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Letters to the Editor

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LONG-TERM TRENDS AND PERIODICITIES IN THE DAILY RAINFALL SEQUENCES OVER UPPER MAHANADI BASIN

1. The analysis of trends in the hydrologic processes gives an indication of the long-term and cyclic climatological changes. Since the stochastic modelling procedures are based on the stationarity assumption, the detection of time trends in these processes becomes a pre-requisite. The establishment of long term linear or curvilinear time trends and low frequency oscillations would necessitate the construction of a non-stationary stochastic model or a homogenization procedure through which the model could be tested in the stationary domain.

1.1. In India, the trends and periodicities in the annual rainfall have been studied by Parthasarthy and Dhar (1974), Sarker and Thapliyal (1988) and Thapliyal and Kulshrestha (1991). Unlike the previous work of various researchers, we have analyzed trends in both the rainfall occurrence and rainfall amount processes because the stochastic nature of the two processes is quite different.

2. The daily rainfall data for seven stations situated in the Pairi catchment (3056 km^2 area) of upper Mahanadi basin (Fig. 1) were analyzed. Data were available for a period of 5 to 16 years. These stations were situated within 20°06′N to 20°43′N latitude and 81°56′E to 82°17′E longitude. Most of the rainfall in the region is received during the period June to September. This analysis, therefore, is confined to this 122 days period, because the distribution of early October or late May or chance occurrence of one or two events in other months is almost insignificant.

2.1. A non-parametric test proposed by Hirsch *et al.* (1982) was used to test the time trends in the data. Hirsch's statistic S is the weighted sum of the Kendall's tau score (Kendall 1938) for each of the m seasons. The statistic S follows a standard normal distribution and the hypothesis testing (H_0 : no trend) is straight forward. The test statistic has sufficient power to detect trends in the small sample data. This procedure basically tests a monotonic (but not necessarily linear) trend over the years. The test implicitly assumes that the trend is homogeneous between seasons which is not always true. Therefore, an extension of this test proposed by Belle and Hughes (1984) is used to test the homogeneity of trend.

TABLE 1

Test of trends in the daily rainfall occurrences

Station	Total S	Variance S	Z- statistic	Chi Square Homogeneity	Chi Square Trend
		Days taken as seasons, m = 122			
Baruka	-685	7945.67	-7.685*	117.157	53.199*
Gariaband	122	30655.99	0.697	116.498	0.337
Chuchurangpur	-616	29130.67	-3.609*	116.379	10.920*
Sikasar	-70	1164.00	-2.052+	86.543	3.791
Mazipur	105	25235.00	0.661	119.447	0.403
Sondur	-100	3130.67	-1.787	112.245	3.854+
Kendri	-249	37099.67	-1.293	122.286	1.059
		Weeks taken as seasons, m = 17			
Baruka	-182	1846.67	-4.235*	33.636*	16.217†
Gariaband	32	6470.33	0.410	8.381	0.166
Chuchurangpur	-192	6307.33	-2.417+	18.021	5.276+
Sikasar	-30	240.00	-1.936	13.287	3.678
Mazipur	85	5240.33	1.174	11.487	1.417
Sondur	-34	686.00	-1.298	8.640	1.725
Kendri	-28	7663.33	-0.319	10.831	0.089

* significant at 1% level

\+ significant at 5% level

† do not use the test

2.2. The power spectral density (PSD) of the rainfall series was estimated by taking the squared magnitude of the Fourier transform of the infinite data sequence with appropriate statistical averaging (the periodogram method). The Welch periodograms (Welch 1967) were used for the PSD estimation for each station.

3. The results of the test for the daily rainfall occurrences are given in Table 1 for 7 stations under study. The Z-statistic (Table 1) gives an overall picture of the trends in the data assuming that the trend is homogeneous between seasons. The Chi Square values explicitly test the homogeneity as well as the trend. When individual days are considered as seasons, the Z- statistic shows a decreasing trend at stations BAR, CHU, and SIK. The χ^2_{homog} (homog-homogeneous) values with 121 degrees of freedom (d.f.) are insignificant for all stations indicating no difference in trend between seasons. The χ_{trend} with 1 d.f. is significant ($p < .01$) for stations BAR and CHU. When weeks are considered as seasons, the significance level of χ^2_{trend} statistic for station CHU is somewhat improved to $p < .05$. The statistic for station BAR, however, now shows trend heterogeneity between seasons, hence the χ^2_{trend} value cannot be used for the hypothesis testing. The test statistic for the daily rainfall amounts revealed the similar results.

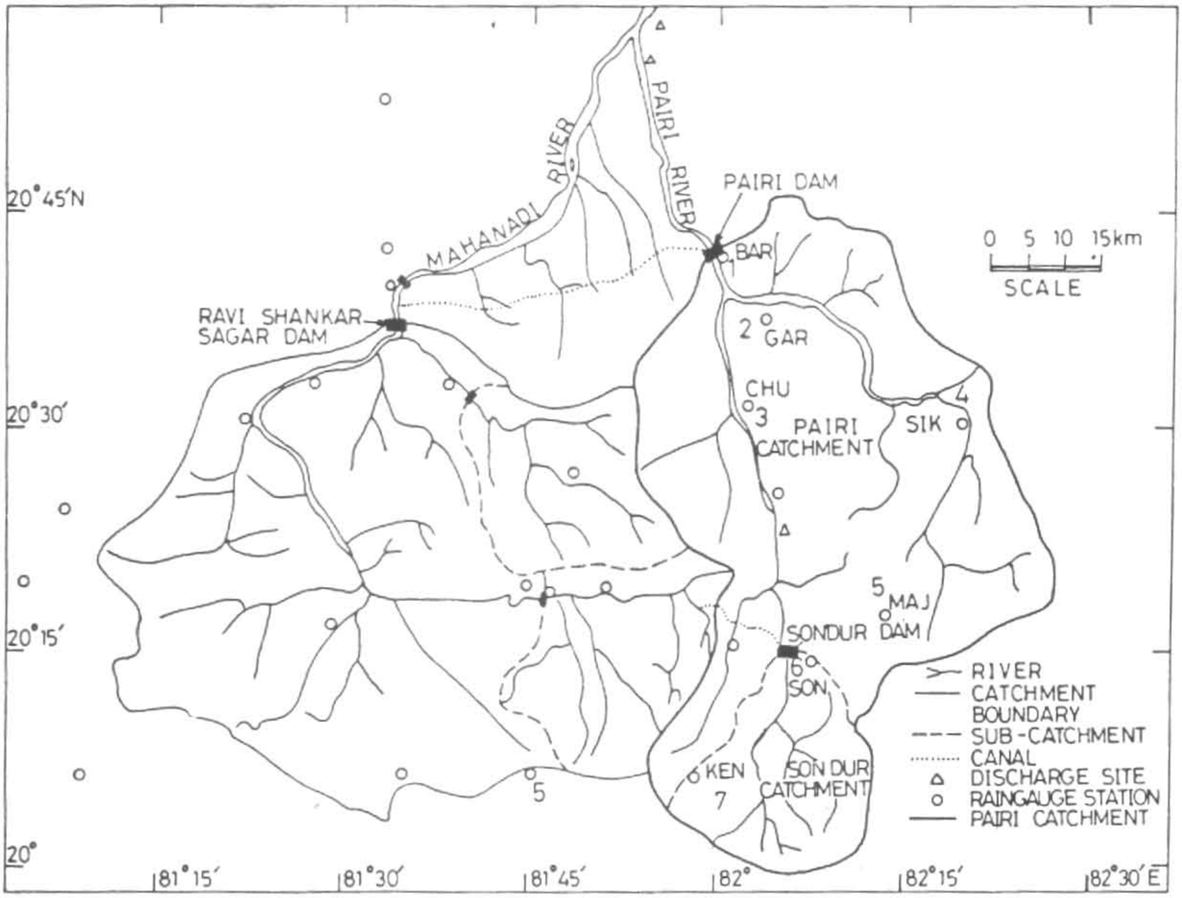

Fig.1. The upper Mahanadi Basin and Pairi catchment under study

3.1. Therefore, it appears that the test is more reliable with weekly data in analyzing the trends both in the rainfall occurrence and in the rainfall amounts. The test indicates a decreasing trend in the rainfall occurrence at stations BAR and CHU and in the rainfall amounts at stations BAR and SIK (Table 2). Other stations do not show any trend in both the processes. It should be noted that, except for the station BAR, the significance level is marginal for other two stations. Considering the geographical locations of 7 stations which is rather close, it is plausible to assume that the point rainfall at these stations is governed by a common rainfall generating mechanism. Hence, the stochastic characteristics of the rainfall process should be the same for all the station. Therefore, it can be concluded that there is no strong evidence of the long- term trend in the daily rainfall occurrence as well as in the amounts over upper Mahanadi basin. Thus, the two processes can be taken as stationary in the period being considered. Our results are in congruence with that of Rao and Krishnakumar (1992) who analyzed 80 years of data of the entire Mahanadi basin and did not find trends in the average seasonal areal rainfall series.

3.2. Power spectral densities (PSD) were estimated for the rainfall occurrence process of the 7 stations. The periodogram used five segments and an overlap between segments equal to 50 percent of the number of samples per segment. A Hamming window was applied to each segment. Thus, 2048 PSD values were estimated for each station.

TABLE 2

Test of trends in the daily rainfall amounts with weeks as seasons (m = 17)

Station	Total S	Variance S	Z- statistic	Chi Square Homogeneity	Chi Square Trend
BAR	-176	1940.00	-3.996*	23.664	14.248*
GAR	-103	6854.99	-1.244	17.774	1.512
CHU	-42	6670.67	-0.514	18.984	0.178
SIK	-37	277.67	-2.220+	16.514	4.932+
MAZ	7	5544.33	0.094	7.377	0.009
SON	19	749.67	0.694	8.330	0.486
KEN	-119	8214.99	-1.313	14.618	1.566

* significant at 1% level

+ significant at 5% level

3.3. The periodogram for the station GAR is shown in Fig.2. The periodograms for other stations were similar to that of the station GAR. For all the seven stations the periodograms indicate one strong peak at 120.5 days/cycle. This time period approximately denotes the end of the

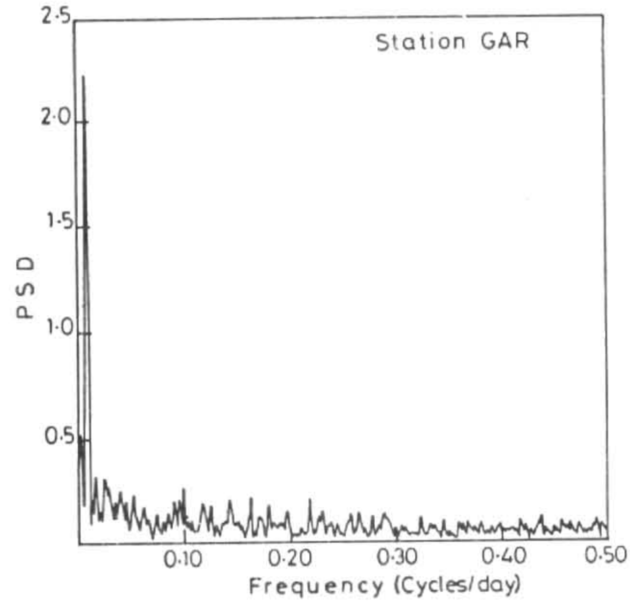

Fig.2. Spectrum of rainfall occurrences with unfiltered data

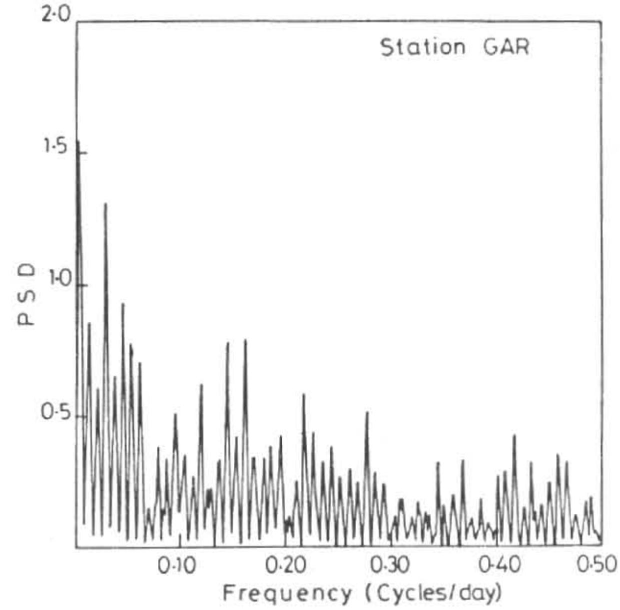

Fig.3. Spectrum of rainfall occurrences with filtered data

TABLE 3

Dominant periodicities obtained from the spectrum of daily rainfall occurrences

Station	Dominant Periods (Days)	
	Unfiltered data	Filtered data
BAR	120.5, 58.5, 43.6	78.7, 45.5, 12.6
GAR	120.5, 60.2, 40.2	255.7,34.7
CHU	120.5,58.5	227.7, 47.6, 26.9
SIK	120.5, 41.8	255.7, 85.3, 34.1
MAZ	120.5, 62.1, 46.6	1020.4, 81.9, 47.6
SON	120.5, 48.8	255.7, 75.8, 47.6
KEN	120.5, 62.1, 40.2	227.7, 78.7

season (which is equal to 122 days/year) and so corresponds to the yearly periodicity. The yearly periodicity is so dominant that it is masking the presence of other peaks. However, first three dominant peaks obtained from Fig.2 are given in Table 3. Table 3 shows second peak at 58.5- 62.1 days/cycle and third peak at 40.2-48.8 days/cycle. Thus, the second and third peaks appear to be the harmonics of the 120.5 days' primary period of the occurrence process.

3.4. In order to study the spectrum in details without the dominant yearly periodicity, the data was filtered by applying a simple linear filter. The new series was constructed as $\Delta x = x_t - x_{t-122}$. The spectral analyses on the filtered series for the station GAR is shown in Fig.3. The dominant periodicities in the filtered data are presented in Table 3. First of all, no obvious patterns are visible in the periodograms with filtered data, except that the yearly component is completely wiped out. The first peak represents a period of 255.7 days/cycle which approximately corresponds to a biennial cycle. The second and third peaks are positioned at 75.8-85.3 days/cycle and 34.1-47.6 days/cycle, respectively. These, rather unusual periods, approximately correspond to 2.5 monthly and 1.5 monthly periodicities. These results, however, should be taken with caution because the seasonal differencing always tends to introduce some artificial periodicities in the data (Judge *et al.* 1988). These periods, however, may be the 30-50 day oscillations of the monsoon. The physical mechanism of these oscillations is under the investigation because this could be of considerable use in medium range prediction of the monsoon (Keshavamurty and Sankar Rao, 1992). From the hydrological point of view, however, Ojasvi (1994) could simulate the rainfall series with the similar observed spectral properties even though the presence of these oscillations was ignored.

3.5. Therefore, it appears that the rainfall occurrence process considered here is only yearly periodic. That is, the process repeats itself every year. This circular stationarity suggests that the probability distribution of the hydrologic quantity in the 122 days season is the same for different years. The general appearances of the spectrum can easily explain the nature of different types of dependence. The exponentially decaying spectrum (Fig:2) indicates a short memory dependence (Chatfield 1975). This short memory dependence in the occurrence process can be modeled by a discrete parameter Markov chain or by a Neyman- Scott cluster model. Since, the daily rainfall amounts are independent, the spectrum of amounts resembles to that of a pure 'white noise' process and therefore, does not reveal any discernible feature.

4. Therefore, our results show that there is no strong evidence of the long term trends in the daily rainfall occurrence as well as in the amounts in the region. The spectral analysis revealed a significant annual periodicity in the

rainfall occurrence. Within the monsoon season the occurrence process appears to be stationary. This circular stationarity suggests that the probabilistic nature of the hydrological events in the 122 days season is same for different years. It is also concluded that a short memory dependence is present in the daily occurrence process which suggests that either the Markov process or the Neyman-Scott cluster process would be the suitable precipitation modelling techniques.

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