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Long-term variations in the rainfall over upper Narmada catchment

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सार — सन् 1901 से 1980 ई० तक अड़तीस केन्द्रों के दैनिक आँकड़ों का उपयोग करके नर्मदा सागर बांध स्थल तक ऊपरी नर्मदा जलग्रहण के मासिक, ऋतुनिष्ठ तथा वार्षिक क्षेत्रीय वर्षा का विश्लेषण किया गया है। सांख्यिकीय प्राचलों को प्रस्तुत किया गया है। इन विश्लेषणों से पता चला है कि पिछले अस्सी वर्षों के दौरान ऊपरी नर्मदा जलग्रहण क्षेत्र की वर्षा में कुछ महत्वपूर्ण परिवर्तन आए हैं। इस शताब्दी के प्रारम्भ से लेकर सन् 1945 ई० तक मानसूनी तथा वार्षिक वर्षा, वृद्धि की प्रवृति दर्शाती है। उसके पश्चात् यह दीर्घ अवधि के माध्य के आसपास स्थिर हो जाती है। जलग्रहण क्षेत्र के ऊपर सन् 1921 से सन् 1950 ई० तक दक्षिणपश्चिम मानसूनी और वार्षिक वर्षा की वृद्धि इस अवधि के दौरान जुलाई की वर्षा में वृद्धि के मुख्य कारण से हुई है। पिछले तीन दशकों (1951–1980) के दौरान ऊपरी नर्मदा जलग्रहण क्षेत्र के ऊपर वर्षा में दीर्घ-अवधि माध्य से कोई महत्वपूर्ण विचलन नहीं था।

ABSTRACT. Monthly, seasonal and annual areal rainfall of the upper Narmada catchment upto Narmada Sagar damsite is analysed using the daily data of 38 stations from 1901 to 1980. The statistical parameters are presented. Trend analysis showed some significant changes in rainfall of the upper Narmada catchment during the past 80 years. The monsoon and annual rainfall showed an increasing trend from the beginning of the present century upto 1945. Thereafter, it stabilised around the long-term mean. The increased southwest monsoon and annual rainfall from 1921 to 1950 over the catchment was mainly due to an increase in the July rainfall of this period. During the last three decades (1951-1980) there was no significant departure in rainfall over the upper Narmada catchment from the long-term mean.

1. Introduction

In the context of construction of water resources projects in the Narmada catchment, it is pertinent to assess the stability of rainfall regime over the catchment. Any trend in the rainfall will have far reaching consequences on the design and operation of these projects. In the meteorological sub-division of east Madhya Pradesh, where the upper Narmada catchment lies, Parthasarathy and Dhar (1976) noticed an increasing trend in annual rainfall from 1901 to 1935 and a decreasing trend thereafter. They utilised data of all raingauges in the sub-division from 1901 to 1960. In a study of the summer monsoon rainfall of contiguous India from 1866 to 1970, Parthasarathy and Mooley (1978) reported that the mean of the standard decades were stable for the period 1871 to 1920 and steadily increased during the period 1920-1950 and thereafter it decreased. More recently by using data of one station from each district from 1871 to 1978, Parthasarathy (1984) did not observe any trend in the summer monsoon rainfall of east Madhya Pradesh. These studies have considered whole India or meteorological sub-divisions as the areal unit for the analysis of trends in monsoon and annual rainfall. In the present study a catchment, namely Narmada catchment, where a number of water resources projects have been planned is taken as an areal unit for the analysis of rainfall trends.

The long series of rainfall data (1901 to 1980) of the upper Narmada catchment upto Narmada Sagar damsite have been examined on a monthly, seasonal and annual basis to ascertain whether there is any statistically significant change in rainfall of this area. The homogeneity of the series have been tested using Swed and Eisenhart's run test and the randomness against trend of the series have been tested using Mann-Kendall rank statistics. To study the nature of the trend, Crammer test and low pass filter were used.

2. Data used

The part of the Narmada catchment upto Narmada Sagar damsite considered in the present study with the network of rainfall stations is shown in Fig. 2. Daily rainfall data of 38 stations from 1901 to 1980 has been used to construct monthly, seasonal and annual rainfall series of the catchment. First the daily areal average rainfall of the catchment has been calculated using arithmatic average method for every day of the 80-year period. Some of the rainfall stations had not started functioning in the beginning of the period considered. The data of these stations have been included in the calculations whenever they started functioning. The data availability of all the stations was checked and only those stations whose data was available for a particular

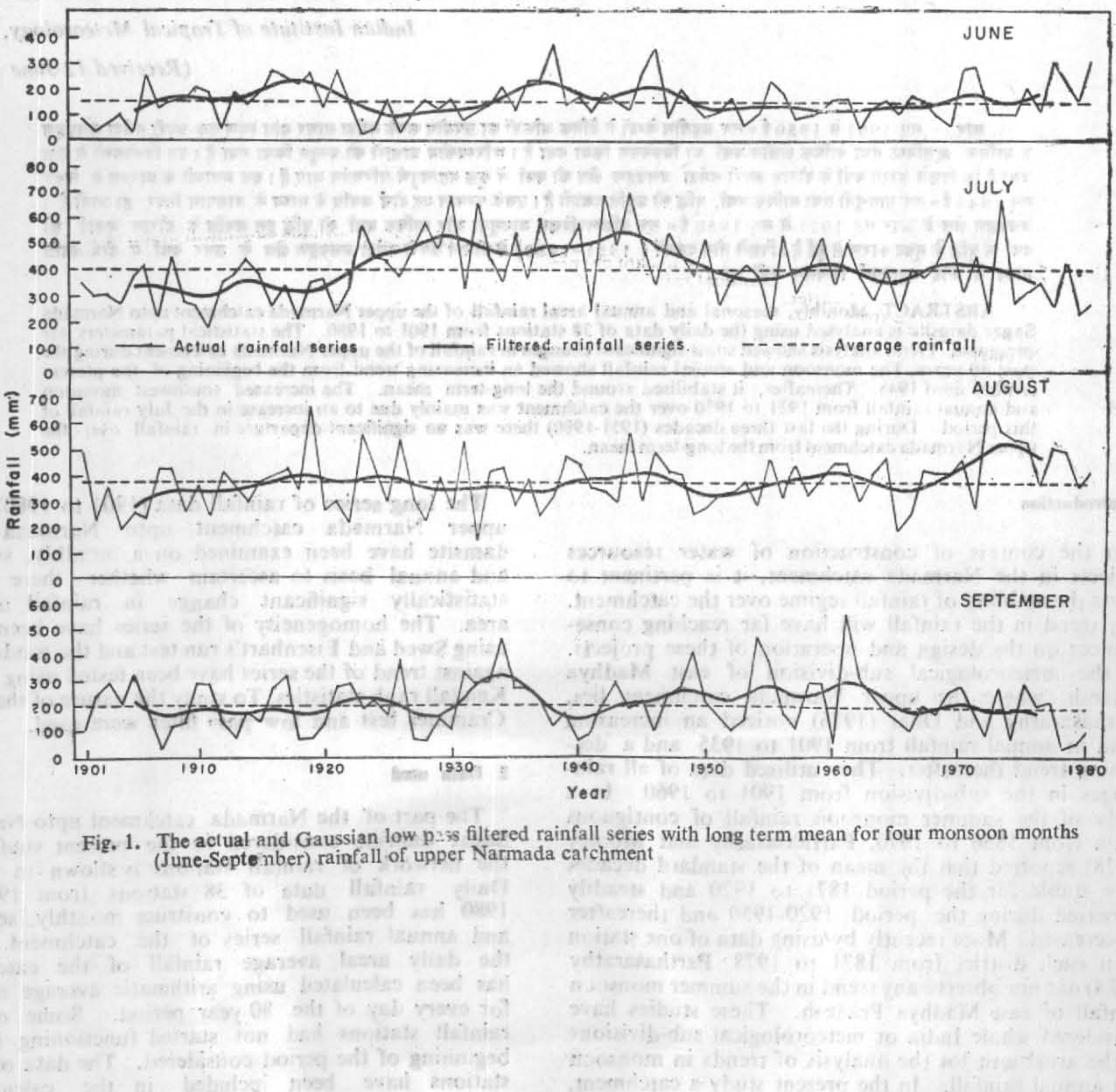

Fig. 1. The actual and Gaussian low pass filtered rainfall series with long term mean for four monsoon months (June-September) rainfall of upper Narmada catchment

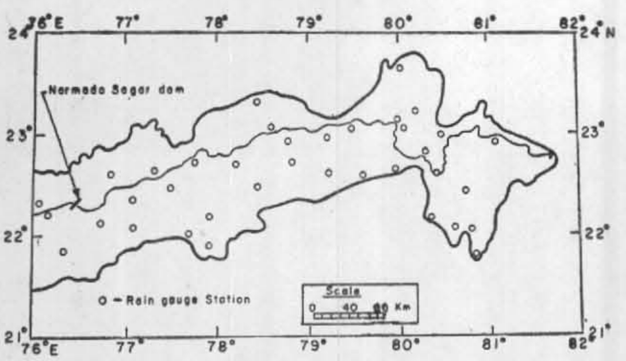

Fig. 2. Network of rainfall stations in Narmada catchment

day were included for that particular day's areal rainfall calculations. The daily, rather than the monthly, areal rainfall has been computed first, to avoid the the difficulties arising from nonavailability of data of a station for a few days. If the monthly rainfall data is used, data of that station has to be neglected or empirically estimated for the whole month. In the present method such stations are omitted from the calculations for those days only when the data is missing.

The daily areal rainfall data thus obtained has been converted into the monthly, monsoon season (June to September) and annual rainfall series of 80-year period. These 14 series were used for the study of statistics and trends of rainfall over the Narmada catchment.

3. Statistical properties of rainfall over the Narmada catchment

The mean, standard deviation and coefficient of variation of monthly, monsoon seasonal and annual rainfall of upper Narmada catchment have been calculated and given in Table 1. The percentage contribution of each month's and monsoon seasonal rainfall to the annual rainfall is also included in the table. The long term mean annual rainfall of Narmada catchment upto Narmada Sagar damsite is 1252 mm and the coefficient of variation is 17.7%. The southwest monsoon rainfall accounts for 90% of the annual rainfall. To see whether the rainfall is normally distributed the statistics g_1/ SE (g_1) and g_2/ SE (g_2) were calculated and it is seen that the monsoon and annual rainfall of the catchment is normally distributed.

There were 11 years when the rainfall over the catchment was —20% or less of long term average and 11 years when it was +20% or more. In the years 1902, 1904, 1907, 1909, 1918, 1920, 1941, 1951, 1965, 1966 and 1979 upper Narmada catchment received deficit rainfall and in the years 1917, 1919, 1926, 1931, 1934, 1937, 1942, 1944, 1948, 1961 and 1973 it received excess rainfall. It is interesting to note that during the twenty-year period from 1921 to 1940 there was not even a single year when the rainfall was deficit. The lowest annual rainfall was 708 mm in 1965 and the highest 1846 mm in 1961, the departures from long term average being —43.5% and 47.4% respectively.

To check whether the series are homogeneous or not, Swed and Eisenhart's run test (1943) was used. The number of runs above and below median for all the monthly, monsoon seasonal and annual rainfall series are given in Table 1. For the eighty years data runs between 33 and 48, both inclusive, indicate that the series is homogeneous. It can be seen that for all the months the number of runs are between the critical values, showing that the series are homogeneous. But in the case of monsoon and annual rainfall series test indicates that trend may be present.

The persistence of the series was tested by using lag 1 serial correlation coefficient. For all the series lag 1 serial correlation was found to be less than critical value at 95% level of significance (Table 1) and hence it can be concluded that there is no year to year persistence in the series.

4. Trend analysis

To test whether the rainfall over the upper Narmada catchment is having any increasing or decreasing trend Mann-Kendall rank statistics, Crammer test and low pass filter are used.

The Mann-Kendall rank statistics was used to test the randomness against linear or nonlinear trend (WMO 1966). The test statistics τ are given in Table 1 for monthly, seasonal and annual rainfall. The limiting value at 95% level of significance is 0.1493 to indicate a trend. The test indicates trend in the case of August and monsoon seasonal rainfall.

Annual rainfall averages, standard deviations and coefficient of variations for standard decades, were computed and are given in Table 2.

To test the hypothesis that the averages of decades were not different from the long term average, Crammer test has been used. The Crammer test statistics t_k has been calculated using the equation :

$$t_k = \left[\frac{n\,(N-2)}{N-n\,(1+A_k^2)} \right]^{\frac{1}{2}} \cdot A_k \qquad (1)$$

where, $A_k = (\bar{x}_k - \bar{\bar{x}})/s$, $\bar{\bar{x}}$ is the average of the entire series, s its standard deviation, $\bar{x}_k$ the decadal mean, N=80 and n=10. The Crammer test statistics and the percentage departures of the decadal averages from the long term average are also given in Table 2. The rainfall of the decade 1901 to 1910 was 15% less than the long term mean and the difference was significant at 99% level of significance. In the two consecutive decades of 1931 to 1940 and 1941 to 1950, the rainfall was significantly above the long term mean. These results are generally in agreement with those obtained by Parthasarathy and Dhar (1976) for east Madhya Pradesh. In the last 3 decades (1951-1980) the decadal average rainfall was very near to the long term mean value.

To examine the nature of the trend, all the 14 rainfall series were passed through a 9-point Gaussion low pass filter (WMO 1966). The actual and filtered series, with the long term mean, in the case of 4 monsoon months of June-September are shown in Fig. 1. The same for monsoon and annual rainfall series are shown in Fig.3. From Fig. 3 it can be seen that the rainfall over Narmada catchment was increasing from 1901 to 1945. Thereafter the increasing trend stopped and the monsoon as well as the annual rainfall was oscillating around the 80-year mean. In the last three decades there was no visible change in the rainfall of the Narmada catchment.

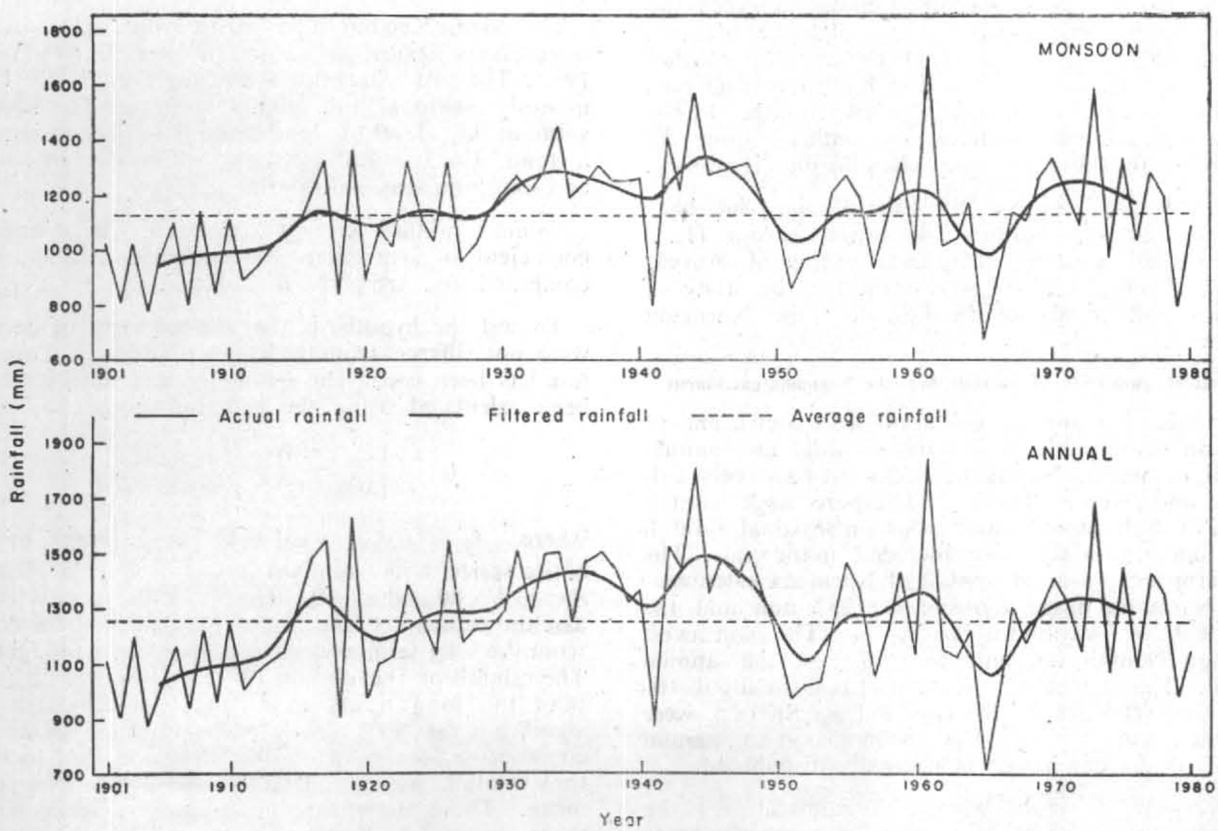

Fig. 3. The actual and Gaussian low pass filtered rainfall series with long term mean for monsoon seasonal (June-September) and annual rainfall of upper Narmada catchment

TABLE 1

Statistical parameters of the monthly, monsoon season and annual rainfall of the upper Narmada catchment

	Average rainfall (mm)	Standard deviation (mm)	Coeff. of variation (%)	Percentage of annual (%)	No. of runs above and below median	Lag 1 correlation	Mann-Kendall rank statistics
Jan	16.1	21.2	132	1.3	37	0.1760	—0.0342
Feb	15.0	16.7	111	1.2	35	0.0628	—0.1032
Mar	12.4	15.7	127	1.0	47	—0.0110	—0.0519
Apr	6.5	9.4	143	0.5	37	—0.1085	—0.0259
May	9.8	15.1	154	0.8	42	0.3060	—0.1241
Jun	150.0	77.7	52	12.0	43	0.1767	0.0139
Jul	395.5	124.7	32	31.6	38	0.0074	0.0367
Aug	374.7	110.7	30	29.9	42	—0.0729	0.1905*
Sep	207.9	107.7	52	16.6	34	0.1601	—0.0190
Oct	39.4	43.5	110	3.1	38	0.1363	0.0006
Nov	16.3	28.3	174	1.3	40	—0.0660	—0.1316
Dec	8.8	17.6	199	0.7	39	0.0141	—0.0563
Monsoon	1128.1	197.8	18	90.1	32*	0.0412	0.1525*
Annual	1252.4	221.8	18	100.0	30*	0.0962	0.1114

*Significant at 95% level

TABLE 2

Statistical parameters of annual rainfall of the upper Narmada catchment for standard decades

Decade	Average rainfall (mm)	Standard deviation (mm)	Coeff. of variation (%)	Crammer test statistics (t_k)	Difference of decadal average from long term average(%)
1901-1910	1063.2	132.5	12.5	—3.00**	—15.1
1911-1920	1218.8	247.3	20.3	—0.50	—2.7
1921-1930	1249.0	128.9	10.3	—0.07	—0.3
1931-1940	1414.8	98.4	7.0	2.54**	13.0
1941-1950	1393.4	226.5	16.3	2.20*	11.3
1951-1960	1196.9	170.8	14.3	—0.84	—4.4
1961-1970	1218.9	279.1	22.9	—0.50	—2.7
1971-1980	1263.9	206.9	16.4	0.17	0.9

*Significant at 95% level. **Significant at 99% level.

From Fig. 1 it can be seen that the increase in monsoon and annual rainfall of the catchment from the beginning to the middle of the present century was mainly due to an increase in the July rainfall. During the period 1921-1950 the mean July rainfall was 20% above the long term mean. Annual rainfall for the same period was 100 mm above the long term mean and out of that, 80 mm was accounted for by an increase in July rainfall. During the same three decades average August rainfall was slightly below the 80-year mean (—3. 6%). From 1951 onwards July rainfall is showing a small decreasing tendency but the decrease is almost compensated by a slight increasing trend in the August rainfall.

6. Conclusions

The following main points emerge out of the present study :

(*i*) The mean annual rainfall of the upper Narmada catchment upto Narmada Sagar damsite is 1252 mm with a coefficient of variation of 18%. The southwest monsoon season (June to September) accounts for 90% of the annual rainfall.

(*ii*) Out of the 80 years considered, 11 years rainfall was excess ($\geqslant +20\%$) and 11 years it was deficit ($\leqslant -20\%$). The deficit years were more frequent in the first decade of the present century and the excess years were more frequent during 1931 to 1950.

(*iii*) The decadal mean annual rainfall of 1901 to 1910 was significantly below and that of 1931-1940 and 1941-1950 was significantly above the long term mean. During the recent three decades (1951-1980) the rainfall was only marginally different from the 80-year mean.

(*iv*) The low pass filtered series showed an increasing tendency from 1901 to 1945 both in the case of monsoon and annual rainfall. After 1945 the rainfall decreased and was oscillating about the long term mean.

(*v*) The increase in mean July rainfall of the order of 80 mm (20% above long term mean) for the three decades from 1921 to 1950 was mainly responsible for the increase in the monsoon and annual rainfall in these three decades. In the last 30 years of the period considered, July rainfall was showing a slight decreasing tendency but it is more or less compensated by a slight increasing trend in August rainfall.

From the above it can be concluded that even though there was some significant increase in rainfall over the Narmada catchment in the past during 1901 to 1945, for last 3 decades the rainfall over the catchment remained stable.

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