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Extension of the Thar desert — A myth or reality ? : Part I — Analysis of rainfall

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सार — थार मरुभूमि के विस्तार के संबंध में हाल में दिए गए परस्पर विरोधी वक्तव्यों को देखते हुए, इस समस्या का मौसम विज्ञान की दृष्टि से परीक्षण किया गया है। इस कार्य के लिए 30 तथा 50 सें. मी. के अंतर्गत वार्षिक समवर्षा रेखा वाले स्टेशनों पर मौसम विज्ञान के तत्वों का विस्तृत गहन सांख्यिकीय परीक्षण किया गया है। इस विश्लेषण में 1901 से 1980 तक के 80 वर्षों के आंकड़ों का प्रयोग किया गया है। इस भाग में वर्षा के अतिरिक्त, जलवायु संबंधी जल संतुलन से मरुभूमि में बढ़ोतरी का भी अध्ययन किया गया है।

अध्ययन से पता चलता है कि 30 और 50 से. मी. समवर्षा रेखा के बीच बफर क्षेत्र में क्रमबद्ध रूप में घटने की प्रवृति नहीं है। थार मरुभूमि के समीप, जलवायु संबंधी जल संतुलन के अध्ययन से भी इस बात का समर्थन नहीं होता कि थार मरुभूमि के आस पास जलवायु में परिवर्तन होने जा रहा है। इस प्रकार वर्षा तथा जल संतुलन से यह कहा जा सकता है कि थार मरुभूमि का आगे बढ़ना या उसमें विस्तार होना वास्तविकता नहीं है।

ABSTRACT. In view of recent contradictory statements about the extension of the Thar desert, this problem has been examined from meteorological point of view. For this purpose meteorological elements for stations located within 30 and 50 cm annual isohyets have been subjected to vigorous statistical tests. Eighty years data (1901-1980) have been used in the analysis. In this part, besides rainfall, the march of the desert has also been studied from climatic water balance.

The study reveals that, the rainfall in the buffer zone between 30 and 50 cm isohyets is not experiencing any systematic decreasing trend. Study of climatic water balance also does not support the view of any climatic shifts, taking place around the Thar desert. Thus, from the rainfall and the water balance considerations, it can be safely said that the so called onward march of the Thar desert is not a reality.

1. Introduction

There has been a fairly widespread conception that the Thar desert is advancing and encroaching upon the adjoining fertile lands. The Planning Commission in the first Five-Year Plan observed that the great Indian desert of Rajasthan is spreading outward in a convex arc at the rate of about ½ a mile (0.8 km) per year and is engulfing approximately 50 sq. miles (140 sq. km) of fertile land every year. This view had been widely held by the public, both lay and informed, but not by the scientific community as a whole. Various biological, climatological and archeological evidences do not unanimously and conclusively support or reject this hypothesis. As early as 1948, Pithawalla (1948) refuted the expansion theory. Gorrie (1950) also maintained that land adjoining the desert is not being engulfed by sand. On the other hand, Banerjee (1952) contended that, there has been a decrease in rainfall and increase in temperature in the region. In recent years the possibility of desert march has been qualitatively analysed by Mann *et al.* (1974) by studying the land use pattern, water availability and crop yield. They observed, at least tentatively, that factors considered do not support the desert spread theory. The only scientific treatment to end the controversy appear to be to have a detailed analysis of the parameters characteristics of the desert conditions. Such an attempt has been made in the present study.

It has been demonstrated by various workers that, the sand dunes stabilise only when the yearly rainfall exceeds 30 cm, because this rainfall amount favours growth of vegetation over the dunes. Satellite imageries have confirmed that active sand dunes are normally confined to the west of 30 cm isohyet. Over long period of time, it implies that once the sand dunes form, they would start drifting more actively if the rainfall continue to be less than 30 cm. The dunes, when the rainfall exceeds 30 cm, tend to stabilize itself, the soil formation occurs and the vegetation starts growing (Agarwal and Misra 1983).

It is for this purpose, the border zone between the isohyets of 30 and 50 cm annual rainfall within the Indian part of the Thar desert was selected for the study.

2. Data set

Based on normal rainfall prepared by India Meteorological Department (1950), annual rainfall of all stations (observatory and state raingauge) in and around the Thar desert was plotted and analysed. From the analysis, area contained in 30 cm isohyet was demarcated. This was taken as the desert. Stations lying within 30 cm and 50 cm isohyets were then selected for a detailed analysis (Fig. 1). Since areas having low mean rainfall, high variability, large amplitude of diurnal temperature and strong surface wind characterise an arid zone, if the Thar desert is really advancing, the meteorological conditions in this corridor zone should show the following tendencies :

(*i*) decrease in rainfall, relative humidity and minimum temperature,

(*ii*) increase in the aridity,

(*iii*) increase in the maximum temperature, daily temperature range and the wind speed,

(*iv*) increase in standstorm incidence.

Under rainfed conditions desertification represents complex, diverse processes and trends that reduce the soil moisture contents and its limits biological productivity. March of desertification can also be gauged by quantifying the aridity. The annual aridity index computed as per Thornthwaite and Mather (1955) technique has been examined in relation to desert spread.

In this part attention is concentrated to find out possible extension of desert from the annual rainfall and aridity points of view. It is proposed to approach to this problem through an analysis of other meteorological parameters (*e.g.*, humidity, temperature, wind and duststorms) and the crop yield in the next part of the study.

Rainfall data of 6 observatory stations, *viz.*, Jodhpur, Pilani, Churu, Nagaur, Bhuj and Dwarka for the period 1901 to 1980 have been used. This was supplemented by available data from 1901-1970 in respect of 13 raingauge stations, *i.e.*, Jodhpur (Sangrur), Siwana, Jhunjhunu, Tharad, Rahapur, Nohar, Pali, Didwana, Hissar, Sachor, Sirsa, Barmer and Naliya. For the sake of aridity anomaly, rainfall data of all the observatories for 1951-1980 and data of state raingauge stations from 1951-1970 have been utilised.

3. Results and discussion

3.1. *Comparison of mean*

One of the methods to find if there is any trend in any two time intervals is to test if the mean for the period differ significantly. The period 1901-1980 has been split into 1901-1950 and 1951-1980 for this purpose, for those stations for which data upto 1980 were available. In case of locations having rainfall records upto 1970 the means tested are for 1901-1950 and 1951-1970 series. If $\overline{X}_1$ and σ_1, are the mean annual rainfall and

Fig. 1. Locator map

standard deviation of the first period which has size n_1 and $\overline{X}_2$, σ_2 and n_2 are the corresponding quantities for the second series, then it can be shown that

$$t = \frac{\overline{X}_1 - \overline{X}_2}{s} \left\{ \frac{n_1 \cdot n_2}{n_1 + n_2} \right\}^{1/2} \quad \text{where,}$$

$$s = \left\{ \frac{(n_1 - 1)\,\sigma_1^2 + (n_2 - 1)\,\sigma_2^2}{n_1 + n_2 - 2} \right\}$$

is distributed as student's 't' with ($n_1 + n_2 - 2$) degrees of freedom.

For none of the stations 't' is significant at 1% or even at 5% level, suggesting that the post-1950 mean rainfall is not significantly different from 1901-1950 rainfall.

Nearly all stations revealed an increasing tendency in 1951-1980 period compared to the reference period of 1901-1950. The increase were conspicuously large at Dwarka, Barmer and Naliya and were 30, 34 and 31% and 10 cm, 6.5 cm and 9 cm in absolute terms. Only two stations, *viz.*, Tharad and Nohar revealed a decreasing trend, *albeit* small, in the 1951-1980 period, the decrease being 7.0 cm and 2.3 cm respectively, and these amounts were 14% and 10% of the normal.

Similarly when the mean for 1901-1950 were compared with 1961-1970 or 1961-1980, depending upon the availability of data, the means were generally not found significant. It is seen that means for 1961-1980 (or 1961-1970) and 1971-1980 do not show any substantially marked difference with 1901-1950 mean except at Nagaur wherein 1971-1980, the mean was significantly large.

Thus not only in post-1950 period was rainfall not different from 1901-1950, even the means for one decade or two decades in post-1950 period, were not different.

3.2. *Comparison of mean for sub-periods : Another approach*

Mean for two different periods can also be compared by another method. It is, however, essential that for such a comparison, same set of stations should be used. Since only for 6 stations, data upto 1980 were available, rainfall data upto only 1970 for all the 19 stations have been considered in this approach. The comparison is given in Table 1 between mean annual rainfall for 1901-1950 and 1951-1970.

The average difference between these two period means taking sign into account was 2.4 cm while the average numerical value of the difference was 3.6 cm. Half of the differences were less than 2.5 cm. The number of negative differences were 6, 5 of which were between 0.1 and 2.5 cm.

The difference in rainfall in the two period can, therefore, be taken as small. In fact, rainfall during 1951-1970 is found unmistakeably more than the normal (1901-1950) for 70% of the stations under consideration. The remaining stations which showed a decline, the decrease is almost negligible.

3.3. *Changes in rainfall*

The above analysis for the "block periods" after 1950 suggest that the desertic conditions did not spread in the neighbouring areas. A more detailed look at this not-so-surprising result is made through a study of decadal rainfall.

Departures of 10 years mean of annual rainfall for selected stations are shown in Fig. 2. There appear to be some uniformity in trend at least in the post-1950 period at most of the stations. While between 1901 and 1950 both positive departures and negative departures occurred in almost equal numbers, after 1950, on the other hand experienced more positive departures than the negative departures.

The highest and lowest decadal averages are also shown in Table 2. As against 9 stations which had the highest decadal average in the period subsequent to 1950, only 4 stations were found to record the lowest decadal average in the corresponding period. Out of the six stations for which the data upto 1980 were examined, 3 recorded the highest average in the 1971-1980 decade. The increase in rainfall in these 3 stations, from the lowest in pre-1950 to the highest in 1971-1980 decade was 31% at Jodhpur, 37% in Pilani and as large as 52% in Nagaur. It is possible that the 13 stations (which had data upto 1970 only) had data upto 1980, a few of them would have also registered the highest in the 1971-1980 decade. The 6 stations recording peak in post-1950 period, the increase from the lowest to the highest ranged from about 22% at Pali to 86% at Naliya. The absolute amount of increase in rainfall varied from lowest at Pali (9.3 cm) to highest at Dwarka (21.7 cm).

TABLE 1

Comparison of 1901-1950 and 1951-1970 mean rainfall

Numerical diff. (cm)	Frequency	Numerical diff. as % of mean for 1901-1950	Frequency
0.1-2.0	8	0.1-5.0	8
2.1-4.0	5	5.1-10.0	4
4.1-6.0	1	10.1-15.0	2
6.1-8.0	3	15.1-20.0	2
>8.0	2	>20.0	3

TABLE 2

Changes in rainfall

Station	Highest decadal average (cm)	Decade	% of the 1901-50 normal	Lowest dacadal average (cm)	Decade	% of the 1901-50 normal
Jodhpur	44.1	1971-80	20	33.8	1901-10	—8
Churu	43.6	1941-50	21	31.1	1931-40	—13
Nagaur	43.8	1971-80	41	28.9	1931-40	—7
Pilani	50.9	1971-80	24	37.3	1951-60	—9
Bhuj	40.9	1951-60	20	27.1	1931-40	—20
Dwarka	53.7	1961-70	50	32.0	1921-30	—11
Jodhpur (Sangrur)	39.2	1901-10	11	33.2	1921-30	—7
Siwana	41.2	1921-30	21	28.8	1941-50	—15
Jhunjhunu	45.9	1951-60	19	36.2	1901-10	—6
Tharad	60.2	1921-30	19	40.5	1961-70	—20
Rahapur	47.7	1951-60	35	33.4	1961-70	—5
Nohar	35.2	1941-50	21	24.4	1921-30	—16
Pali	46.8	1951-60	14	37.5	1921-30	—9
Didwana	41.1	1911-20	15	31.8	1931-40	—11
Hissar	43.2	1941-50	6	36.3	1931-40	—11
Sachor	41.4	1941-50	9	34.8	1931-40	—9
Sirsa	39.5	1931-40	23	27.9	1961-70	—13
Barmer	34.7	1941-50	80	10.1	1901-10	—48
Naliya	42.3	1951-60	44	22.7	1921-30	—23

In the 1931-1940, at as many as 6 stations the largest negative departures occurred, followed by 5 in 1921-1930.

On the basis of this analysis also, it may be stated that the changes in rainfall do not reveal a uniform decreasing tendency in recent years. On the contrary, results give enough indication that the rainfall, has generally increased.

3.4. *Secular variation*

Two classical tests of randomness against trend are normally performed in order to detect any trend in a time series. These are : Mann-Kendall ranking statistics and Spearman-Rank test, the null hypothesis being

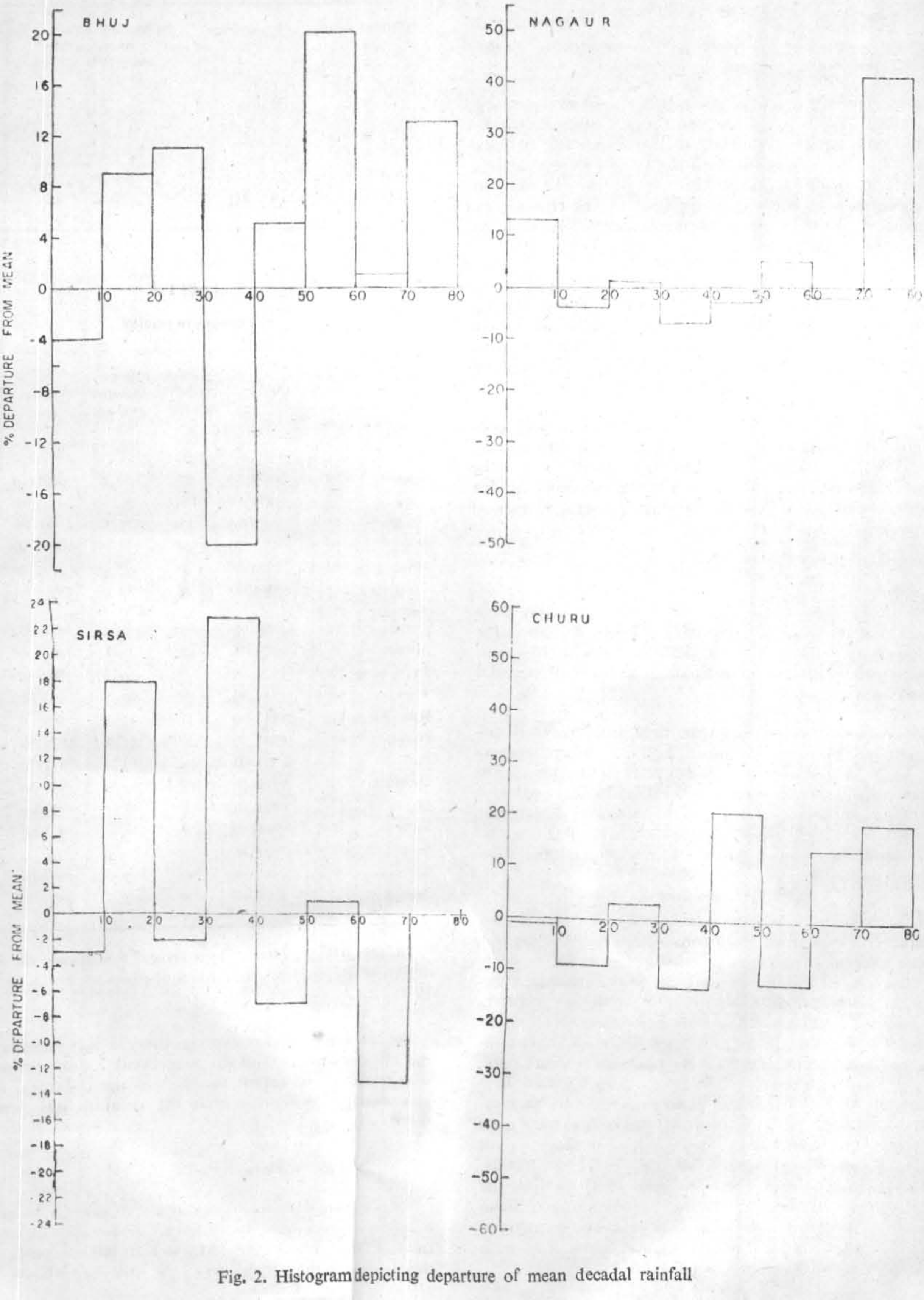

Fig. 2. Histogram depicting departure of mean decadal rainfall

no trend. The rainfall for the period available was subjected to these analysis to find out if rainfall is really showing a declining trend. The results are discussed below :

(a) Mann-Kendall statistics

This is one of the well recognised method to examine trend in a data series. Accordingly if,

$$P = \sum_{i=1}^{n-1} n_i$$

$$\gamma = \frac{4P}{n(n-1)} - 1 \quad \text{and}$$

$$\gamma(t) = \pm t_g \left\{ \frac{4n+10}{9n(n-1)} \right\}^{1/2}$$

where n_i are the number of later terms whose value exceed n_i (the element) or k_i (the rank) and t_g is the desired level of probability. None of the values are found significant.

(b) Spearman's coefficient

Spearman's coefficient of rank correlation was also used to test trend in rainfall. Unlike Pearson's coefficient usually used at lag one, it is sensitive to various types of trend. The coefficient is given by,

$$\gamma_s = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{n(n^2-1)} \quad \text{where,}$$

$$d_i = k_i - i$$

k_i is the rank of the element.

The coefficient is tested by computing,

$$t = \gamma_s \left(\frac{n-2}{1-\gamma_s^2} \right)^{1/2}$$

and comparing with γ_s

In this case also none of the values are found significant for a two tailed test, though the stations behaved differently with respect of secular variation in rainfall. Assuming γ_s values less than 0.15 to represent slight degree of trend, Bhuj, Dwarka, Siwana, Jhunjhunu, Tharad, Pali, Didwana and Naliya appear to be nearly stationary in a rainfall sense. On the other hand Jodhpur, Churu, Nagaur, Pilani, Jodhpur (Sangrur), Nohar and Hissar appear to be experiencing an upward trend in rainfall. Only Sachor, Sirsa and Barmer show somewhat decreasing trend, none of them, however, being satistically significant.

(c) The correlograms

For each of the 19 stations, for which data at least upto 1970 were available, serial correlation coefficients were calculated upto a maximum lag of 10 years. The persistence of rainfall would be indicated by the high

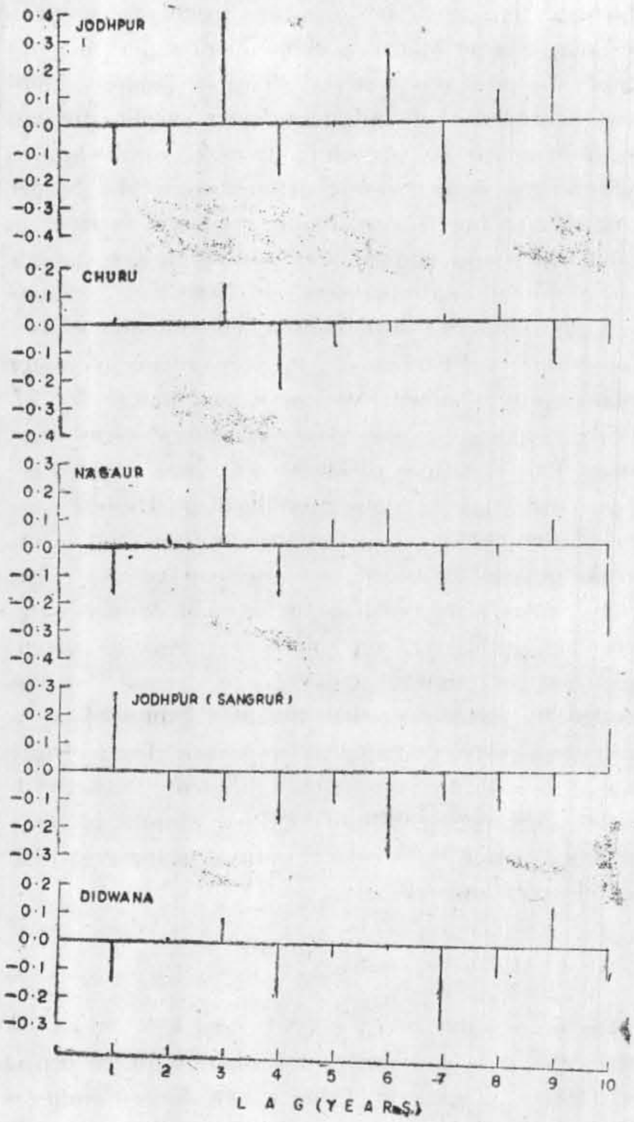

Fig. 3. Correlogram for the annual rainfall time series

values of auto-correlation. The correlograms shown for some selected stations are in Fig. 3. The analysis revealed that the rainfall at each of the stations is complex, containing a number of super-imposed oscillations of different length. Without exception the rainfall series do not have correlograms which are significant or reach 95% or 99% confidence level.

These results clearly show that none of the stations in the area bordering the Thar desert behave differently with respect to secular variation in rainfall. They do not reveal presence of any trend or cycles at any of the stations.

3.5. *The climatic water balance approach*

Any physically sound discussion of the meteorological conditions of the apparent or real fluctuations of margins of continental desert should take into account the water budget. A study of climatic water balance is interesting since in the semi-arid region, water balance reportedly fluctuate frequently and violently from year to year, so that even in moderate climatic situations, extreme aridity due to severe water shortage or humid conditions arising out of enormous water surplus are not uncommon. It is, therefore, thought worthwhile to examine the water balance at stations in the border zone to find out if there is any persistent increase in water deficit and aridity. For this purpose, 6 stations having rainfall and other data upto 1980 and 7 stations with data upto 1970 were chosen. The potential evapotranspiration (PE) one of the constituents of water balance, was obtained from the works of Rao *et al.* (1971). For stations not having PE values, linear interpolation with stations of known PE, was resorted to. Using the book keeping procedure of Thornthwaite and Mather (1955), the water balance from 1901 to the period of availability of data, was worked out. The aridity index I_a (defined as the ratio of annual water deficiency to the total water need, expressed as percentage) and the humidity index I_h, *i.e.*, water surplus divided by the water need and also expressed as a percentage, were computed for each year. The moisture index I_m was then computed as a difference between I_h and I_a. The period 1901 to 1950 was considered as a reference period with which indices in the post-1950 period were compared.

3.5.1. *March of aridity*

The mean value of I_a, it's S.D. and C.V. based on 1901-1950 data and similar information for the period 1951-1980 are given in Table 3. The largest aridity is observed for both the periods at Bhuj and it is 83.7 and 83.8. Churu recorded the lowest aridity (*i.e.*, 75.9) in 1901-1950 period but in the post-1950 period the lowest aridity, *i.e.*, 74.2 is observed at Pilani. The S.D. and C.V. values are quite low in the 1901-1950, the highest figures being 2.5 and 3.0 respectively recorded at Bhuj. Surprisingly in the post-1950 period, the S.D. and C.V. are extremely small and do not exceed even 0.5. Also a comparison between the two means shows that except at Churu where the aridity has increased in 1951-1980 period, none of the stations revealed any significant increase.

For selected stations, yearly values of I_a are graphically represented in Fig. 4. In nearly all the cases studied aridity after 1950 was found to be lower than the normal. In Churu, the departures of I_a were positive for all years from 1951-1980, though these were lower than the standard deviation for the station. At Nagaur in both periods the aridity was nearly identical. Surprisingly after 1974, the yearly aridity departures were negative at Nagaur.

TABLE 3

Comparison of mean aridity between 1901-50 and 1951-80

Station	Aridity during 1901-50			Aridity during 1951-80		
	Mean	S.D.	C.V. (%)	Mean	S.D.	C.V. (%)
Jodhpur	83.2	1.8	2.2	81.8	0.2	0.2
Bhuj	83.7	2.5	3.0	83.8	0.2	0.2
Dwarka	83.0	2.3	2.8	81.5	0.4	0.5
Churu	75.9	1.9	2.5	77.0	0.2	0.3
Nagaur	82.8	1.5	1.8	82.8	0.3	0.4
Pilani	76.1	1.9	2.5	74.2	0.3	0.4

3.5.2. *Climatic shifts*

Yearly variation of moisture index for a few locations is also shown in Fig. 4. Pattern of moisture regime at nearly all the stations was nearly similar. At most of the stations the moisture index did not decrease during 1951-1980 as compared to the normal for 1901-1950. The climatic fluctuations are summarised for the period 1951-1980 and also for 1971-1980 in Table 4. It is seen that in almost all stations, there was a clear and perceptible migrations into more humid spectrum. This was conspicuously so at Dwarka. The moisture index at Churu, was, however, less than its normal value and more or less corresponds to its aridity pattern. Nagaur had 5 migrations in drier side of the regime in the 1951-1980 period. In the remaining cases the moisture index was much above the normal. Even when data was analysed for 10 years period, *i.e.*, 1971-1980, the pattern remained more or less similar.

From what has been said above, it may be hypothised that the border zone had not experienced increased arid conditions in recent years.

4. Conclusion

The major difficulty in arriving at a study of possible desert expansion is that so many factors are *involved*. Rainfall when subjected to the trend tests, was not found

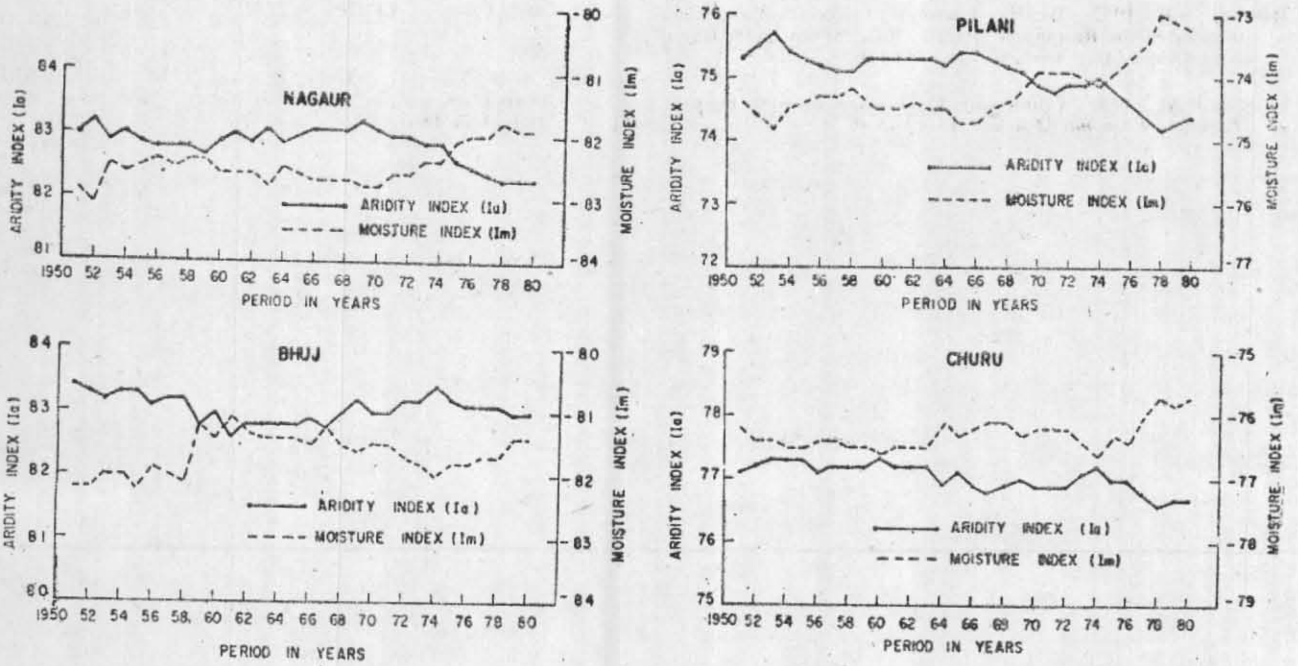

Fig. 4. Yearly variation of aridity index and moisture index

TABLE 4

Climatic shifts (based on data from 1951-1980)

Station	Range: $\bar{I}_m-\sigma$ to $\bar{I}_m$	$\bar{I}_m$ to $\bar{I}_m+\sigma$	$\bar{I}_m+\sigma$ to $\bar{I}_m+2\sigma$
Jodhpur		10(30)	
Bhuj		10(30)	
Dwarka		11	10(19)
Churu	10(30)		
Nagaur	5	10(25)	
Pilani		10(30)	

Note : $\bar{I}_m$: mean moisture index
σ : standard deviation

Figures in the parentheses refer to frequency of moisture index for the period 1971-1980.

to indicate significant changes. The serial correlation also shows that the rainfall series are wholly random. Study of climatic water balance and the aridity pattern suggests, on the contrary some indications of migration of the climate into more humid regimes. Thus taking into account, the rainfall pattern in the border zone, the climatic water balance and the aridity, there does not appear to be implacable advances in recent years of the arid tracks of Thar desert into neighbouring regions.

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