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Correlation study between sunspot and rainfall in Udaipur subregion

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सार — उदयपुर उप-उष्णकटिबंधीय क्षेत्र के 102 वर्षो के वर्षा के आँकड़े और सूर्य के धब्बों में परस्पर सह-संबंध से उदयपुर की जलवायविक स्थितियों पर सौर्य गतिविधियों के पड़ने वाले प्रभाव का पता चलता है। जयसमन्द झील का जल संग्रहण तथा जाखम और करमोई दो नदियों के गेज़ मापन, जैसे, वर्षा और अन्य आंकड़ा समूहों के प्रयेाग से संबंधित आवर्तिता, सूर्य के धब्बों की आवर्तिता के समान ही है, जो कि वर्षा और सूर्य के धब्बों की गतिविधियों के परस्पर संबंध को इंगित करती है। उदयपुर उप-उष्णकटिबंधीय क्षेत्र की वर्षा की कुल अवधि की लगभग 27 प्रतिशत अवधि में सामान्य वर्षा के स्थान पर बाढ़, अतिवृद्धि और अनावृष्टि होती है। खगोल भौतिकी के संदर्भ में सूर्य और मौसम के परस्पर संबंधों की व्याख्या करने के लिए संभावित भौतिक क्रियाविधि के बारे में बताया गया है।

ABSTRACT. The cross correlation among 102 years rainfall data in Udaipur subtropical region and sunspots show the influence of solar activity on the climatic conditions of Udaipur. The periodicity obtained using rainfall and other data sets, such as, water storage of Jaisamand lake and gauge measurements of two rivers, Jakham and Karmoi, are similar to the periodicity of sunspots, which indicates a relationship between rainfall and sunspot activity. A period of about 27% is found to deviate from normal rains in the form of flood, excess and deficit of rains in Udaipur sub-tropical region. The possible physical mechanisms to explain sun-weather relationship in astro-physical context are discussed.

Key words — Rainfall, Sunspot periodicity, Solar cycle.

1. Introduction

The possible relationship between sunspot cycle and rainfall has been a subject of prolonged study mainly to predict flood and drought conditions. The correlation between these two quantities may be positive, negative or non existent, depending upon where the meteorological measurements are made (Herman and Goldberg 1978). For example, in the regions of orographic rainfall near the Himalayas strong positive correlation is found, whereas in other regions there are negative correlation (Jagannathan and Bhalme 1973, Bhalme 1975). Nevertheless, many investigators have confirmed the influence of sunspot activity on rainfall using large period samples scattered all over the globe. Mitchell *et al.* (1979) showed 22-year rhythm of drought in western USA. Hameed (1984) found a periodicity of 19 years in the Nile flood data and attributed it to the lunar tide of 18.6 years. Similarly, Letfus (1986) found that secular variations of the river Nile levels, measured regularly from the 7th to 15th century AD, correlate well with the solar variations.

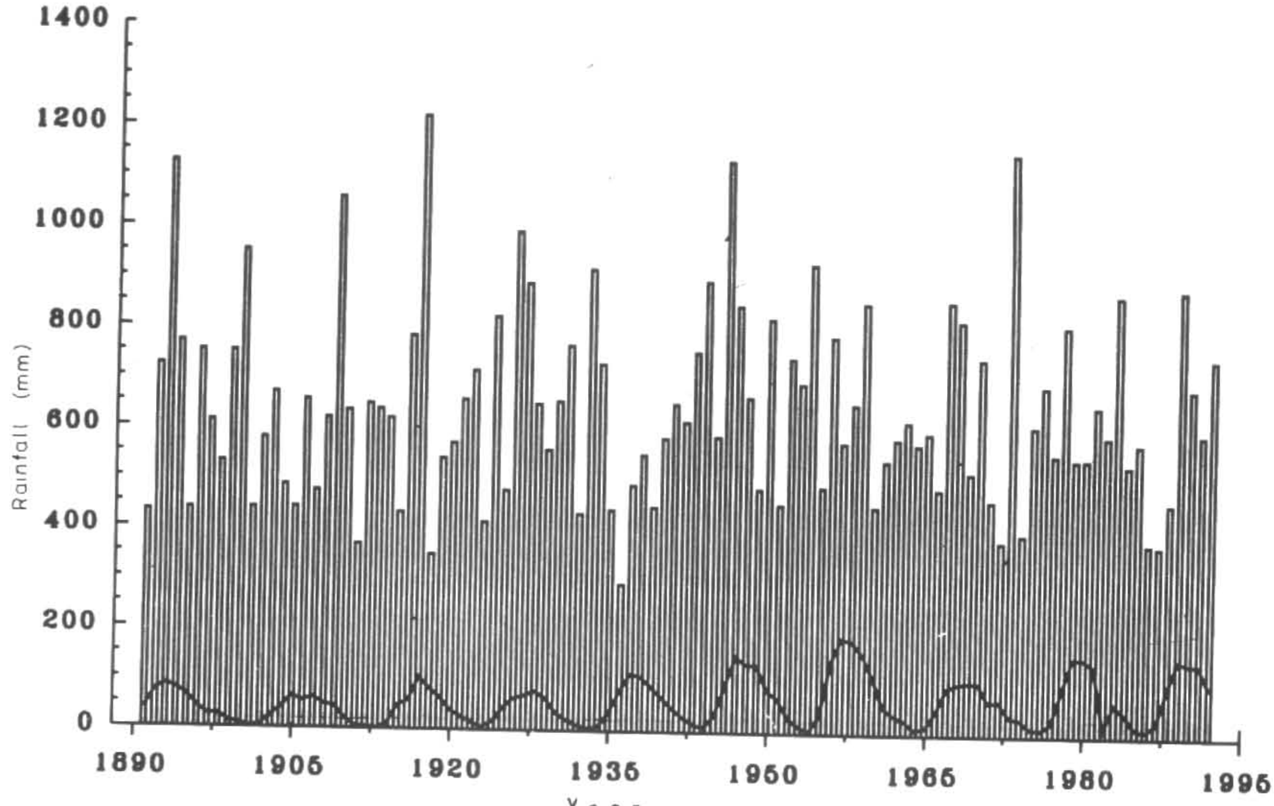

Fig. 1. The mean annual rainfall of Udaipur subregion in mm. The thick continuous curve overlaid on the rainfall represents the sunspot number

This suggests solar influence on the climatic changes in the east African tropics. Similar evidence was previously detected in precipitation records of North and South America, India and China. An and You (1993) showed the 11 and 22-year periodicity in water logging and droughts in China. In the Indian context, rainfall periodicity of 11 and 22 years coinciding with the sunspot cycle has also been observed in various studies (for a review see Bhalme *et al.* 1981). Bhalme and Mooley (1983) found a strong evidence between the extent of flood over India and the double sunspot cycle of 22 years. Bhalme and Yadav (1984) by means of statistical data analysis showed that floods occur more frequently during positive sunspot cycle. Reddy *et al.* (1989) utilising the maximum entropy spectral technology found a significant 11-year cycle between the Indian monsoon rainfall and solar activity. More recently, Mitra (1992) investigated the effect of 18.6 luni-solar and 10-11 year solar cycle on rainfall in India.

In this paper we find the degree of correlation between the sunspot activity and the rainfall in Udaipur subtropical region (Rajasthan). A similar study by Jagannathan *et al.* (1978) over different areas of Rajasthan showed periodicity in good agreement with the observed sunspot cycle. Here, we use rainfall data alongwith storage and gauge levels of different rivers and lakes to find out any possible significant periodicity between the rainfall and solar cycle in Udaipur subregion. The nature of the data and the source is described in section 2. The data analysis and the results obtained are presented in section 3. Some of the possible physical mechanisms to explain these periodicity from an astrophysical point of view is presented in section 4 and conclusions are drawn in section 5.

2. The data

The rainfall data for the period 1891-1992 for Udaipur was obtained from Meteorological Observatory at the College of Technology and Agriculture Engineering (CTAE), Udaipur located at 582.17 m altitude. The daily rainfall data in mm is being recorded by this observatory (24° 35′ N, 73° 42′E) on a routine basis. However, the data used in our analysis is an

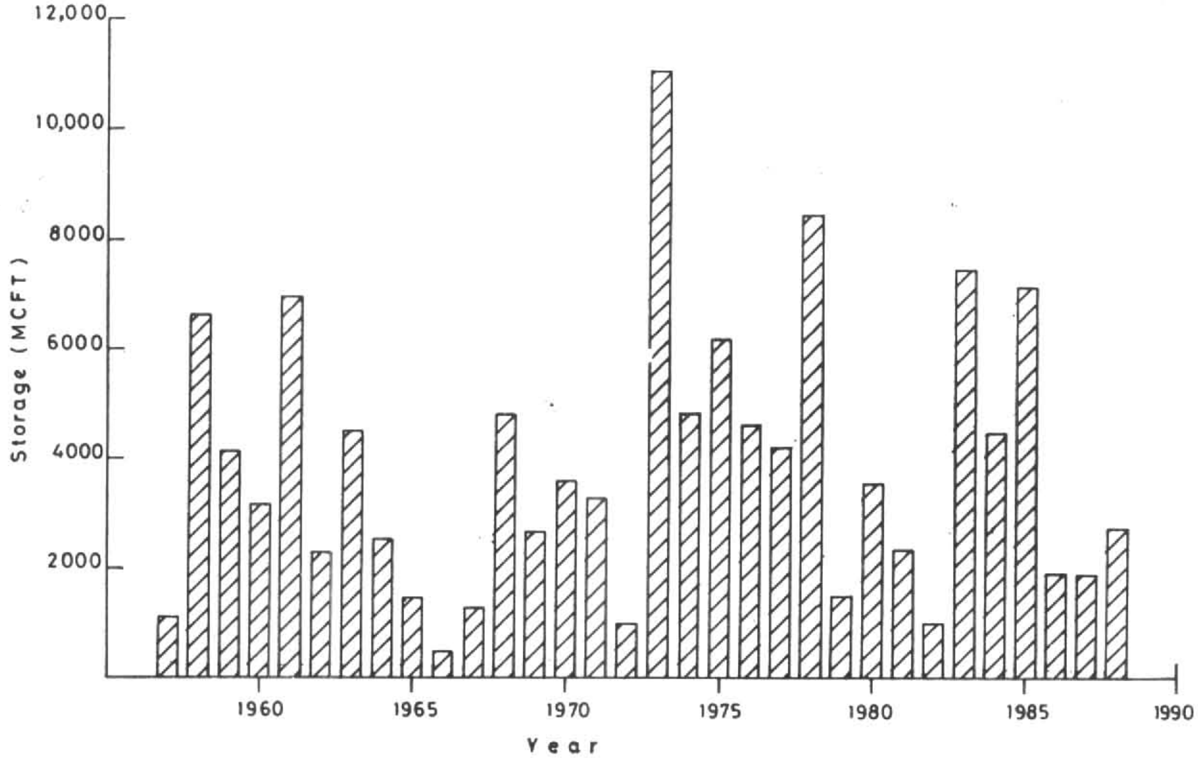

Fig. 2. The mean annual water storage of Jaisamand lake

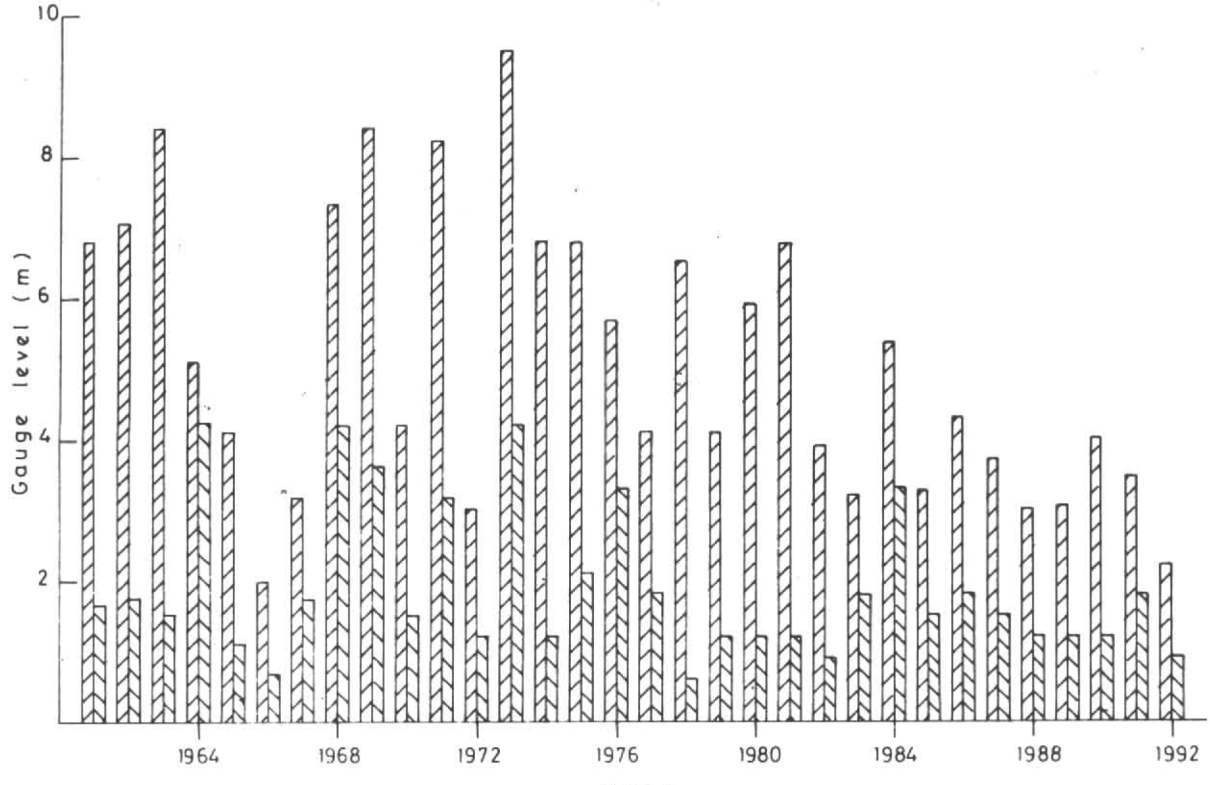

Fig. 3. The mean annual gauge level of Jakham (rising to right) and Karmoi rivers (rising to left)

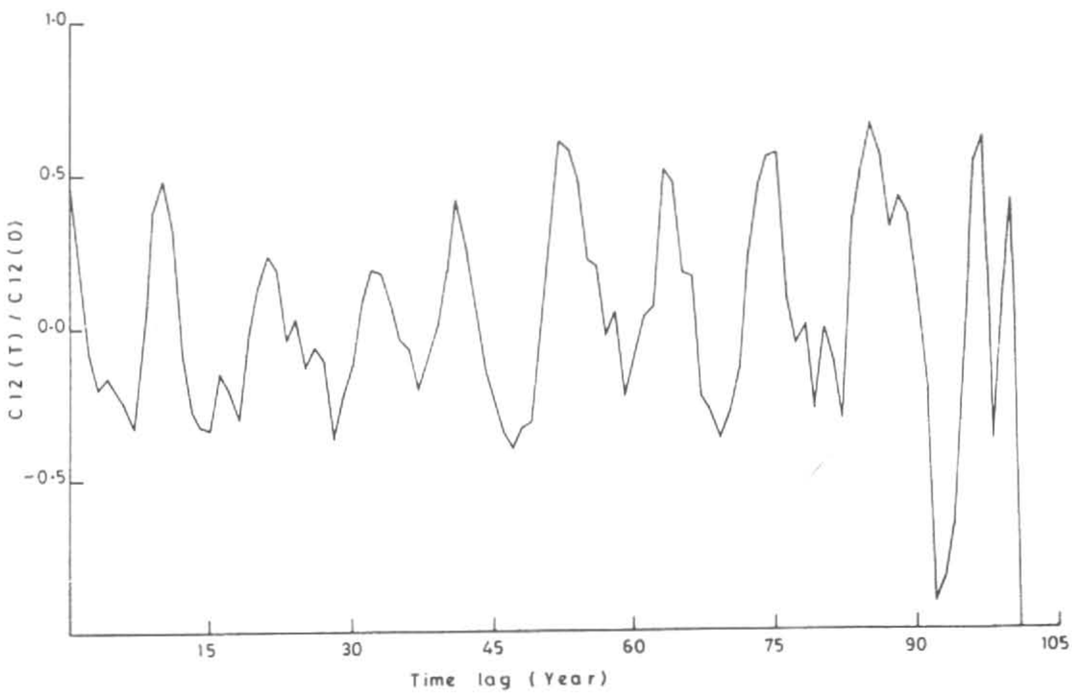

Fig. 4. Normalized cross-correlation coefficient $C_{12}(T)/C_{12}(0)$ starting from 1891 (t=0)

annual mean (R_a) in mm and spaced over an interval of one year without any interruption over a period of 102 years from 1891 to 1992. The data for sunspot number (R_z) for the period 1891-1960 was taken from the compilation of Waldmeier (1961) and from Solar Geophysical Data Reports published by NGDC (NOAA), Boulder, USA for the period 1961-92. Fig. 1 presents the annual mean rainfall data along with the sunspot number.

The relationship of sunspot activity with rainfall is further examined by carrying out correlation and harmonic analysis between sunspot numbers and the storage and runoff of Jaisamand lake and gauge levels of Jakham and Karmoi river flows. These places are situated within 50 to 150 km from Udaipur in southern Rajasthan. The data for Jaisamand lake and Jakham and Karmoi rivers as shown in Figs. 2 & 3 have been obtained from Department of Irrigation, Udaipur.

3. Data analysis and results

3.1. *Rainfall and sunspot activity*

To analyse the relation between sunspot activity and rainfall we have determined average rainfall over 10 sunspot maximum and 9 minimum years. Surprisingly, the average rainfall of sunspot maximum years is 762.8 mm while for sunspot minimum year it is 655.7 mm. At a first glance, this difference of 107 mm rainfall between sunspot maximum and minimum years suggests that sunspot activity may have some influence on the variation of rainfall in Udaipur subregion. The association between these two data sets is calculated by means of the linear correlation coefficient (also called Pearson's r) as given by the formula,

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x}) \sum_i (y_i - \bar{y})}} \qquad (1)$$

where, x is the mean of the x_i's and y is the mean of the y_i's (Press *et al.* 1986). We find r = 0.145 with a confidence level of 95% signifying a weak correlation between the two parameters. Thus it appears that parameters, such as planetary waves and winds during summer - monsoon and clouds during winter, may be affecting the rainfall to some significant extent. To avoid the effect of local parameters, we have further calculated the normalized cross correlation coefficient $C_{12}(T)/C_{12}(0)$ of R_z and

R_a using the formula,

$$C_{12}(T) = \frac{1}{N-T} \sum \left[x(t) - \bar{x} \right] \left[y(t+T) - \bar{y} \right] \quad (2)$$

where, N is the total number of data points, T is the lag number (T = 0, 1, 2, ..., tm; tm being the maximum lag). The result presented in Fig. 4 reveals a periodicity of about 11-year or its multiples between normalized cross correlation coefficient $C_{12}(T)/C_{12}(0)$ and time lag. This periodicity matching no doubt gives a positive evidence for the relationship between the sunspot activity and mean annual rainfall in Udaipur subregion.

3.2. *Periodicity of floods and droughts*

It may be noted that the average annual rainfall (R_m) is 637 mm while the standard deviation (σ) of the rainfall distribution is 200 mm approximately. The level of rainfall, such as normal, above normal and below normal, may be defined in view of the standard criteria as following:

(*i*) Normal = $R_m \pm 1\sigma$

(*ii*) Above Normal > $R_m + 1\sigma$

(*iii*) Below Normal < $R_m - 1\sigma$

The statistical analysis based on the equal probability of occurrence of rainfall with respect to average (R_m) and standard deviation (σ) shows that the number of years for above and below normal rains is 16 and 12 respectively which are approximately same. This shows that a total 28 years out of 104 years deviated from normal rains, thereby indicating a 27% period as fluctuating from average rainfall in Udaipur. We may further define as following, the rainfall in standard 5 categories, *viz.*, normal, excess, flood, deficit and drought to understand better the rainfall characteristics in Udaipur sub-tropical region:

(*i*) Normal = $R_m \pm 1\sigma$

(*ii*) Excess $\geq R_m + 1\sigma$ but < $R_m + 2\sigma$

(*iii*) Flood > $R_m + 2\sigma$

(*iv*) Deficit < $R_m - 1\sigma$ but > $R_m - 2\sigma$

(*v*) Drought < $R_m - 2\sigma$.

Given in Table 1 are the number of years for different levels of rainfall during each sunspot cycle from cycle number 13 (1889-1900) to 22 (1986-95) as defined above. The table shows that Udaipur has observed a total of 5 floods (water-logging) and almost equal number of years of excess and deficit rainfall, *i.e.*, 11 and 12 years respectively. However, according to above definition of rainfall categories, Udaipur has not observed any drought which does not appear true. Thus, we define a special rainfall category, "severe drought", only for Udaipur sub-tropical region and not in general, as the deficit rainfall year for which the rainfall is less than the preceding two years and a trend of continuous decrease in rainfall for consecutive three years is observed. The definition of "severe drought" is further extended to total rainfall of these three consecutive years and that it should not exceed $3R_m$. Considering this definition, Udaipur has observed 5 such droughts in 1899, 1915, 1936, 1972 and 1987. This indicates the average periodicity of the severe drought is about 21 years,

TABLE 1

No. of years for different levels of rainall during each sunspot cycle

Period	Sun-spot cycle	Cycle years	Number of years				
			Nor-mal	Exc-ess	Flood	De-ficit	Dro-ught
1889-1900	13	12	8	1	1	2	0
1901-1912	14	12	10	0	1	1	0
1913-1922	15	10	7	0	1	2	0
1923-1932	16	10	6	2	0	2	0
1933-1943	17	11	9	1	0	1	0
1944-1953	18	10	7	2	1	0	0
1954-1963	19	10	8	2	0	0	0
1964-1975	20	12	8	1	1	2	0
1976-1985	21	10	9	1	0	0	0
1986-1995 (upto 1992)	22	7	4	1	0	2	0
Total			76	11	5	12	0

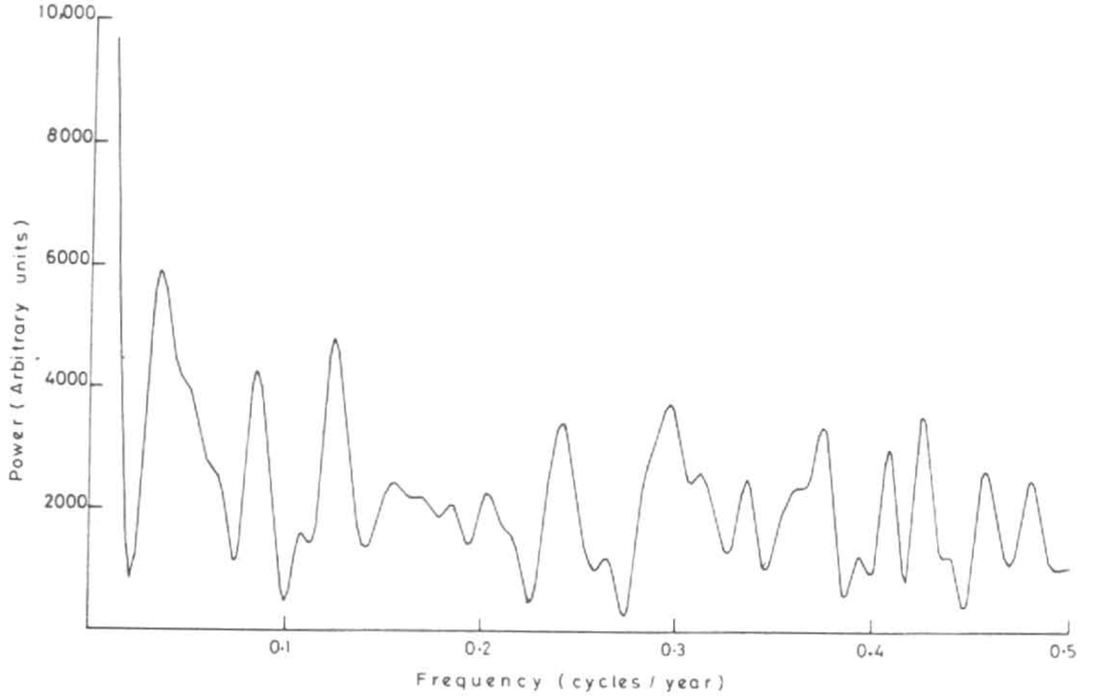

Fig. 5. Power spectrum of annual average rainfall in Udaipur subregion over a period of 102 years (1891-1992)

a period close to Hale sunspot cycle, i.e., 22 years. Similar results regarding droughts were shown earlier by Mitchell et al. (1979) for western USA and recently by An and You (1993) for China. On the other hand, the power spectrum of rainfall in Udaipur (Fig. 5) clearly indicates flood periodicity of about 25 years and excess rainfall periodicity of 11.5 and 8.3 years which are closely related to sunspot cycle frequency. The lower peaks corresponding to normal rains have periodicity in the range 2-4.5 years, while the flat spectrum of lower power in the periodicity range of 5-6.5 years corresponds to deficit in rainfall. In Table 2, we have shown how all these periodicities coincide with main and/or quasi-periodicity of sunspots as determined by Currie (1973).

3.3. *Periodicity of Jaisamand lake, Jakham and Karmoi rivers*

The analysis is further extended to include areas away from Udaipur in southern Rajasthan, i.e., Jaisamand lake & Jakham and Karmoi rivers which are situated about 50 and 150 km away from Udaipur respectively. More than 200 large and small rivers are the sources for water-logging in Jaisamand lake. As mentioned earlier, this large mass of water is stored and daily measurement is made by Department of Irrigation, Government of Rajasthan. We obtained the yearly average storage and runoff data for 32 years for Jaisamand lake. A power spectrum analysis of this data shows the maximum storage frequency to be 24, 12 and 2.4 years. Similarly, the periodicity of the maximum runoff of lake water is found to be 16.8, 11.8, 8.2 and 3 years. But the higher frequency of 24 and 16.8 years cannot be considered to be true as the Nyquist frequency of the data set is only 16 years. The power spectrum of the gauge data of Jakham and Karmoi rivers shows gauge frequencies of 12 and 3 years while the drought period frequency is about 10 and 3 years. It is remarkable that even with a limited data set of 32 years, the storage, the runoff and the river gauge frequencies are in close correlation with the 11-year periodicity determined using the rainfall data. The linear correlation analysis of the rainfall with the storage and runoff data of the Jaisamand lake yields $r = 0.58$ and 0.63 respectively with a confidence level of 99.5%. However, the river gauge data shows a weak correlation with the rainfall. Nevertheless all these periods, as presented in Table 2, have a close coincidence with main and quasi-periodicity of sunspots as determined earlier by Currie (1973).

TABLE 2

Details of preferred periods and sunspot periods (from Currie 1973)

Data Set	Preferred periods (years)	Sunspot periods (From Currie)	Comments
1. Rainfall data			
(a) Floods	25.0	23.60	Main period
(b) Excess rainfall	11.5	11.10	Main period
	8.3	9.90	Quasi period
(c) Deficit rainfall	6.0	6.76	Quasi period
(d) Severe Droughts	21.0	23.60	Main period
2. Jaisamand lake data			
(a) Storage	12.0	11.10	Main period
	4.0	3.68	Quasi period
	2.4	2.27	Main/Quasi period
(b) Runoff	11.8	11.10	Main period
	8.2	9.90	Quasi period
(c) Droughts	8.0	9.90	Quasi period
	6.6	6.76	Quasi period
3. River gauge data			
(a) High gauge	12.0	11.10	Main period
	3.0	3.68	Quasi period
(b) Droughts	10.0	9.90	Quasi period
	3.0	3.68	Quasi period

4. Possible physical mechanisms

Although the possible mechanisms coupling the sunspot cycle and weather or in particular, rainfall has been widely investigated, a unique and unambiguous physical mechanism has not yet emerged. Here we discuss some of these mechanisms from a purely astrophysical context and the reader is referred to Bhalme *et al*. (1981) for a discussion on some other mechanisms. Morth and Schlamminger (1979) have considered the changes in orbital angular momenta of planets due to gravitational perturbation for showing the climatic variation. It is known that almost 98% of the angular momentum of the solar system is contained in the orbital motion of the four giant planets — Jupiter, Saturn, Uranus and Neptune. Considering the potential relevance of the motion of these giant planets to the sunspot variation, they show that certain pairs and pair groupings have highly commensurable mean motions. The synodic half periods of these motions correspond to the principal sunspot number frequencies, such as, 10-year period appears to be associated with relative motion of the pair Jupiter-Saturn, the 90-year period with that of Uranus and Neptune and the 11-year period with the motion of the pair Jupiter-Saturn relative to the pair Uranus-Neptune. The periodicity of rainfall as determined from this analysis particularly that of 8-12 years is in good correlation with the synodic half periods of motion of these giant planets.

The physical link between planetary motion and sunspots is probably seen in the outward transfer of the angular momentum from the sun to the outer fringes of the solar system. We assume the existence of a basic outward energy flow from the sun, affected by acceleration of outer planets through gravitational perturbation by inner planets, which is rhythmically modulated by the orbital configuration of all the planets. The transmission of gravitational torque in the solar system is assumed to cause changes in the global and local vorticity patterns of low inertia materials, such as the solar photosphere and the terrestrial atmosphere. This provides a mechanism of control on the terrestrial atmospheric circulation and climate by extra-terrestrial forces.

We have also explored the possibility of correlation of rainfall with tidal forces due to various planets which change with time due to radial alignment of one or more planets with Jupiter. Recently, it has been shown by Verma (1993) that the tidal forces may initiate the process for formation of sunspots on the sun. His argument is based on one-to-one correlation between the changes in sunspot number and tidal forces periodicity. If this interpretation is considered to be correct, then the influence of these tidal forces on the earth cannot be ignored. In this connection, Mitra (1992) has shown 18.6 year luni-solar tidal response and also 8-9 years and 11-14 years solar signal components which may produce an element of climatic variability in India. Thus we comprehend that the global rainfall on earth may be associated with the tidal forces of the planetary motion. It may also be possible that sunspot activity, planetary motion, tidal forces and climatic variations on the earth are all correlated with each other. However, in this study we have investigated only the relationship with the local scale rainfall of Udaipur.

5. Conclusion

The periodicity obtained in this paper, using various data sets, can be broadly divided in the following groups: 21-25, 16-17, 8-12 and 2-6 years. All these periods are well correlated with sunspot main periods and/or quasi-periods. The slight difference may be attributed to local effects including orography which may cause changes in the local circulation patterns of winds, erratic formation of clouds and condensation. These local effects and other factors like planetary waves of similar periodicity may also attenuate or even mask the luni-solar or solar cycle period in the rainfall data. This may be one reason why all data sets (also from different places) do not show the exact periodicity. In context to physical mechanisms discussed, it is possible that sunspot activity, planetary motion, tidal forces and climatic variation on the earth are all correlated with each other.

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