
2.	Teresina	33	7	1	8	-
3.	Natal	46	11	6	1	3
4.	Tapacura	25	4	4	4	-
5.	Alagoinhas	25	4	4	2	2
6.	Fortaleza	46	12	2	8	-
7.	Anadia	33	6	4	3	-
8.	Umbuzeiro	30	3	5	4	2
9.	Propria	27	3	2	7	1
10.	Iguatu	48	7	9	6	1
11.	Quixeramobim	39	6	3	8	1
12.	São Goncalo	38	9	4	5	1
13.	Quixada	26	6	2	4	1
14.	Remanso	31	7	5	3	-
15.	Compina Grande	32	4	7	3	1

TABLE 3

Water balance parameters at some stations in northeast Brazil

Year	PE (mm)	P (mm)	Water deficit (mm)	Aridity index (%)	Drought category
			Teresina		
Normal year	1678	1326	783	47	—
1926	1674	1239	1101	66	Severe
1937	1665	1074	809	49	No drought
			Anadia		
Normal year	1277	1200	287	22	—
1937	1266	1124	458	36	Severe
1955	1242	949	284	23	No drought
			Fortaleza		
Normal year	1631	1303	686	42	—
1957	1630	1160	947	58	Severe
1930	1586	1003	737	46	No drought
			Alagoinhas		
Normal year	1332	1201	185	14	—
1951	1308	1134	458	35	Severe
1957	1319	1001	178	13	No drought
			Tapacura		
Normal year	1269	1329	277	22	—
1958	1319	1443	508	39	Severe
1946	1282	1281	298	23	No drought
			Natal		
Normal year	1547	1492	473	31	—
1950	1556	883	725	47	Large
1951	1545	906	898	58	Disastrous

Often precipitation is used as the sole parameter in studies on drought climatology of arid and semi-arid regions. However, precise analysis of drought requires a comparison between precipitation and the water need of a region. Data presented in Table 3 more than amply proves that drought intensities cannot be assessed on the basis of precipitation records alone.

Teresina received in 1937 rainfall much less than in 1926. However water deficit in 1926 is nearly 300 mm higher than in 1937 and as a consequence Teresina experienced no drought in 1937 and drought of the third degree (severe) in 1926.

In Fig. 3 are shown the water balances at Alagoinhas for the years 1951 and 1957. The potential evapotranspiration (PE) values in these two years are nearly the same being 1308 and 1319 mm respectively. In 1957 the precipitation (1001 mm) was lower than in 1951 (1134 m). However, the water deficit in 1957 was 178 mm while in 1951 it was much higher, being 458 mm. As a result Alagoinhas experienced drought of the third degree (severe) in 1951 and no drought in 1957.

The PE values at Anadia in 1937 and 1955 are 1266 mm and 1242 mm respectively. Precipitation

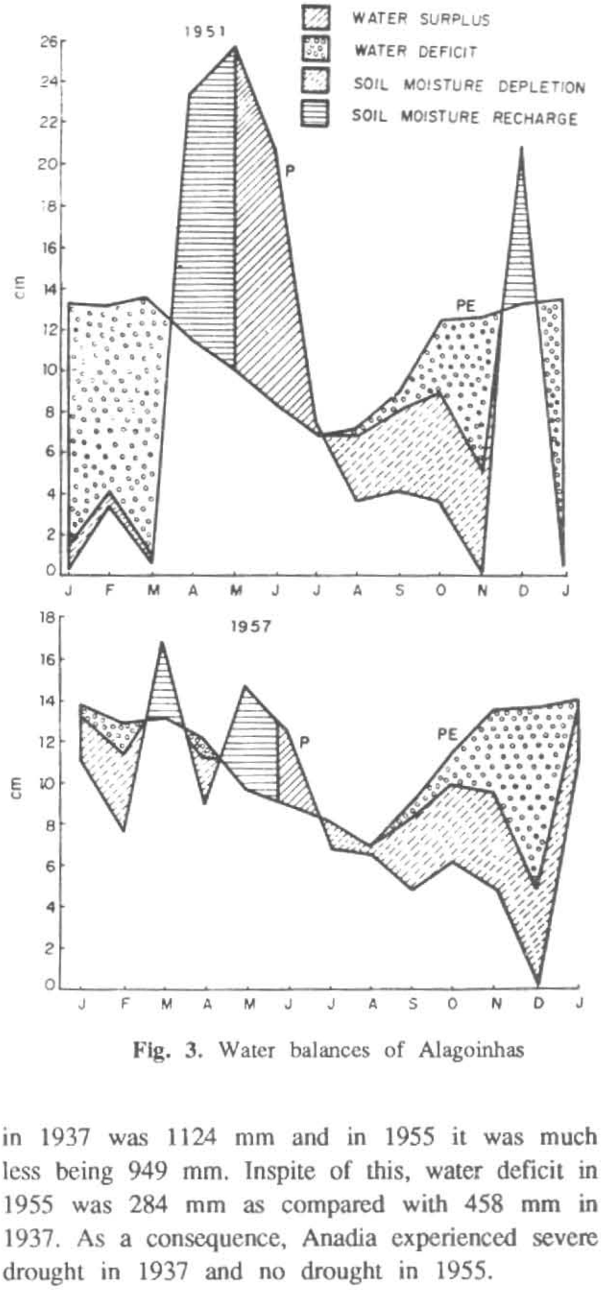

Fig. 3. Water balances of Alagoinhas

in 1937 was 1124 mm and in 1955 it was much less being 949 mm. Inspite of this, water deficit in 1955 was 284 mm as compared with 458 mm in 1937. As a consequence, Anadia experienced severe drought in 1937 and no drought in 1955.

This kind of situation, obviously due to the maldistribution of precipitation during the year, results in wrong assessment of drought intensities at a station when the analysis is based on precipitation values alone.

Conditions responsible for aridity variations naturally produce pronounced variations in the moisture regime of the climate too. In recent times much attention is being paid to the so called "Climatic shifts". At certain stations there would be occassional departures of the annual water balance of such a high magnitude that the very climatic type of the station would be shifted by one or more steps towards the drier or wetter direction. Such climatic shifts, though temporary, are of significance in the assessment of the climatological potentialities of a region for development.

Climatic shifts at four stations are shown in Fig. 4 and shifts at all the stations are summarized in Table 4. The climates of Quixada, Propria, Iguatu, Campina Grande, Quixeramobim and São Goncalo appear rather conservative being most of the time in the respective normal climatic regimes. Violent and frequent year-to-year fluctuations in the moisture index and consequent shifts towards the wetter or drier direction are observed at the remaining elght stations. This is as it should be since these stations belong to the so called borderline climatic type, namely the sub-humid type.

An interesting point observed is that Teresina experienced semi-arid climatic conditions in 14 years and dry sub-humid conditions in only 9 years even though the normal climatic regime of the station is the dry sub-humid category.

In 1950, PE at Teresina (1645 mm) was less than the climatic figure of 1678 mm while its precipitation (3014 mm) was more than double the normal yearly value of 1326 mm. As a result, the water balance of Teresina jumped into the fourth humid (B_4) type, its moisture index having risen to 83%. In 1932 and 1944 PE at this station is slightly higher than the normal climatic value and the low precipitation received, 508 and 506 mm respectively caused the moisture climate of the station to shift into the arid type.

Stations with such sub-humid climates are said to possess critical water balances and it is in such regions that serious efforts are needed for combating droughts and to conserve the meager water resources in times of excess precipitation for use in the subsequent dry spells.

An interesting point noticed is that there need not always be a strict correlation between the magnitude of the shift in the drier direction and the drought intensity at the station. The reason for this is that moisture regime depends upon the annual values of water surplus, water deficit and PE while the drought as defined in the present analysis depends on the deviation of the aridity index from the median value.

Liability of a region to droughts of varying intensities is an important aspect of drought climatology.

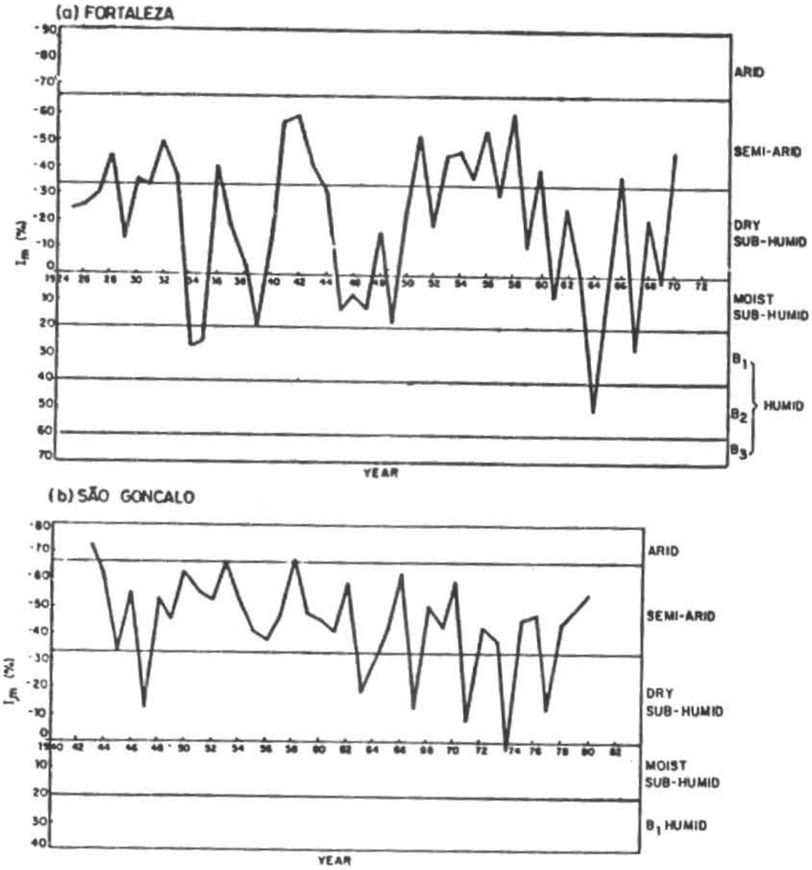

Fig. 4. Climatic shifts

TABLE 4

Climatic shifts in northeast Brazil

Station	Number of shifts to Perhumid	Humid				Sub Humid		Semi-arid	Arid
	A	B_4	B_3	B_2	B_1	Moist C_2	Dry C_1	D	E
Quixada	-	-	-	-	-	-	2	19	5
Propria	-	-	-	-	-	-	7	19	1
Fortaleza	-	-	-	1	4	8	16	17	-
Anadia	-	-	-	-	4	7	21	1	-
Remanso	-	-	-	-	-	-	-	12	19
Iguatu	-	-	-	-	-	-	7	30	11
Umbuzeiro	-	-	-	1	-	-	15	13	1
Campina Grande	-	-	-	-	-	1	8	22	1
Quixeramobim	-	-	-	-	-	-	1	26	12
São Goncalo						1	7	28	2
Tapacura	-	-	-	-	3	13	9	-	-
Teresina		1	2	1	-	4	9	14	2
Natal	-	1	-	1	8	10	20	6	-
Alagoinhas	-	-	1	2	1	4	13	4	-
João Pessoa	-	1	-	3	6	13	6	1	-

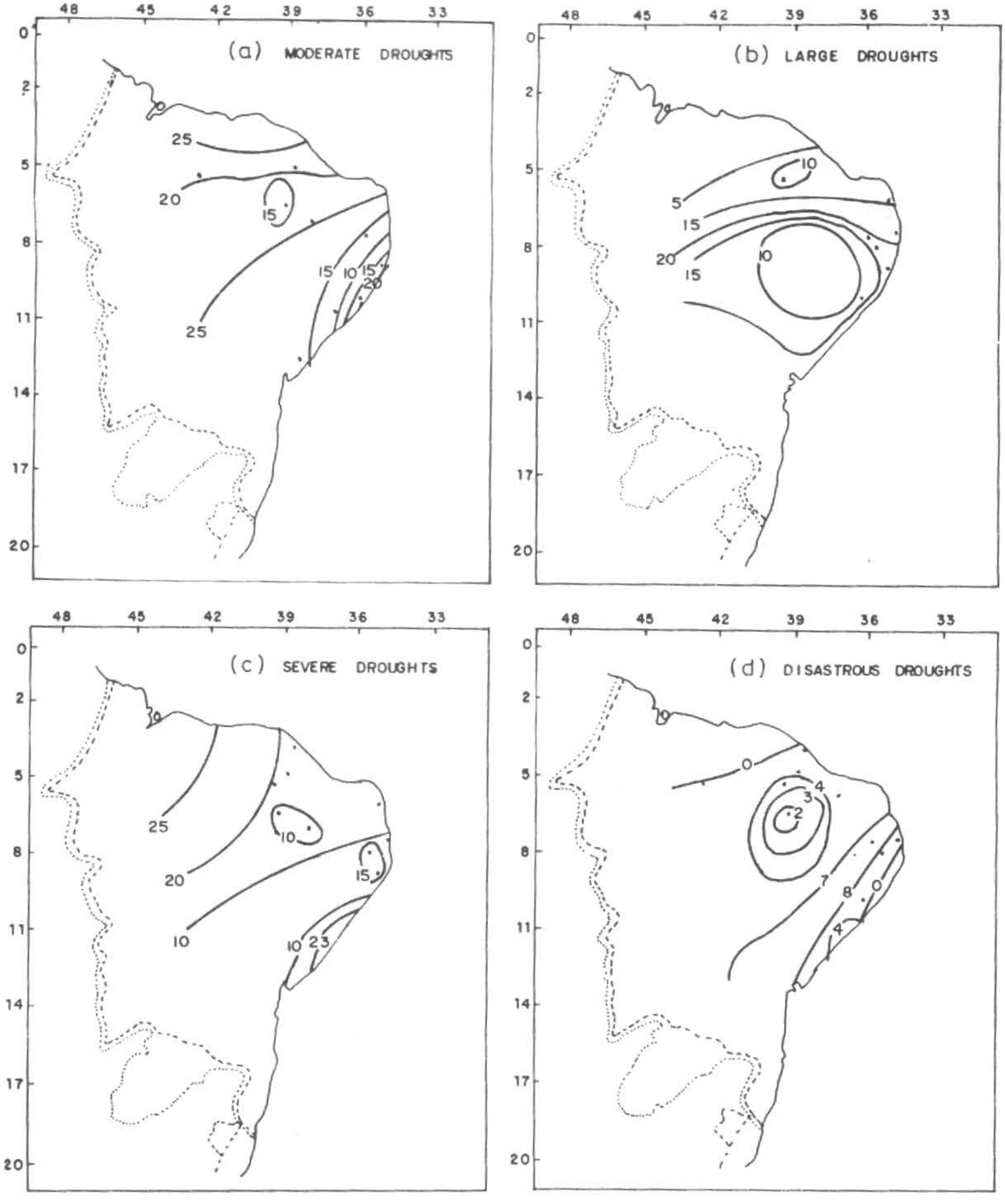

Fig. 5. Proneness of droughts in northeast Brazil

For the sake of simplicity, in the present study, the percentage number of drought years of different categories moderate, large, severe and disastrous for the entire periods of study has been employed as the criterion for the liability or proneness of the station to droughts of the corresponding category. Diagrams showing the proneness of northeast Brazil to droughts of the four categories are presented in Fig. 5.

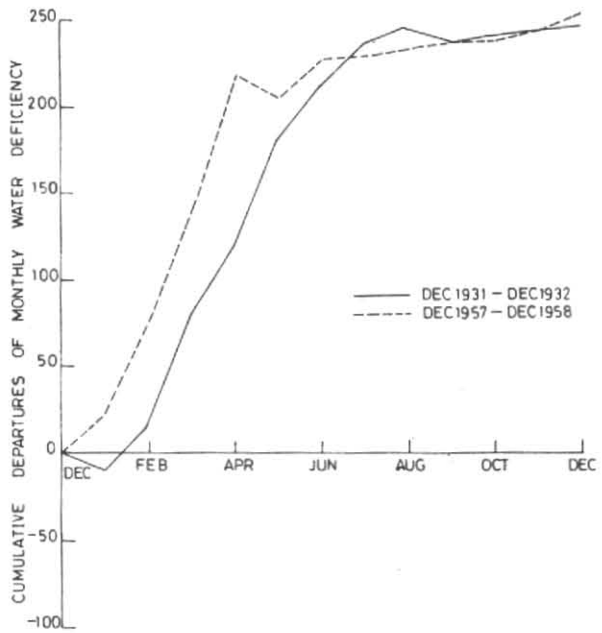

Fig. 6. Cumulative deviation curves at Quixeramobim

The duration of a drought spell is as important as its intensity since both of them together determine the ultimate effect of water shortage on the economic situation. Following the technique of cumulative deviations of the water deficit the duration and intensity aspects of droughts may be studied.

Since the water deficiency by itself has no meaningful significance, monthly water deficiency deviations from the climatic normal are taken and expressed as ratios of the normal annual water need in units of thousands. These units are then accumulated from an arbitrary origin (zero) and plotted against months as was done by Foley using rainfall deviations (Foley 1957). The core of the drought is then indicated by the steepest rise of the curve, the gradient of which gives the severity of drought during the period under study.

Cumulative deviation diagrams for Quixeramobim for the years 1932 and 1958 are shown in Fig. 6. On the basis of annual values of water deficit and PE Quixeramobim experienced in these two years disastrous and severe droughts respectively.

In Fig. 6 the core of the drought periods are indicated by the steepest rise of the mass curves. In 1958 the drought severity index (DSI) is 66 for the three month period January-April. In 1932 DSI is 55 for the three month period February-May. Since for the same duration the DSI in 1958 is greater than in 1932 the drought of 1958 must be considered much more severe from the economic point of view than the drought of 1932. This result contradicts the earlier conclusion based on annual values of water deficit and PE.

Occasionally it may happen that the DSI at a station may be higher and the core of the drought spell shorter in duration than in another year. In this context the crucial question to the answered is whether a brief duration of drought with intense severity or a prolonged one with mild severity has the greater impact on the economic situation. The need for detailed agricultural statistics in such studies is obvious.

4. Conclusion

Most of the earlier studies on droughts in northeast Brazil are based on rainfall data alone. The present study suggests that rainfall data by itself may not be sufficient to provide correct information concerning the drought intensities in the region. Climatic shifts observed at the stations indicate the unstable character of the moisture regime in northeast Brazil. This aspect also suggests that the climate of a station evaluated using longterm mean climatic data may sometimes be of little significance. The uneven distribution of rainfall during the year may result in a drought situation at a station even though the rainfall in that year may be nearly the same or even greater than the climatic mean value.

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