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Climate change and its impact on drought and floods in Luni river basin of north-west arid India

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ABSTRACT

The Luni river and its tributaries in the north-west arid India form integrated drainage Basin of 34,866 km². Annual rainfall in the basin is highly variable, ranging from 600 mm in the southeast to 300 mm in the north-west, 85% of which is received during the months of June to September. Long-term fluctuations and trends in rainfall within and adjoining areas of Luni Basin were studied for the period 1901-1996. The long-term monthly variation and trends in minimum, maximum and mean air temperatures of Jodhpur and Pali were also worked out to quantify possible changes on seasonal basis. In general, either apparent or significant increasing trends in air temperature as well as in rainfall were found at most of the places. Increasing (warming) trends in minimum temperature of May, June and August were found which was significant at 5 per cent level. However, in case of annual rainfall, increasing linear trend at eight locations (with a maximum rate of 1.6 mm year^{-1} at Ajmer) and weak decreasing trend at four locations were observed during the study period. Mann-Kendall rank statistics revealed that this increasing trend rate in the annual rainfall at Ajmer is significant at 5 per cent level.

Impact of these climatic changes on intensity and frequency of droughts and floods were also described. Since 1901 there were fifteen flash floods and several droughts of moderate to severe intensity in the Basin.

Key words : Climate change, Trends, Temperature, Luni Basin, Drought, Floods

Much work has been done and initiated on trends and fluctuations of temperature and rainfall, notably by Reynolds (1953), Willett (1950), Turkes, (1996), Kadioglu (1997) and Komuscu (1998). However, a few studies on temperature and rainfall trends have also been made in India. The Indian arid region has a history of about 3000 years (Pant and Maliekal, 1987). Winstanley (1973 a and b) analyzed the rainfall of Bikaner and Jaisalmer of north-west India and reported that the monsoon in the arid region was favourable during 1900 to 1930 and has been unfavourable since 1970. Pant and Hingane (1988) studied the trends in rainfall and temperature during 1901-82 for the northwest India covering the regions of Punjab, Haryana, west Rajasthan and west Madhya Pradesh. Their studies showed an increasing trend in the mean annual rainfall (141.3 mm per 100 years) and a decreasing trend in air temperatures (-0.52°C per 100 years) contradicting the earlier studies made by Winstanely (1973 a&b). Ramakrishna and Rao (1991) and Rao (1996) also observed an increase in the mean decadal rainfall at Ganganagar which is under extensive irrigation.

The Luni River Basin is a part of the Thar desert comprising about 20% area. Drought and floods are the manifestations of rainfall variation in the Basin. Rainfall is highly erratic and restricted to a part of the year and is only major source of water for agriculture.

Availability of drinking water and lack of fodder for the cattle are the major considerations. Economy is adversely affected by drought. Floods are also not unusual in the region. There are occasions when single rainstorm produced more than normal annual rainfall.

In this study, the long-term time series of air temperatures and rainfall of Luni Basin are analysed in order to demonstrate any existence of climatic changes in the Basin. Authors have also tried to quantify the change in the climate which is taking place in the basin. Frequent occurrence of drought and flood and changes in hydrometeorology of the Basin are also described.

MATERIALS AND METHODS

The weather data has been obtained from India Meteorological Department, Pune and CAZRI, Jodhpur. Monthly, seasonal and annual values of rainfall were computed using daily rainfall data for twelve stations in the Basin (Fig. 3). Monthly and annual maximum, minimum and mean temperatures were also worked out for Jodhpur and Pali stations of Luni river Basin. The data were subjected to statistical analysis to determine presence, if any, of trend in the rainfall and temperature series of the Basin. The long term trends in respect of annual rainfall and mean annual air temperatures for some locations were analysed using linear regression analysis with time as dependent variable and tested for significance. To support the trend in annual rainfall in the basin, decade-wise shift in rainfall at Ajmer, Pali, Jalore, Bilara, Bali, Jaitaran, Siwana and Sojat in the catchment area and Barmer, Jodhpur and Nagaur adjacent to the Basin were also analysed for the period 1901-96. The statistical significance of trends in temperatures and rainfall series were examined by Mann-Kendall rank statistics (WMO, 1966). The Mann-Kendall rank statistic (τ) is computed from

$$t = \frac{4 \Sigma n_i}{N(N-1)} - 1 \quad \ldots\ldots\ldots (1)$$

where n_i is the number of values larger than the i^{th} value in the series subsequent to its position in the time series. The test statistic (τ), is

$$(\tau)_t = \pm t_s \, [(4N+10)/(9N(N-1))]^{0.5} \ldots\ldots\ldots (2)$$

where t_s is the value of t at the probability point in the Gaussian distribution appropriate to the two-tailed test.

Meteorological droughts were worked out based on departures from the aridity index of Thornthwaite in terms of the standard deviation of aridity index (Subrahmanyam and Subramaniam, 1964). Floods based on wet spells with concentrations of rainfall i.e., those received 200 mm or more in four days were identified. In situations where such rainfall occurred in a common period at 2-3 stations these have been considered as localised, at 3 to 5 stations as fairly wide-spread and more than five as wide spread flood. An average rainfall above 350 mm for the wet spell was assumed to be associated with severe flood situation (Dhir *et al.*, 1982; Singh *et al.*, 1992).

RESULTS AND DISCUSSION

Fluctuations in the long-term temperature series

Due to non availability of long term

Table 1: Basic statistical parameters of the long-term monthly and annual mean temperature data of C. R. Farm, Jodhpur (1967-96) and R.R.S., Pali (1978-96)

Station: Jodhpur

Months	Record duration	long-term mean (°C)	Lowest temp °C	Highest temp °C	Std. Dev. (°C)	C.V. (%)
Jan	30	17.66	16.4	20.1	1.03	5.8
Feb	30	19.83	16.7	22.5	1.40	7.0
Mar	30	25.40	22.8	27.7	1.35	5.3
Apr	30	30.54	27.7	33.1	1.09	3.6
May	30	33.80	31.1	35.8	1.05	3.1
Jun	30	33.83	30.6	35.4	1.31	3.9
Jul	30	31.15	29.4	33.4	0.93	3.0
Aug	30	29.53	28.2	32.9	1.05	3.5
Sep	30	29.30	26.1	32.0	1.53	5.2
Oct	30	27.87	25.9	30.4	1.08	3.9
Nov	30	23.29	20.9	26.0	1.31	5.6
Dec	30	19.14	17.0	21.1	0.92	4.8
Annual	30	26.75	25.9	28.1	0.55	2.1

Station: Pali

Months	Record duration	long-term mean (°C)	Lowest temp °C	Highest temp °C	Std. Dev. (°C)	C.V. (%)
Jan	19	16.82	15.1	19.3	1.12	6.7
Feb	19	19.33	15.9	22.1	1.32	6.8
Mar	19	24.86	23.3	27.0	1.30	5.2
Apr	19	30.29	27.6	32.9	1.29	4.3
May	19	34.22	30.4	36.1	1.29	3.8
Jun	19	34.68	33.2	36.3	0.86	2.5
Jul	19	31.17	29.4	33.8	1.00	3.2
Aug	19	29.45	27.0	33.4	1.59	5.4
Sep	19	29.37	27.1	32.9	1.48	5.0
Oct	19	27.65	25.8	30.8	1.34	4.9
Nov	19	22.32	19.4	24.1	1.40	6.3
Dec	19	18.16	16.0	19.3	0.83	4.6
Annual	19	26.52	25.8	28.3	0.61	2.3

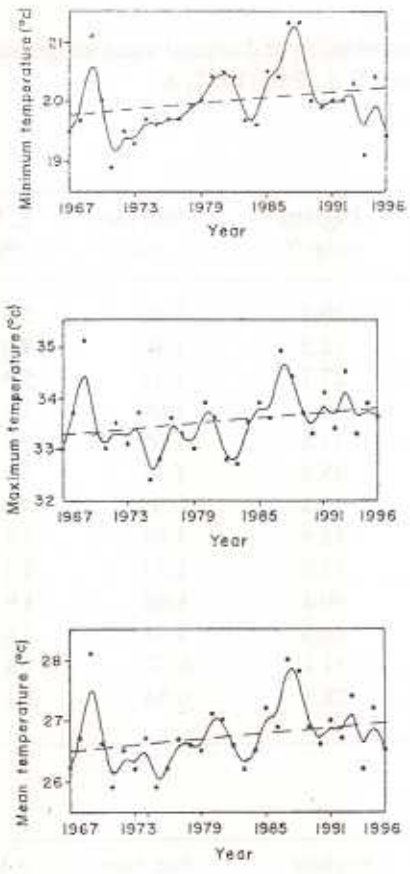

Fig. 1a : Variations in the long-term annual air temperatures of Jodhpur (the broken lines indicated the linear trend)

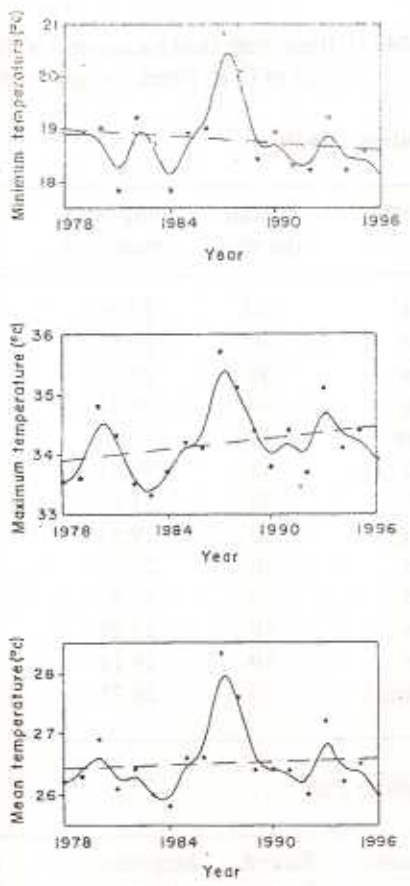

Fig. 1b : Variations in the long-term annual air temperatures of Pali (the broken lines indicated the linear trend)

air temperature data in the basin, the annual time series of maximum, minimum and mean air temperatures at the Central Research Farm, Jodhpur (1967-96) and Regional Research Station, Pali (1978-96) were plotted in order to analyse year to year fluctuations and shifts during the study period (Fig. 1a,b). The study indicated rising trends in annual mean air temperature at a rate of 0.015°C year^{-1} at Jodhpur and 0.008°C year^{-1} at Pali. The average temperatures of the period up to 1990 (assumed as 'normal') was taken as a base period. Short-term fluctuations within the series were then filtered out by five-point Gaussian filtering, superimposed on the actual annual series, in order to identify cycles and trends a little easier by smoothing the extreme irregularities. The weights applied in the filtering process were 0.0625, 0.25, 0.375,0.25 and 0.0625. The Gaussian filtering takes more of the form of a normal curve and is considered to be more appropriate than the classical five-

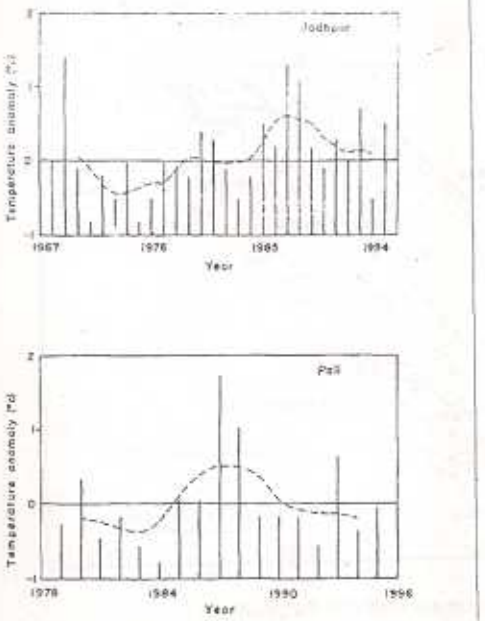

Fig. 2 : Long term annual mean temperature anomalies (°c) for Jodhpur and Pali station with the departures from the base period mean (the fitted curve is the result of five point Gaussian filtering.

year moving average, which is a rectangular filter and not always considered optimum.

Anomalies in mean temperature for Jodhpur are also plotted (Fig. 2). At first glance, several distinctive phases of temperature variations can be identified visually; a cool period during entire 1970s and early 1980s, a warming from mid-1980s and continued more or less up to 1993. Besides these, a short period warming is observed during 1980, 1981 and 1995. Annual mean temperatures remained above the normal in 11 out of 30 years; and were below the average for the other 19 years. A sharp increase in the annual mean temperatures is observed in 1987 (possibly consecutive drought effect in western Rajasthan). This exhibited a rising trend in 1991, 1993 and 1995, but decreased suddenly in 1994 and 1996. It is interesting to note that anomalies in the annual mean during the last 10 years are higher than they were in the previous two decades. The annual mean temperature at Jodhpur was 26.73°C for the base period (1967-90), this value increased to 26.83°C for the period from 1991 to 1996 (Table 1 & 2). Thus, a 0.1°C increase and 0.2°C decrease in the annual mean temperature was observed in the last 6 years at Jodhpur and Pali, respectively.

Trends in air temperature

Long term daily air temperature data recorded at C.R. Farm, Jodhpur (1967-96) and R.R.S., Pali (1978-96) were taken in search for possible trends over the Luni Basin. Mean, unfiltered, monthly and annual minimum, maximum and mean temperatures are analyzed using the Mann-Kendall rank statistics to demonstrate any existence of possible trends. Table 3 shows the rank statistic values with regards to maximum, minimum and mean air temperatures of Jodhpur (1967-96) and Pali (1978-96) for different months. A positive value of Mann-Kendall rank statistics indicates that the trend has increasing tendency while a negative value indicates a decreasing tendency. It is seen that significant positive (warming) trend is noticed in the minimum temperatures at Jodhpur during May, June and August. It is also seen that mean temperature during May at Jodhpur indicates significant warming trend. Whereas significant decreasing trend is observed in minimum temperature series of December at Pali in contrast to maximum temperature showing significant positive trend during the same month in the Basin.

In general, temperatures during May are significantly increasing at both the places.

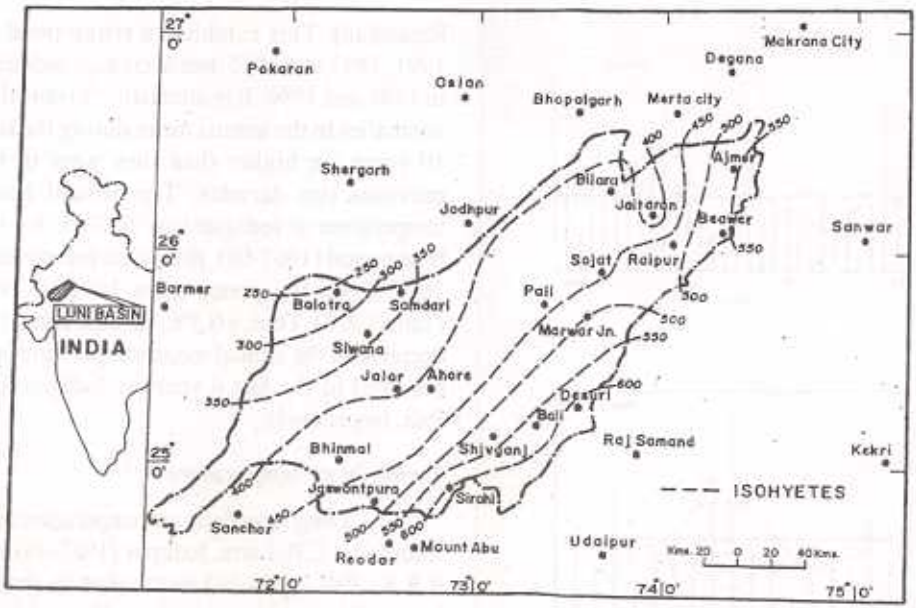

Fig. 3 : Location map of Luni basin and rainfall distribution

The variations in annual temperatures, however, are not statistically significant in and adjacent to the Basin. Comparatively greater warming effects have occurred at Jodhpur rather than at Pali. Therefore, besides the green house gases, urbanization and desertification could have contributed a small component to global warming.

Rainfall distribution

Annual precipitation in the Luni Basin is highly variable, ranging from 600 mm in the south-east to less than 300 mm in the north-west, more than 85% of which is received during the months June to September (Fig. 3). Mean class-A pan evaporation is 2640 mm year^{-1}, exceeding precipitation several fold, so that stream flow is near zero for much of the time. The Luni River is an ephemeral flow system, conveying runoff only in direct response to the torrential monsoon rainfall; hence subject to extreme variability from year to year between no flow and 13,920 m^3s^{-1} ($2409*10^6$ m^3, the highest flow with a return period of 100 years). Since 1917 there have been fifteen flash floods of moderate to severe intensity in the Luni Basin. Thus, for a detailed understanding of the climatic resources of the Basin, it is essential to look into the monthly/ seasonal variations of various climatic parameters and specific synoptic conditions over the region.

Fluctuations in long-term annual rainfall series

The Luni River emanates from the hilly areas adjacent to Ajmer. Ajmer receives a mean annual rainfall of 542 mm and climatically classified as semi-arid. The coefficient of variation in annual rainfall (1901-96) is 39%. On an average, climatic droughts prevailed in the region in every one

Table 2: Monthly and annual trends (Mann-Kendall rank statistics) in minimum, maximum and mean temperatures for Jodhpur (1967-96) and Pali (1978-96)

Station: Jodhpur

Months	Minimum	Maximum	Mean
Jan	0.1701	0.0713	0.1241
Feb	-0.0552	0.1402	0.0414
Mar	0.1862	-0.0092	0.1057
Apr	0.0391	-0.0828	-0.0414
May	0.3425*	0.2184	0.2966*
Jun	0.2529*	0.1793	0.2276
Jul	0.1563	-0.0368	0.0115
Aug	0.2805*	0.0322	0.1287
Sep	0.0874	-0.0092	0.0575
Oct	0.1402	0.1356	0.1333
Nov	-0.2115	0.0529	-0.1241
Dec	-0.0713	0.2138	0.1816
Annual	0.2253	0.2069	0.2276

Station: Pali

Months	Minimum	Maximum	Mean
Jan	-0.0936	0.1462	-0.0468
Feb	-0.2222	0.2339	0.0234
Mar	0.1111	0.2222	0.1520
Apr	-0.2105	-0.0702	-0.1754
May	0.1404	0.3275*	0.2105
Jun	0.1287	0.0292	0.1053
Jul	0.1170	0.0058	0.0175
Aug	0.0936	-0.1345	0.0234
Sep	0.1111	-0.2456	-0.0351
Oct	-0.0175	0.0117	-0.0409
Nov	-0.3216	0.1462	-0.2105
Dec	-0.3801*	0.3567*	-0.1462
Annual	-0.1696	0.2222	0.0117

* Significant at 5 per cent level

out of six years (17% chances) during 1901-96 resulting in partial/ complete failure of crops. In the Ajmer region, severe drought prevailed during 1905, 1911, 1918, 1938, 1939, 1951, 1972 and 1987 and moderate drought during 1901, 1912, 1921, 1922, 1923, 1925, 1941, 1965 and 1969. However, annual rainfall was in excess resulting into floods in the region during 1917, 1924, 1933, 1955, 1975, 1976, 1979, 1983 and 1996.

The annual rainfall at Ajmer showed an overall increasing linear trend at the rate of 1.6 mm year^{-1} during the period 1901-96 (Fig. 4a). This rate of increase in the annual rainfall is comparable with the irrigated part of the arid region as well as other regions in the northern India (Pant and Hingane, 1988; Rao,1996). The decade-wise mean annual rainfall showed that the increase in rainfall was high during last three decades since 1971 which could cause, flash floods in the surrounding regions.

The normal annual rainfall at Pali is 423.3 mm with a higher coefficient of variation (49%). Pali region experienced droughts in one out of every three years (33% chances). Severe drought occurred in the region during the years 1901, 1905, 1918, 1922, 1924, 1968, 1969, 1974, 1981 and 1987 and moderate drought during 1911, 1913, 1914, 1915, 1921, 1923, 1925, 1936, 1939, 1941, 1946, 1949, 1958, 1960, 1962, 1971, 1972, 1980, 1984, 1985, 1986 and 1989. However, Pali observed a weak upward trend (0.4 mm year^{-1}) in rainfall during the same period (Fig. 4b), which may be due to four consecutive droughts (1984-87) experienced during 9th decade (1981-90) of the century. However, Pali also experienced moderate flood during 1916, 1955, 1973, 1992, 1994 and 1996 and severe flash floods during 1908, 1910, 1917, 1944, 1953, 1967, 1975, 1979, and 1990.

Table 3: Average air temperature (°C) for various periods at Jodhpur and Pali

Period	Jodhpur			Pali		
	Max.	Min.	Mean	Max.	Min.	Mean
1967-76	33.36	19.70	26.50	-	-	-
1977-86	33.39	20.11	26.73	33.89	18.69	26.32
1987-96	33.91	20.17	27.03	34.46	18.88	26.70
up to 1990	33.49	20.03	26.73	34.15	18.95	26.58
up to 1996	33.55	19.99	26.75	34.19	18.79	26.52
1991-96	33.80	19.87	26.83	34.27	18.43	26.38

Table 4: Basic statistical characteristics of the annual rainfall (mm), Mann-Kendall (M-K) rank statistics for the 12 stations in and adjoining area of the Basin

Station	Length of record (Years)	Long term mean (mm)	SD (mm)	CV (%)	M-K rank statistics (T)
Ajmer	96	542.1	212.5	39.2	0.1511*
Pali	96	423.3	205.6	48.6	0.0382
Jalore	96	381.9	198.1	51.9	0.1022
Jodhpur	96	368.1	188.6	51.2	0.0774
Sirohi	96	598.2	292.5	48.9	0.0260
Barmer	96	266.8	166.5	62.4	-0.0039
Nagaur	96	345.6	187.0	54.1	0.1193
Siwana	96	346.3	208.6	60.2	-0.0669
Bilara	96	436.6	230.3	52.7	0.0096
Bali	96	562.9	269.0	47.8	-0.0715
Sojat	96	446.8	233.2	49.1	0.0754
Jaitaran	96	391.0	192.0	52.0	-0.0020

* Significant at 5% level

Jalor, which is located in the south central part of the Luni river basin, receives a mean annual rainfall of 382 mm, with a considerably high coefficient of variation (52%). The rainfall in the area is erratic and poorly distributed with drought occurring atleast one in every four years (27%). This part of the Luni River Basin experienced severe droughts during 1901, 1902, 1911, 1915, 1918, 1925, 1936, 1939, 1968, 1969, 1974, 1987 and moderate droughts during 1904, 1912, 1923, 1930, 1935, 1940, 1949, 1951, 1962, 1963, 1964, 1980, 1981 and 1984. However, moderate to severe floods in this part of the

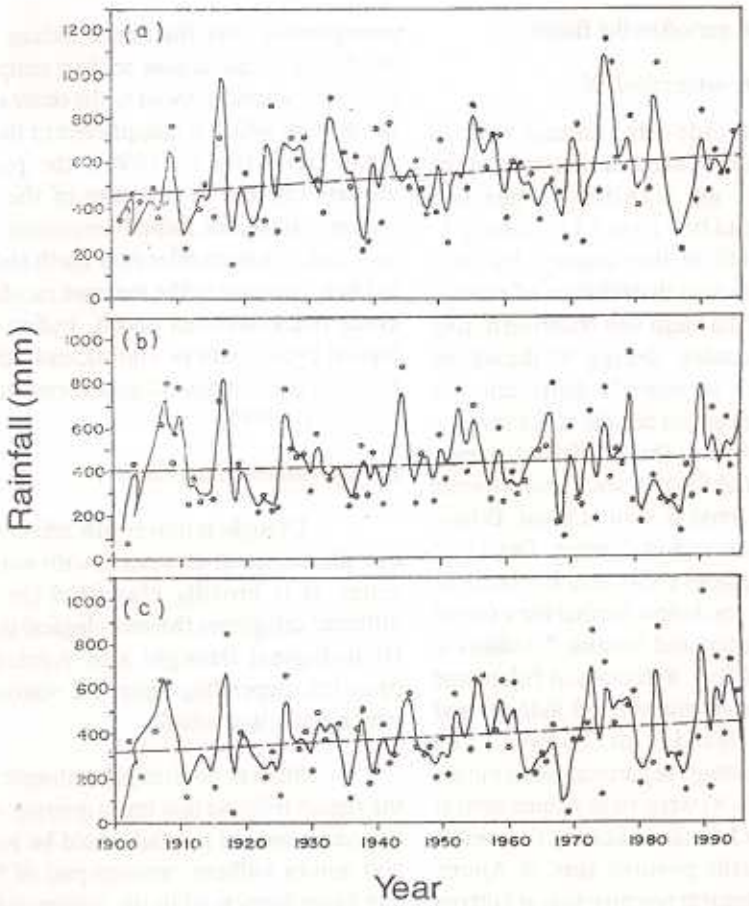

Fig. 4 a,b,c : Fluctuations in long-term annual rainfall series at Ajmer, Pali and Jalor (the broken lines indicated the linear trend in the time series

basin was observed during 1907, 1908, 1917, 1926, 1945, 1952, 1955, 1956, 1959, 1961, 1973, 1975, 1979, 1983, 1990, 1992, 1994,and 1995. This has resulted into a increasing trend in rainfall at the rate of 1.4 mm year^{-1} during this century (Fig. 4c).

Trends in annual rainfall

Table 4 gives the Mann-Kendall rank statistic values. A positive value indicates an increasing tendency while a negative value indicates a decreasing tendency. This test was applied to all the series irrespective of whether or not the first test indicated a trend. The long term linear rising trend in the annual rainfall was observed at eight locations out of twelve stations with a maximum of 1.6 mm year^{-1} at Ajmer followed by Nagaur, Jalor, Jodhpur, Sojat, Pali, Sirohi and Bilara during the same period. Four locations; namely Jaitaran, Barmer, Siwana and Bali showed slower decreasing linear trend in the annual rainfall

during the same period in the Basin.

Shifts in decade-wise rainfall

The decade-wise annual rainfall departures (Table 5) showed that most of the locations put up significant positive (increasing) trend by +10 to +45% during 8th decade (1971-80) of this century. No such widespread and even distribution of rainfall over the area of the basin was observed during the previous decades. During 9th decade no definite pattern in rainfall distribution is observed. In the current decade of the century, positive departure in the rainfall at Ajmer, Jalor, Barmer and Siwana are found whereas weak negative trend is seen at Sojat, Bilara, Jodhpur, Jaitaran and at Nagaur. Out of 10 decades starting from 1901-10 to 1991-96, the annual rainfall was below normal for a period of 4 decades at Sojat and Siwana, 5 decades at Ajmer, Pali and Bali, 6 decades at Bilara and Jalor, 7 decades at Jaitaran and Jodhpur and maximum 8 decades at Nagaur. The cumulative percentage departure values during 1901-10 to 1991-96 were +6 at Ajmer, zero at Jalore and -24 at Jaitaran indicating the rainfall departure towards positive side at Ajmer, whereas it was towards negative side at Jaitaran and at Pali.

By the end of 5th decade, most of the locations in the basin showed higher cumulative departure towards negative side than that in the current (last) decade of the century. This preliminary analysis indicates that there is upward shift in rainfall during the second half of the century in comparison to the first half of this century over the Luni River Basin.

Researchers in the recent past also indicated that the historical data, do not show any appreciable trend in respect of change in precipitation over the entire Indian region. While the mean annual surface temperature showed a warming trend to the order of 0.4°C per century which is comparable to the global mean trend (IPCC, 1996), the projected climate change in the case of the $2*CO_2$ scenario indicates rather favourable impact over India, in particular over north India, due to likely increase in the summer rainfall. In a green house-warmed epoch, Indian hydrological cycle could be significantly different from the present day balance (Srivastava and Sinha Ray, 1994).

Drought in the Luni Basin

Drought is universally acknowledged as a phenomenon associated with scarcity of water. It is broadly classified into three different categories (Meteorological drought, Hydrological drought and Agricultural drought), depending upon the source from which water is available.

Studies on drought vulnerability of the region indicate that on an average once in five years annual rainfall would be less than 200 mm in Jodhpur, western part of Nagaur and Jalore districts while the regions of Barmer districts receive less than 100 mm. Some times droughts occur in succession for 4 to 5 year period as was the case during the recent past 1984-1987 (4 years).

Frequency and intensity of droughts

Analysis of the incidence of droughts and their intensity in western Rajasthan during the current century indicated that 47 to 62% of the years (43 to 51 out of 96 years) experienced drought of one or other intensity. During 1901-10, 1911-20, 1961-70 and 1981-90 highest number of moderate to severe droughts (3.72 to 4.00 years per decade) were

recorded.

During 1987, the Basin experienced more than 40% deficiency in seasonal rainfall. The deficiency of seasonal rainfall was highest in Barmer (80%) regions and in eastern part it varied from 40 to 60%. The region experiencing severe drought conditions during the year 1987 covered more than 60% area of the Basin.

A study of the impact of drought on the productivity of pearl millet in the basin indicated that yield in 1984, 1985 and 1986 (drought years) decreased by 55 to 77% to that recorded in 1983 (Table 6). The most affected districts being Barmer, Jodhpur and Jalor. However, the impact of drought on pearl millet was considerably low in N and Pali districts due to favourable l patterns even during the drought years.

Frequency and intensity of floods

Floods in the Luni River Basin, associated with monsoon depressions or low pressure system over the region, are not an unusual phenomena. People in the basin recall that a flood in the Luni of as much a severity as the years 1979 and 1990 had occurred 117 years back. But floods of lesser magnitude are more frequent now during recent years in the basin as well as in the surrounding districts. Unfortunately, no systematic record is available. However, rainfall data for the period 1901 to 1996 of some stations located in or in immediate vicinity of the Luni Basin was tabulated (Table 7). Admittedly, the approach used is rather rough, but the results are quite suggestive of the situation. Widespread, severe floods in the Luni seem to have occurred 7 times in a period of 96 years, and fairly widespread severe floods five times. However, localised severe floods appear to be much more common.

Table 5 : Decade-wise percentage departure of annual rainfall at some locations in the Luni river basin of northwest India

Decade	Ajmer	Pali	Bali	Jaitaran	Sojat	Jodhpur	Bilara	Jalore	Barmer	Siwana	Nagaur
1901-10	-20	+05	-22	+18	+02	-09	+09	-06	-04	-13	0
1911-20	-10	-06	-07	-21	+03	-02	+10	-14	-03	-10	-14
1921-30	0	-12	+12	-14	+15	-05	+01	-13	-04	+19	-10
1931-40	+03	-08	+05	+11	+09	-02	-13	-10	+01	+11	-18
1941-50	-02	+06	+12	-04	+07	+11	-05	-02	+25	-35	-10
1951-60	+08	+13	-08	-10	+06	+01	-09	+19	+01	+15	-01
1961-70	-09	-02	-06	-14	-21	-06	-08	-26	-22	+05	-09
1971-80	+24	+10	+13	+27	-06	+16	+29	+26	-02	+11	+45
1981-90	-05	-16	-11	-13	-28	-05	-12	+09	-03	-10	-02
1991-96	+17	0	0	-04	-09	-05	-10	+17	+06	+03	-04
Normal Rainfall (mm)	539.0	423.3	562.9	391.0	446.8	368.1	434.5	381.9	266.8	346.3	346.6
SE_m	21.5	21.0	27.5	19.6	23.8	19.3	23.4	20.2	17.0	21.2	19.3

Table 6 : Impact of drought on productivity of pearl millet in the Basin

Station	Pearl millet yield in kg ha^{-1}		
	Good monsoon year (1983)	Mean of three drought years (1984-85 to 1986-87)	Per cent decrease
Barmer	285	65	77
Jalore	468	105	77
Jodhpur	337	79	77
Nagaur	721	265	63
Pali	553	248	55

Table 7 : Occurrence of likely floods in the Basin for the period 1901-96

Extent	Magnitude	
	Moderate	Severe
Localised	1919, 1931, 1937, 1938, 1940, 1947, 1956, 1958, 1961, 1962 (10)	1903, 1905, 1910, 1912, 1916, 1917, 1921, 1924, 1929, 1931, 1945, 1946, 1960, 1967 (14)
Fairly wide-spread	1926, 1927, 1972, 1977, 1983 (5)	1928, 1941, 1943, 1952, 1996 (5)
Widespread	1975,1994 (2)	1907, 1908, 1944, 1973, 1979, 1990, 1990 (7)

Flash floods

Occurrence of more than 700 mm rainfall in a period of 5-6 days is a rare event in the Indian desert. Such events occurred once in 1979 (15th to 19th July, 1979) and two times during 1990 itself, (i) 3rd to 8th July and (ii) 3rd Aug to 8th Aug.,1990 in the recent past.

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