messages (of importance in defence) where the messages are masked by synchronizing with chaotic waveforms.

T. R. Krishna Mohan (C-MMACS, Bangalore) explained the procedures for reconstruction of a phase space from single variable time series and the estimation of correlation dimension (Grassberger–Procaccia algorithm[7]) and Lyapunov exponents from the phase space dynamics. Pradhan (NIMHANS, Bangalore) discussed and explained the problems associated with ascertaining whether a time series originates from nonlinear, deterministic evolution or from a linear, stochastic process which can give rise to coloured noise having similar spectral properties. Prabhakar Vaidya (Washington State University, now visiting C-MMACS) gave a talk on methods that can be used for unambiguously confirming the presence of a nonlinear, deterministic process in time series; the methods he spoke on (trans-spectral coherence) are related to higher order spectral methods and can also be used in connection with premonition of chaos, i.e. to identify possible transition to chaotic states.

Deepak Dhar (TIFR, Mumbai) gave two lectures on self-organized criticality and sandpile models; he showed the relationship of abelian sandpile models to other related models such as Potts model, Voter model, Takayasu aggregation model and river networks.

Anita Mehta (S. N. Bose Institute for Basic Sciences, Calcutta) spoke on the complexity of granular materials, namely sand, and the relevance of ideas such as self-organized criticality to the physics of actual sandpiles. Sudeshna Sinha (Indian Institute of Astrophysics, Bangalore) discussed the general strategies of modelling spatio-temporal phenomena by coupled–map lattice models.

Three afternoon sessions were devoted to experiments. A variety of PC-based computer programs were made available to participants in order to help them understand the various concepts covered during the lectures, and to enable them further explore different aspects of chaotic dynamics and fractal geometry through numerical experiments. There were also experiments using electronic circuits to show the period doubling route to chaos, as well as strange attractors. A practical realization of the phenomenon of chaotic synchronization using two circuits was shown, and the ideas of secure communication using chaotic masking was demonstrated by Manu and Kapilanjan Krishan of Khalsa College, New Delhi.

Three evening colloquium talks marked the conclusion of the workshop activities on each day. Anita Mehta gave a general overview of the physics of sand, of the physics of granular state, in her colloquium talk, 'Probing Sand'. Rahul Pandit (IISc, Bangalore) talked on homogeneous, isotropic turbulence with emphasis on the scaling of velocity structure functions, on the multiscaling and self-similarity aspects. In another, R. Narasimha (IISc and JNCASR, Bangalore) talked on aspects of clouds as complex systems with focus on understanding of entrainment process in tall cumulus clouds where horizontal diffusion is practically nil and vertical diffusion is practically infinite! He described experiments being carried out at IISc (with Prabhu and Bhat) to study the mechanism of this strange behaviour. The large-scale vortical structures in the flow 'engulf' ambient fluid from the surroundings in the first process of entrainment, followed by 'mingling' of the engulfed fluid into the core flow and, finally, it is 'mixed' in at the molecular level. The experiments are designed to study the modifications brought about by local heating which takes place, for example, by the release of latent heat during condensation, in clouds.

1. Lorenz, E. N., *J. Atm. Sci.*, 1963, **20**, 130–141.
2. May, R., *Nature*, 1976, **201**, 459–467.
3. Gleick, J., *Chaos*, Viking, Penguin, New York, 1987.
4. Ott, E., *Rev. Modern Phys.*, 1981, **53**, 655–671.
5. Bak, P., Tang, C. and Wiesenfeld, K., *Phys. Rev. Lett.*, 1987, **59**, 381–384.
6. Prigogine, I. and Stengers, I., *Order out of Chaos*, Flamingo Fontana, London,, 1985.
7. Grassberger, P. and Procaccia, I., *Phys. Rev. Lett.*, 1983, **50**, 346–349.

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OPINION

Monsoon: A bioclimatologist's point of view

V. M. Meher-Homji

A plant geographer's main concern with the climate is to seek correlations with the vegetation. Precipitation, temperature and evapotranspiration have been commonly used. Lesser known factors like the régime (season of occurrence of rains) have been developed here for a better understanding of eco-diversity. Briefly discussed are the different origins of rainfall in India, the variability in the climatic factors and the transition from the Mediterranean régime to the west of the Indian sub-continent to the tropical monsoon type in the peninsula, across the Thar desert. A critical review is presented on palaeopalynological studies that tried to make out monsoon fluctuations during the Holocene. Deforestation may affect the local rainfall pattern without there being a change in the intensity of monsoon as a planetary phenomenon.

The monsoon, the very pulse of the Indian economy, is a word of Arabic origin 'mausim' meaning season. The term implies the seasonal reversal of the wind systems on which depended the marine navigation for the purpose of trade. Since the south-west winds are accompanied by rains, the layman tends to equate the monsoon with rainfall.

Different meteorological origins of rainfall

In a country like India, rainfall could be of different origin in meteorological sense. The south-west monsoon, the major source of moisture in the Indian peninsula, prevails from May–June to September–October. This system very much depends on the sea surface temperature and pressure. El Nino years witness reversal of normal conditions and consequently the monsoon fails in India.

There are two branches of the SW monsoon, the Bay of Bengal branch arriving earlier than the Arabian sea branch. Calcutta receives rain in the last week of May but Bombay only towards the second week of June. After September with the shift in the heat belt from Rajasthan–Punjab to the equator, the winds change direction; from mid-October to December dominate the north-east winds. The rains received in the Coromandel–Circar coastal region during this season are assigned to the NE monsoon. Earlier, the geographers believed that the winds from the north blowing over the Bay of Bengal picked up moisture and provided rains to coastal Tamil Nadu and Andhra Pradesh during the cooler season. Hence the term NE monsoon or retreating monsoon. However, when the winds are blowing from the north-east, the weather remains bright and clear. These are the depressions and cyclones formed during this season in the Bay which bring rains on the east coast. As the frequency of depression formation is highly variable, the rainfall also fluctuates a good deal, from 600 mm to 2000 mm at Madras.

Rainfall may be of orographic origin in the hills. The principle is that an air-mass striking a vertical obstacle like a mountain tends to rise. Finally, the rainfall may be of convectional origin. Due to excessive heating of certain pockets of land, especially in the pre-monsoon months, rising currents of air are set into motion taking the cloud moisture to considerable heights. Perhaps, it is the convectional type of rainfall that is most affected by the forest cover. Historical records reveal that the Chota Nagpur plateau of Bihar used to receive regular afternoon showers in April–May which favoured tea gardens but as probable result of massive deforestation carried out towards the turn of the century, this instability rain disappeared and it is no longer possible to grow tea in the area. Yet another example is that of Udhagamandalam (Ooty) which had 375 rainy days for the 5-year period 1870–1874, excluding the SW monsoon months June to August. For the 5-year period a century later, applying the same criteria, the number of rainy days has declined to 270 (ref. 1). It would be an interesting exercise to work out the contribution of these different categories of rainfall to the annual total.

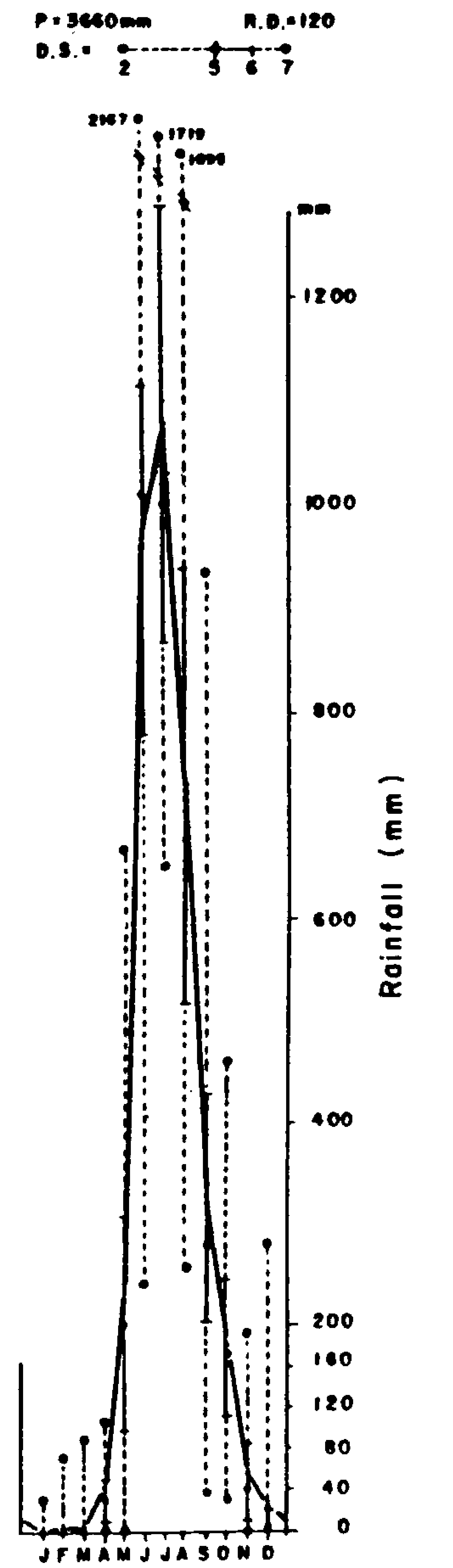
Régimes of rainfall

Though India is a tropical country, the season(s) of occurrence of rains vary from one part to the other. Mangalore (Figure 1) represents the typical tropical *régime* with rains beginning in late May and terminating after October, the peak being in July. Thus the rainfall curve maintains a perfect symmetry in the course of the year. Coming to the east coast of Tamil Nadu, at Tirunelveli (Figure 2), the symmetry of the curve is lost as the bulk of rains are received in October–November from the so-called NE monsoon. The rainfall is not only low but also erratic during the SW monsoon season over the Coromandel coast. In fact the character of rainfall in June, July, August at Madras and Pondicherry suggests that these are convectional showers (thunderstorms); over 85 per cent of rains occur between sunset and sunrise in short spells mostly accompanied by thunder and lightening.

Mysore (Figure 3) also experiences little rains during the SW monsoon; the *régime* is characterized by two peaks, one in April (due to convection) and the other in October (depressions and convection). The two peaks are reminiscent of the equatorial *régime* of the stations close to the equator like Colombo. Udhagamandalam (Figure 4) has a three- peak *régime*: July (SW monsoon), besides April and October. These few samples illustrate the range of *régime* in India[2,3].

Régimes and vegetation

Realizing that the vegetation is determined by several variables of climatic factors, Köppen[4] used the data of precipitation together with the temperature to establish the boundaries between the arid, semi-arid and humid climates and the corresponding vegetation. Given that the precipitation



Typical tropical régime

Figure 1. Rainfall *régime* at Mangalore (alt = 22 m). Λ = Rainfall curve; $\overset{\circ}{\underset{\circ}{!}}$ = Octile values; P = Rainfall; RD = Number of rainy days; DS = Length of dry period in months.

is more effective if it occurs during winter than in summer, he assigned different weightage to the areas of summer rainfall and winter rainfall.

We wish to highlight the role of *régime* factor, i.e. of the season of occurrence of rains with reference to some noteworthy examples of vegetation in India. The forest map (Figure 5) shows the dominance of sal (*Shorea robust*) in the eastern half of the peninsula and that of teak (*Tectona grandis*) in the western half. In terms of rainfall quantum, temperature, length of the dry period there is not much difference in the ranges of these factors. What is important is the timely arrival of rains when the viable seeds of sal are available. The seeds have a short period of viability of about ten days. If the rains are not in time, the germination fails. The rains which set in earlier in the eastern part of the peninsula favour the sal germination. As rains are delayed in the western counterpart, sal gradually disappears westwards and the dominance is taken by teak. In coastal plains of Tamil Nadu prevails a very unique vegetation type termed as the *tropical dry evergreen forest*. Occurring in the physiognomic form of scrub jungle, it is deprived of the typical species of the deciduous forest like teak, sal, rosewood and many more. The distribution of this type coincides with the zone experiencing the dissymmetric type of rainfall *régime* illustrated in Figure 2.

The economically valuable red sanders tree (*Pterocarpus santalinus*) is confined to the Cuddapah basin and the Nallamalai Hills in Andhra Pradesh. Its endemic occurrence corresponds to the zone where the transition is taking place from the dissymmetric *régime* of Nellore on the Coromandel coast to the typical tropical *régime* of Kurnool on the Deccan plateau (Figure 6) (ref. 5). These few instances bring out the significance of rainfall *régime* factor in bioclimatology, a factor ignored both in geography and forestry.

Variability of monsoon

The inter-yearly variability in the wake of the vagaries of monsoon distorts the image of the climate based on averages. The variations in the annual quantum of rainfall are too familiar to merit further discussion. The consequent fluctuations in the length of the dry period though significant in plant geography have been almost overlooked. At Kodaikanal, the majority of individual years experience a dry period of 1 to 4 months, yet on the basis of averages, the dry season does not come out as the dry spells occur in different months in different years. New Delhi, with an average dry period lasting for 9 months, has the range of dryness of 7 to 11 months.

In other cases, the variations involve

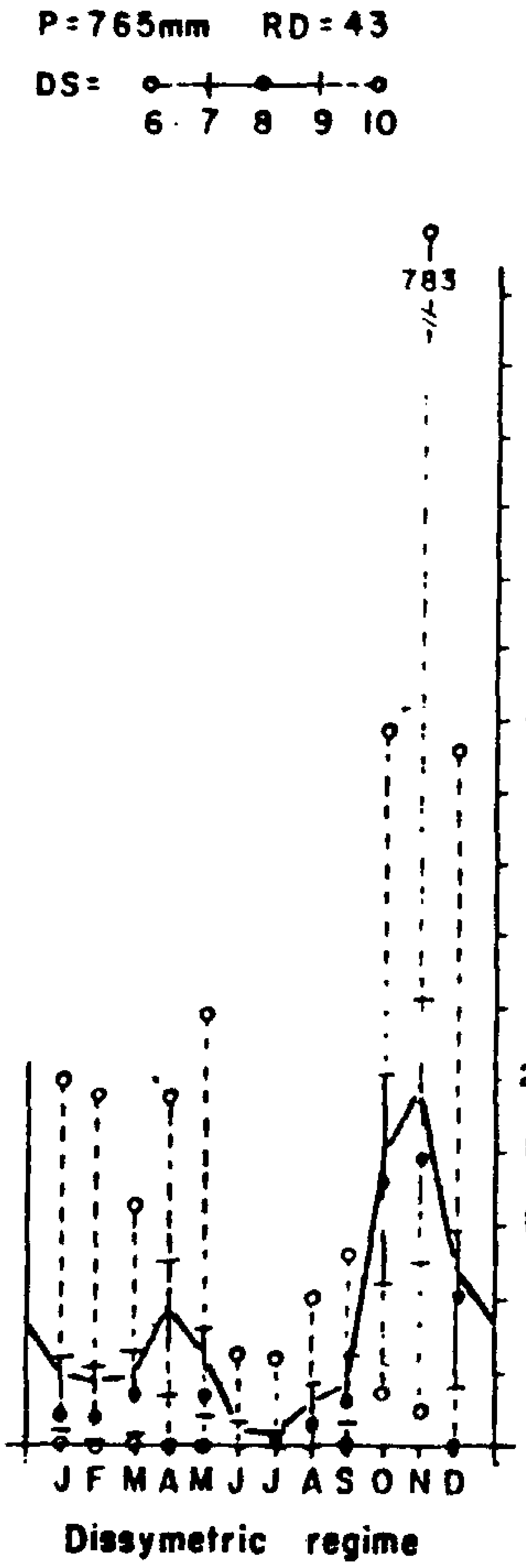


Figure 2. Rainfall *régime* at Tirunelveli (alt = 42 m). Λ = Rainfall curve; $\vdots$ = Octile values; P = Rainfall; RD = Number of rainy days; DS = Length of dry period in months.

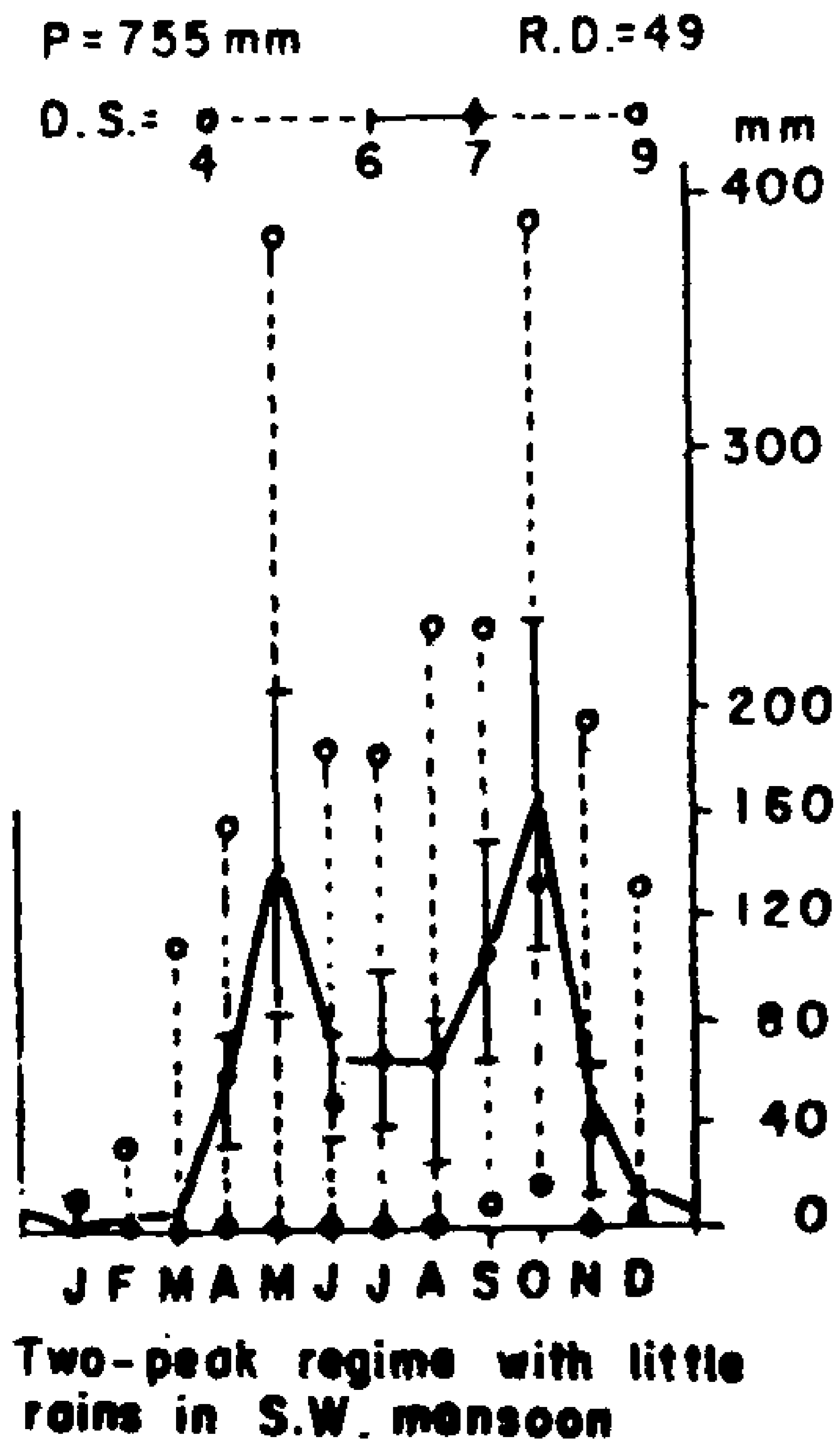


Figure 3. Rainfall *régime* at Mysore (alt = 767 m). Λ = Rainfall curve; $\vdots$ = Octile values; P = Rainfall; RD = Number of rainy days; DS = Length of dry period in months.

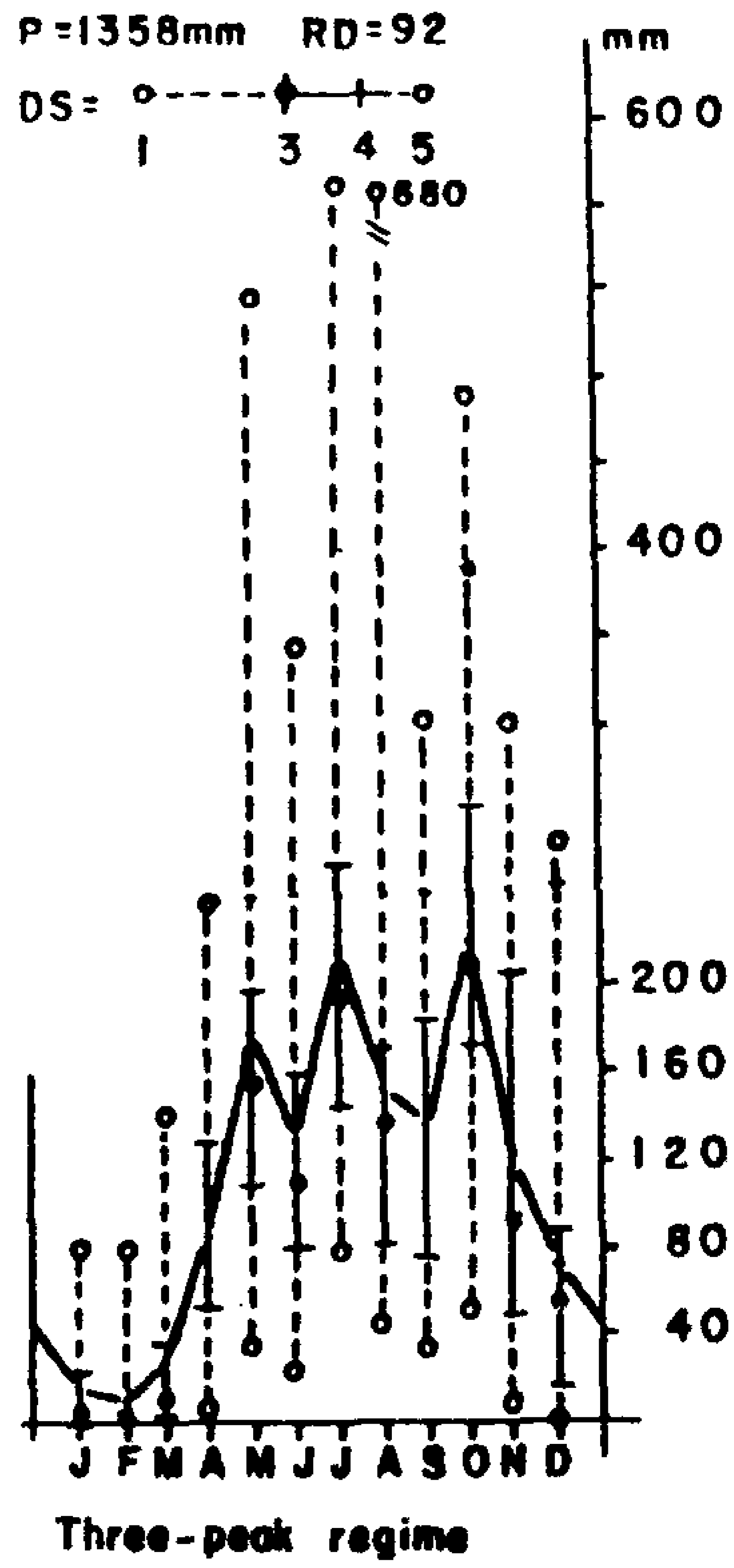


Figure 4. Rainfall *régime* at Udhagamandalam (alt = 2249 m). Λ = Rainfall curve; $\vdots$ = Octile values; P = Rainfall; RD = Number of rainy days; DS = Length of dry period in months.

the *régime*. Some stations in the northern and north-western parts of the sub-continent present the average *régime* of Mediterranean type with winter-spring rains brought on by the western disturbances, and summer dryness. However, the *régime* tends to vary from year to year as exemplified by the climate diagrams of Peshawar (Figure 7). The interplay between the two rain-bearing meteorological phenomena, – western disurbances and summer monsoon, in the Indo-Pakistan arid zone results in a series of *régimes* shown in Figure 7. It is in this desertic tract of the Thar and adjoining regions that the transition takes place from the Mediterranean *régime* of countries like Iran and Afghanistan to the tropical monsoon *régime* of peninsular India.

Palynology and the intensity of monsoon during the Holocene

Palynological data have been used to

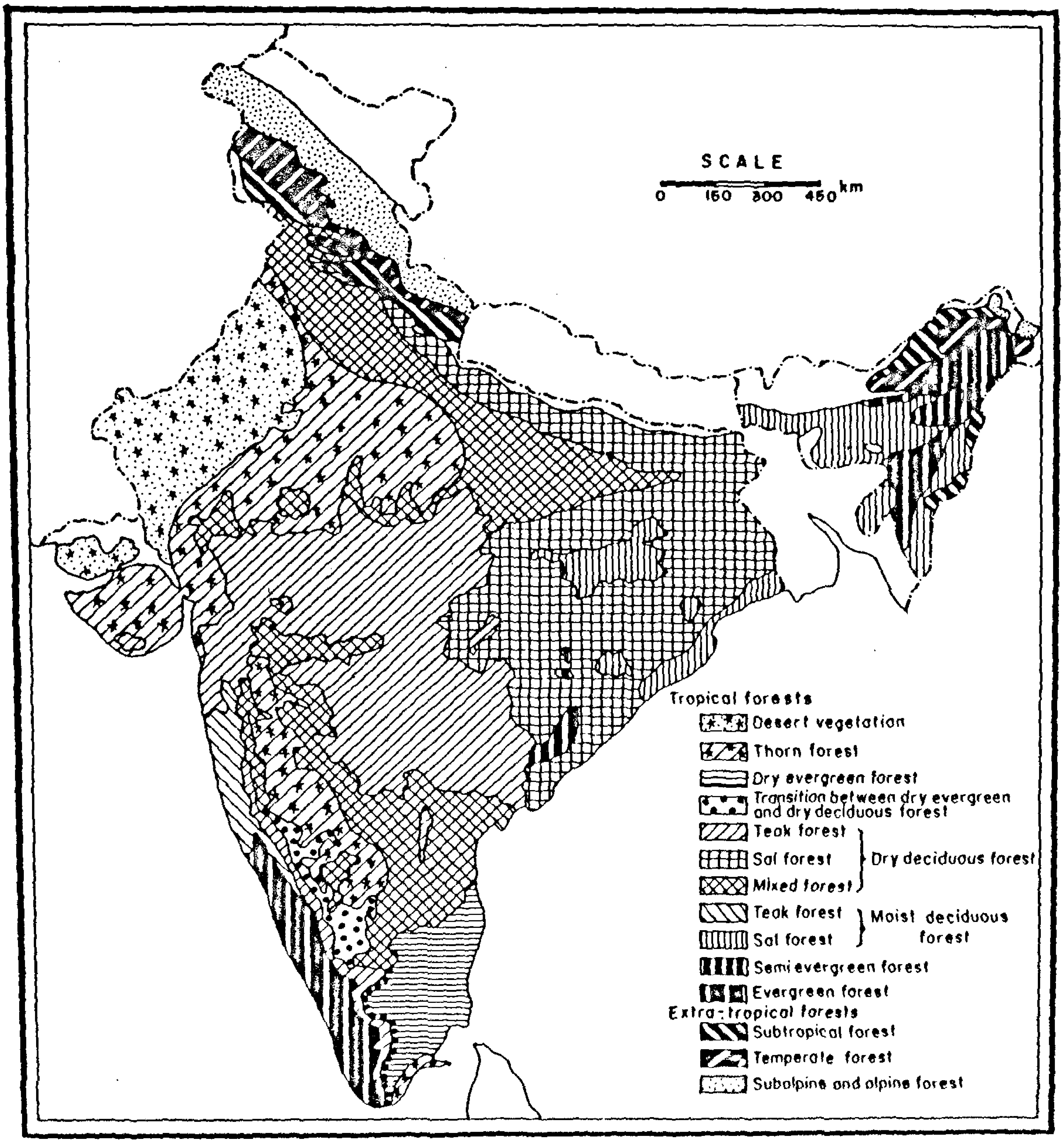


Figure 5. Forest types of India.

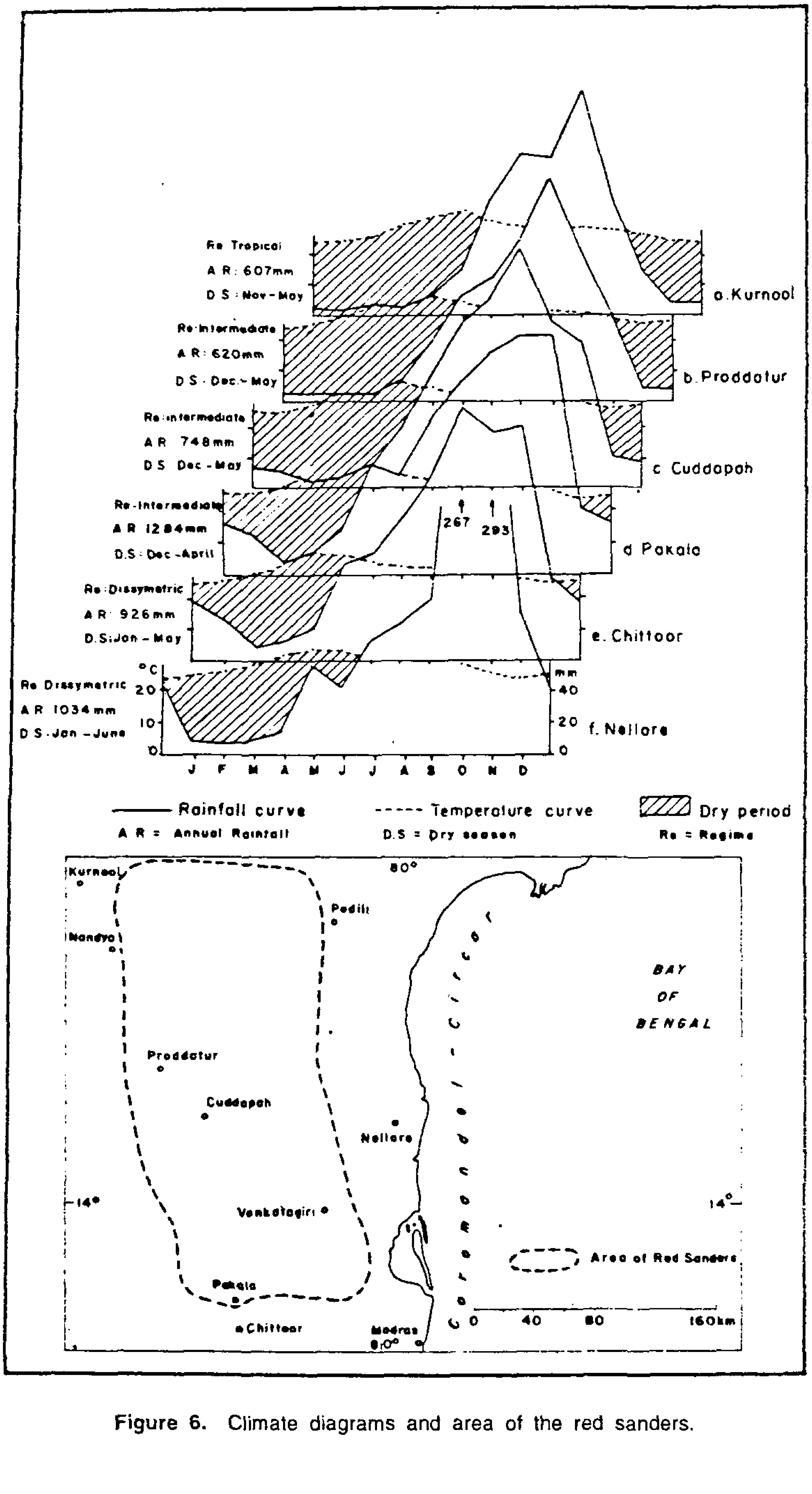


Figure 6. Climate diagrams and area of the red sanders.

decipher the strength of monsoon, weak or strong, within the last 10,000 years. Gurdip Singh *et al.*[6], based on the analysis of pollen grains of sediments of lakes in Rajasthan suggested alternation of several relatively humid phases with drier ones during the Holocene. However, the species selected as markers of stronger monsoon activity are unfortunately not very fidel indicators of humid conditions[7–9]. If the rainfall had taken a distinct upward trend, why do the pollen of deciduous forest species of the Aravallis find no representation in the profile of the Sambhar lake?

Caratini *et al.*[10] analysing two marine cores collected from the inner shelf off Karwar opposite the mouth of the Kalinadi for their pollen content observed a change in the vegetation pattern beginning around 3200 years BP, getting more pronounced a millennium later and stabilizing thereafter. A marked decline in the pollen of the evergreen, deciduous and mangrove forest species in the favour of grassland species was taken as an indication of onset of a less humid phase linked to a weaker monsoon. However, the anthropogenic interference cannot be ruled out altogether in bringing about the vegetation change. Man's activity started with iron implements around 1000 BC or even earlier with slash and burn agriculture[11,12]. Grasslands are essentially the result of passage of fire at low and middle elevation. Paddy cultivation in the estuaries was probably the reason for the decrease of mangroves[11].

The decline in rainfall need not necessarily imply a weakening of monsoon activity; large scale deforestation may affect the microclimate and local rainfall. The link between forests and rainfall has been a controversial issue and a debated topic. Gadgil and Prasad[13] have stressed the use of realistic models capable of simulating the various effects of deforestation such as changes in albedo and soil moisture. Their computer experiments have shown that model simulated climates are influenced by land–surface boundary conditions. The areas most likely to undergo desertification in view of deforestation and the attendant biogeographic feedbacks are those in the vicinity of arid zones. The increasing marine influence noted by Caratini *et al.*[10] through proliferation of marine organisms like copepods, dinoflagellates, foraminifera and organic carbon of marine origin around 2200 years BP was likely due to a decrease in the flow of fresh water, in turn probably linked to massive deforestation.

In conclusion, the archaeological evidence of increasing human influence on the vegetation cover and the role of forests on the local climate deserve consideration

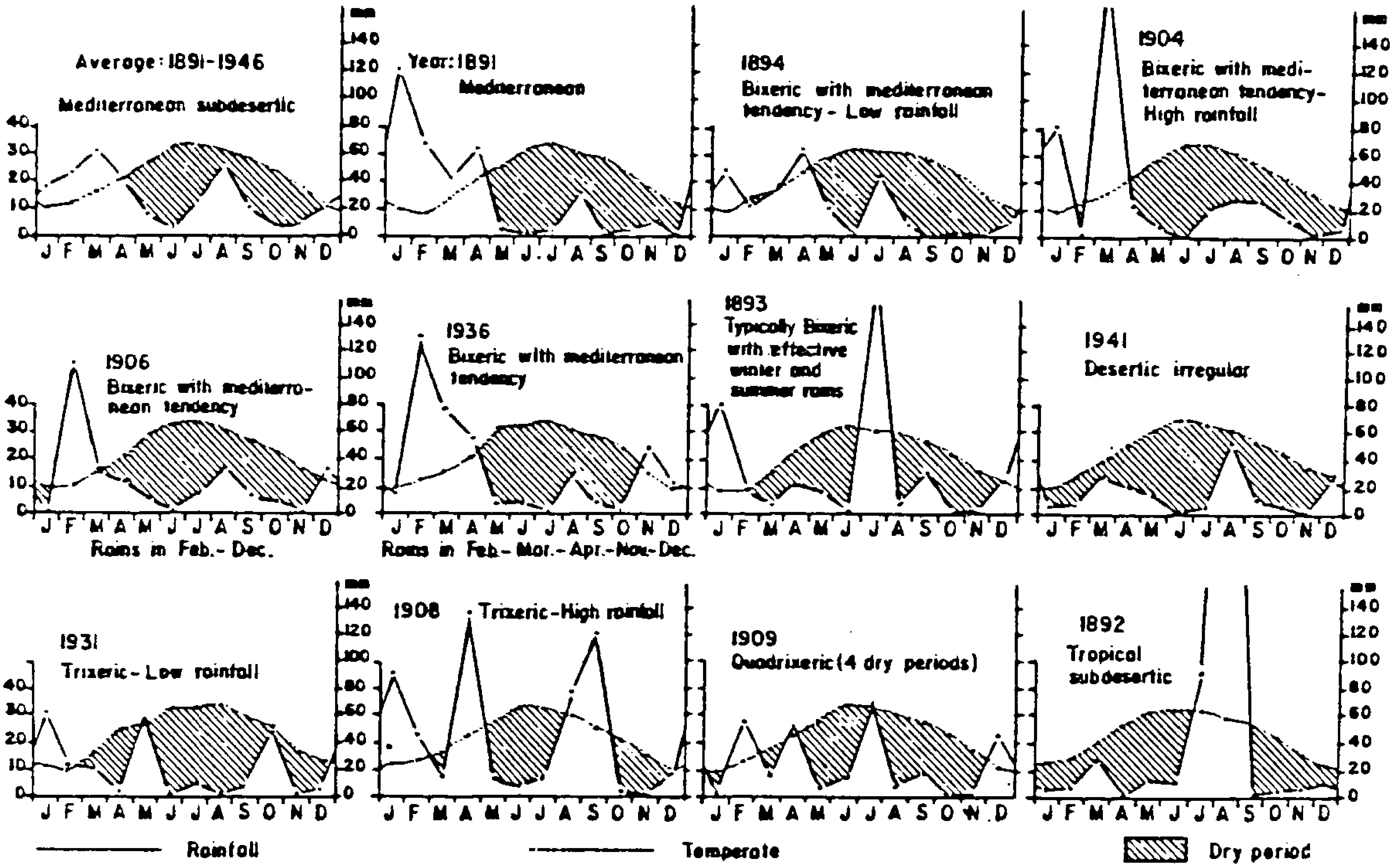


Figure 7. Inter-yearly variations in *régime* of Peshawar.

while discussing climatic fluctuations and monsoon behaviour in the later half of the Holocene.

1. Meher-Homji, V. M., in *Global Warming and Climate Change, Perspectives from Developing Countries* (eds Gupta, S. and Pachauri, R. K.), Tata Energy Research Institute, New Delhi, 1989, pp. 115–129.
2. Bagnouls, F. and Meher-Homji, V. M., *Inst. Fr. Pondichéry, Tr. Sect. Sci. Tech.*, 1959, **1**(4), 207–240.
3. Pascal, J. P., *Inst. Fr. Pondichéry, Tr. Sect. Sci. Tech.*, Hors Série No. 17, 1982.
4. Köppen, W., *Peterrn. Mit.*, 1918, **64**, 193–203, 243–248.
5. Meher-Homji, V. M., *Int. Tree Crops J.*, 1980, **1**, 143–146.
6. Gurdip Singh, Joshi, R. D., Chopra, S. K. and Singh, A. B., *Phil. Trans. R. Soc. Lond.*, 1974, **B267**, 467–501.
7. Vishnu-Mittre, *Geophytology*, 1974a, 4(1), 46–53.
8. Vishnu-Mittre, Symposium on Late Quaternary Development in Extra-European Areas, Special Publ. No. 5, 16–51, Birbal Sahni Institute of Palaeobotany, Lucknow, 1974b.
9. Meher-Homji, V. M., *Man Environment*, 1980, 4, 1–7.
10. Caratini, C., Fontugne, M., Pascal, J. P., Tissot, C. and Bentaleb, I., *Curr. Sci.*, 1991, **61**, 669–672.
11. Gadgil, M. and Subhash Chandran, M. D., *Changing Tropical Forests* (eds Dargavel, J., Dixon, K. and Semple, N.), Workshop meeting, Australian National University, Canberra, 1988, pp. 47–58.
12. Sundara, A., in *Rising Trends in Palaeoanthropology, Environmental Change and Human Response (Last Two Million Years)*, 1990.
13. Gadgil, S. and Prasad, C. R., *Science Age*, 1986, July, 25–28.

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