Mausam, (1984), 35, 3, 379-386

551.577.38 : 551.553.21 (548)

An analysis of trends in the rainfall and droughts occurring in the southwest monsoon and northeast monsoon systems in the southern Peninsular India

A. KRISHNAN

University of Agricultural Sciences, Bangalore

सार — दक्षिणी भारत के प्रायःद्वीप में कर्नाटक और तमिलनाडु राज्यों का, जहां दक्षिण-पश्चिम और उत्तर-पूर्व दोनों मानसूनों में वर्षा होती है, विस्तृत जलवायु संबंधी वर्गीकरण कर लिया गया है। इसे 1901–1975 की अवधि में इन राज्यों में कार्यरत सभी प्रान्तीय वर्षा-मापक स्टेशनों के आंकड़ों का उपयोग करके तैयार किया गया है। फिर इसकी तुलना पिछले वर्षों के विस्तृत जलवायु वर्गीकरण से की गई है।

1951-1975 के दौरान इन राज्यों में विभिन्न स्टेशनों पर रिकार्ड की गई वर्षा मात्रा की 1901–1950 के दौरान सामान्य वर्षा से तुलना करने पर पाया गया कि तमिलनाडु के बहुत से क्षेत्रों में जहां प्रधानतया उत्तर-पूर्वी मानसून के दौरान वर्षा होती है, बाद के वर्षों के दौरान वार्षिक वर्षा में कमी आई है। दूसरी ओर मालनाड क्षेत्र, तटीय कर्नाटक तथा कर्नाटक के भीतरी भागों में जहां दक्षिण-पश्चिम मानसून के दौरान वर्षा होती है, वार्षिक वर्षा में वृद्धि हुई है। इन वर्षो में वर्षा-मात्रा में आए अन्तरों को दर्शाने वाले मानचित्र दिए गए हैं।

दक्षिणी-पश्चिमी मानसून, उत्तर-पूर्वी मानसून और इन क्षेत्रों के विशिष्ट स्टेशनों पर मानसून-पूर्व गर्ज के साथ आंधी वाली ऋतुओं में होने वाली वर्षा और कुल वार्षिक वर्षा की प्रवृत्तियों का अध्ययन किया गया है। फिर इसके परिणामों पर विचार-विमर्श किया गया है। प्रवृत्तियों के अध्ययन के लिए स्वसमाश्रयण मॉडलों के उपयोग पर विचार-विमर्श किया गया है।

ABSTRACT. A detailed climatic classification of Karnataka and Tamil Nadu States of southern Peninsular India which receive rainfall from both southwest and northeast monsoon has been made by using the data of all provincial raingauge stations in these States for the period 1901-75 and a comparison of the same is made with earlier classifications.

A comparison of the rainfall normals (1901-1950) with the rainfall amounts recorded at different stations in these States during 1951-1975 indicates that decreases in annual rainfall have occurred in the latter period for many regions in Tamil Nadu which receive rainfall predominently during northeast monsoon, whereas increases have occurred in Malnad area, coastal Karnataka and north Interior Karnataka which receive rainfall mostly during southwest monsoon. Maps showing differences between rainfall during these periods have been presented. Trends of annual rainfall as well as rainfall during principal seasons, *viz.*, southwest monsoon, northeast monsoon and pre-monsoon thunderstorm season of typical stations in these regions have been studied and results discussed. Use of auto-regressive models for study of trends is discussed.

1. Introduction

Based on Thornthwaite's method, Subrahmanyam (1956) and Carter (1954) classified India's climate into 6 climatic regions ranging from arid to per-humid zones and 5 thermal efficiency types. Shanbagh (1956) and Bharucha and Shanbagh (1967) also applied the above mentioned classification method to 104 stations in India (Prepartition) and Burma. Subrahmanyam *et al.* (1965) utilised modified criteria of Thornthwaite and Mather (1955) for mapping climates of India in terms of moisture and thermal regions. Krishnan and Mukhtar Singh (1968) demarcated soil climatic zones of India by superimposing the moisture index and mean air temperature isopleths on a soil map of India showing major soil types. Rao *et al.* (1972) classified India's climate according to the water balance method of Thornthwaite and Mather, but used the mean monthly potential evapotranspiration computed by Penman's method. These climatic classification studies of India were based on the data of only meteorological observatories for which long period normals were available. Since the network of such stations is not dense enough for detailed climatic delineation

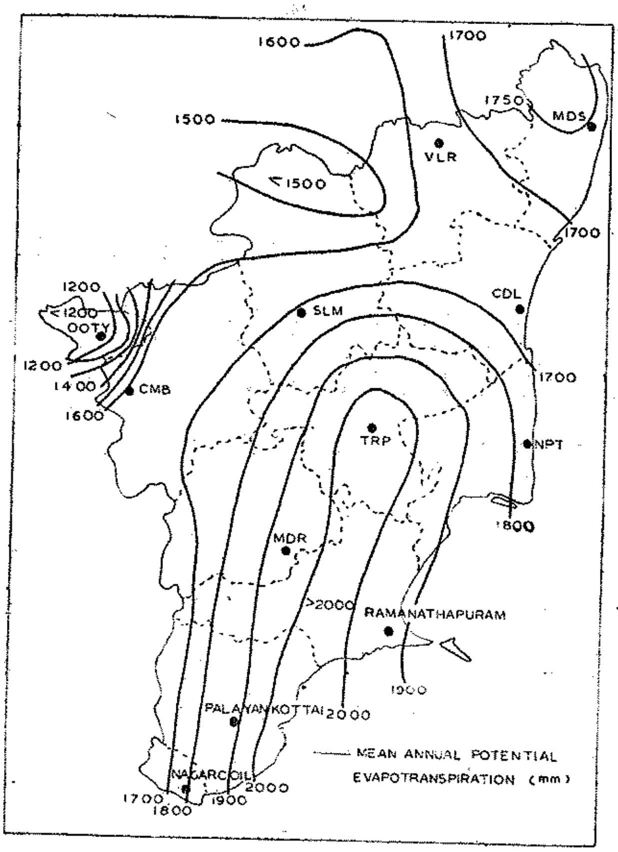

Fig. 1. Mean annual potential evapotranspiration (mm) of Tamil Nadu in Penman's method

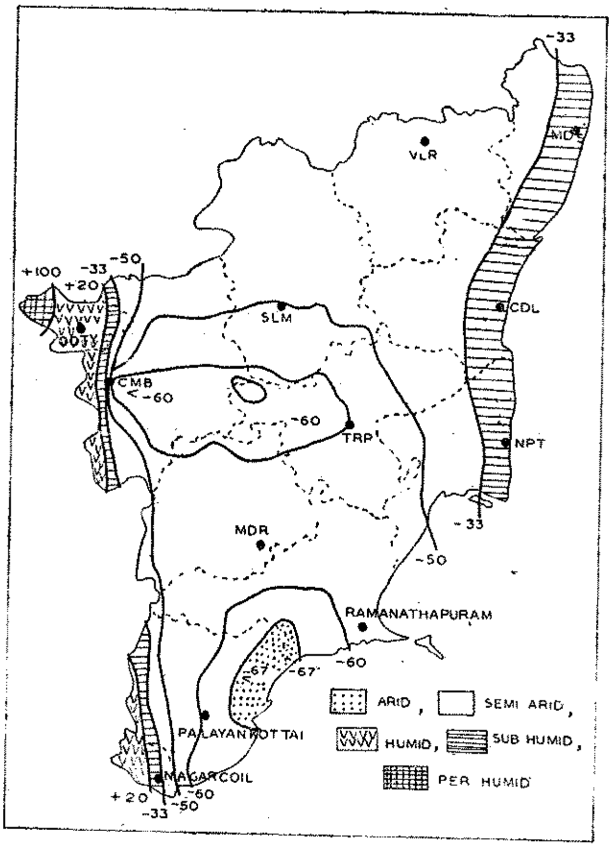

Fig. 2. Moisture index patterns and climatic classification of Tamil Nadu

of arid and semi-arid zones of India, Krishnan (1968) classified these zones in India using not only normals of meteorological observatories but also those of provincial raingauge stations which are numerous. In the present study, climatic delineation of the two southern States of India containing large areas under semi-arid zone, *viz.*, Tamil Nadu and Karnataka has been attempted utilizing the up-to-date data (1901-1975) of all provincial raingauge stations and using the potential evapotranspiration computed by Penman's method in the water balance calculations. A comparison of the rainfall normals and their seasonal distribution during 1901 to 1950 with the same pertaining to the period 1951-1975 has also been made.

2. Detailed climatic classification of Tamil Nadu

Fig. 1 shows the mean annual potential evapotranspiration (PE) of Tamil Nadu with values computed by Penman's method. PE values for individual raingauge stations were determined from this map by interpolation. The largest PE values exceeding 2000 mm are noticed in a strip extending from eastern coastal regions of Tirunelveli district to the southern portions of Tiruchirapalli district. There is a sharp decreasing gradient from east and westwards of this zone. The smallest PE values of less than 1500 mm are noticed in Dharmapuri district and Nilgiri district. The regions with mean annual PE values ranging from 1600 to 1700 mm are confined only to northern portions of Salem, Coimbatore, North Arcot and South Arcot districts.

Using the normal rainfall data PE of individual raingauge stations based on the data for the period 1901-1975 and the PE values interpolated from Fig. 1, moisture indices (P — PE)/PE were worked out and climatic classification was made according to Thornthwaite and Mather's (1955) method. This climatic map is presented in Fig. 2.

According to the present classification, the boundary between semi-arid and sub-humid zone is very much pushed towards east and passes through Tirutharaipundi, Tiruvarur, Villupuram and Tiruvallur whereas according to the earlier classification, the same commencing slightly north of Arantangi, passes through

TABLE 1

Number of raingauge stations in different districts of Tamil Nadu where the departure of mean annual rainfall during 1951-1975 from 1950 normals exceeds 50 mm [*viz.*, mean (1951-1975)—1950 normals]

Departure of mean rainfall (mm)	Chin-gleput	North Arcot	Salem*	South Arcot	Tiru-chi	Tan-jore	Madu-rai	Rama-natha-puram	Tiru-nel-veli	Kanya-kumari	Coimba-tore	Nilgiris
Positive departure												
51 to 100 mm	0	3	5	0	2	2	1	0	0	0	0	0
101 to 150 mm	0	0	1	0	0	2	1	0	0	0	0	0
151 to 200 mm	0	0	0	0	0	0	0	0	0	0	0	0
>200 mm	0	0	0	0	0	0	0	0	0	1	0	0
Negative departure												
—51 to —100 mm	3	2	6	8	8	7	5	6	4	0	6	1
—101 to —150 mm	3	1	0	3	3	4	3	4	4	0	1	0
—151 to —200 mm	1	0	0	1	3	2	1	0	2	0	0	0
<—200 mm	5	0	0	1	2	0	0	0	1	1	1	4
Total No. of stations under study	14	14	25	17	29	26	17	19	20	4	22	9

*Salem including Dharmapuri

Papanasam, Ulundurpet, Polur, Cheyyar and Arkonam. Thus in the present classification, there is no sub-humid zone at all in North Arcot district.

Further, existence of arid zone with moisture index less than —67 around Tuticorin has been reported by Rao *et al.* (1972). The present study has demarcated the exact shape of the same, *viz.*, it contains Tuticorin, Ottapidaram, Arasadi and Kumudhi regions.

Further, extremely dry area with moisture index value of less than —60 covers central portion of Coimbatore district and western Tiruchi district and small portions of adjoining Madurai and Salem district. Another extremely dry area of large magnitude covers eastern half of Tirunelveli district and adjoining south-western Ramanathapuram district. The moisture index values in Coimbatore, Madurai, Ramanathapuram and Tirunelveli districts are less than —50 except in case of their hilly regions and their surroundings.

3. Detailed climatic delineation of Karnataka State

Fig. 3 shows the mean annual potential evapotranspiration (PE) of Karnataka State computed by Penman method. The highest annual PE of more than 1950 mm occurs in the region covering Raichur and Yadgir of Gulbarga district. Values decrease towards north as well as south of this region. The least values of less than 1400 mm occur in Malnad areas and coastal regions of North Kanara. In the south Interior Karnataka, values range from 1400 to 1600 mm. In the coastal region of South Kanara, values increase towards Mangalore in the southwest.

Using the above method, climatic delineation of Karnataka State has also been made (Fig. 4). While the earlier boundary of the arid zone (Krishnan 1968) in Chitradurga, Raichur and Bellary districts have been confirmed in the new classification also, an additional narrow inverted L-shaped arid belt in Bijapur and adjoining northeast Belgaum district is revealed in the new analysis. Very dry areas with moisture indices of less than —60 cover Chitradurga, Bellary, Raichur and Bijapur districts, eastern portion of Dharwar and Belgaum district and western portion of Gulbarga district. While nearly whole of South Kanara district falls in per-humid zone, only western portions of North Kanara and Mercara districts fall under this zone. Sub-humid zone in the State exists only in a very narrow belt

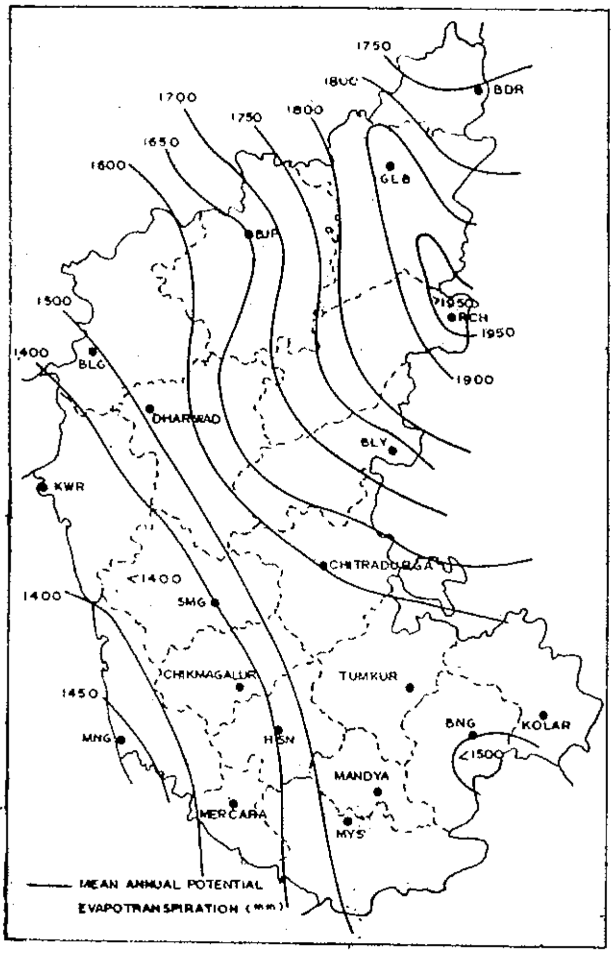

Fig. 3. Mean annual potential evapotranspiration (mm) of Karnataka

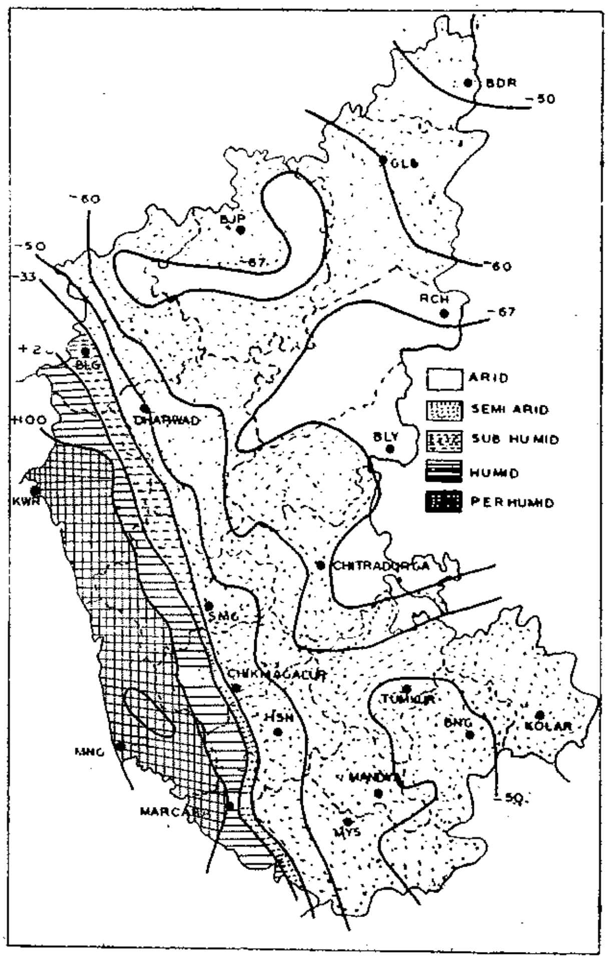

Fig. 4. Moisture index patterns and climatic classification of Karnataka

just east of Western Ghats extending from Balgaum to Mysore district.

4. Comparison of annual rainfall normals (1901-1950) of Karnataka and Tamil Nadu States with mean annual rainfall during 1951-75

(a) Karnataka State

Fig. 5 shows the difference in mm between annual rainfall normals (1901-1950) and mean annual rainfall during 1951-1975. It is seen that the region where the latter exceeds the former by more than 50 mm covers Gulbarga, Bijapur, Raichur, western Bellary and Dharwar districts as well as coastal and Malnad regions of Karnataka State. This difference exceeds 100 mm in coastal and Malnad regions and parts of Bijapur, Gulbarga and Bellary districts. In many coastal areas, mean rainfall (1951-1975) exceeds 1950 normals by more than 300 mm. It is interesting to note that these regions are those which receive their annual rainfall mostly during the southwest monsoon.

In another region covering mostly Bangalore district and adjoining parts of Tumkur and Kolar districts, mean annual rainfall (1951-1975) exceeds 1950 normals by more than 50 mm. These are practically no region where the former is less than the latter by more than 50 mm except for some isolated small pockets shown in Fig. 5.

Isolines in Fig. 5 for differences are in multiples of 50 mm. The minimum range chosen, *viz.*, 50 mm is more than the standard error for statistically testing the difference between 1901-1950 normals and 1951-1975 means for the drier Interior Karnataka stations. The statistical significances of differences between 1901-1950 normals and 1951-1975 means have also been tested by appropriate '*t*' test at 5 per cent level of signi-

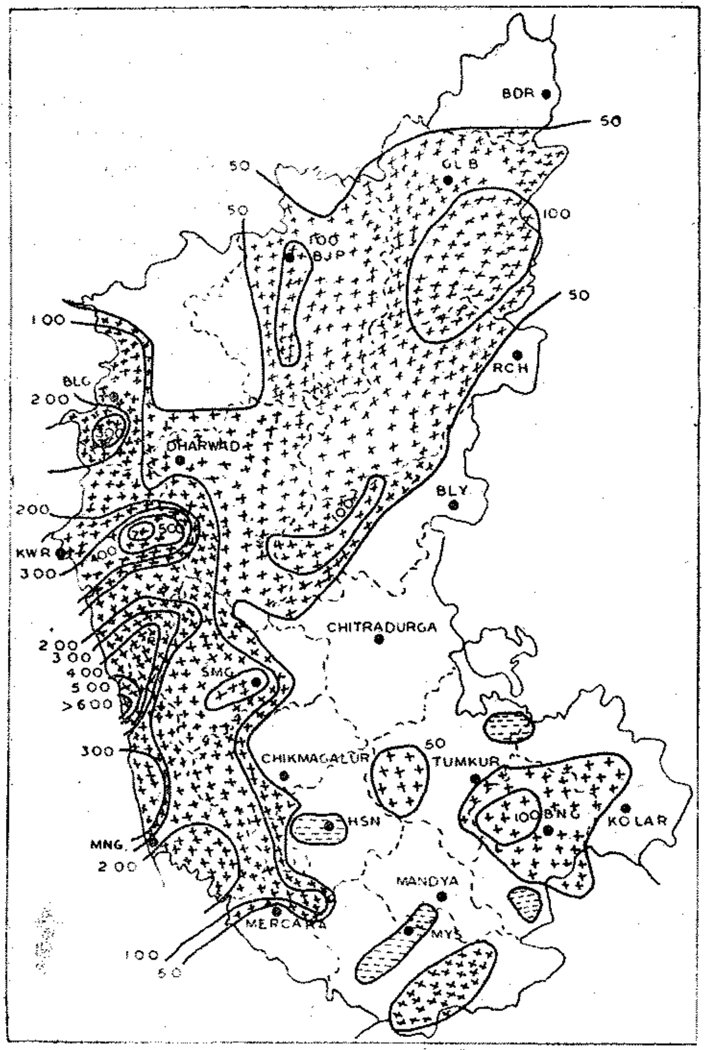

Fig. 5. Differences (mm) between rainfall normal based on 1901-1950 and mean rainfall during 1951-1975

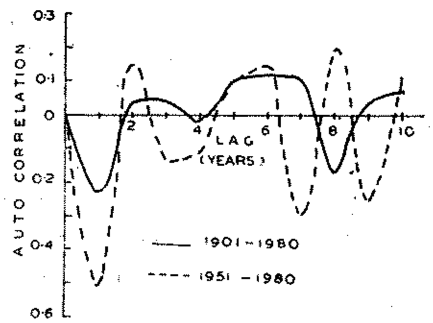

Fig. 6. Auto-correlation function of annual rainfall of Bangalore

ficance for all the raingauge stations in Karnataka. It is found that for almost all the interior stations within "50 mm difference" isolines in Fig. 5, the differences are statistically significant. Similarly, for Maland region and coastal regions also, differences are statistically significant except for a few stations for which also actual differences though not statistically significant are very close to critical differences for significance. Thus, there is an indication that the period 1951-1975 has been wetter in these regions as compared to the earlier 50-year period.

(b) Tamil Nadu State

Another feature noticed during the computation of normals for the period 1901-1975 is the large decrease noticed in the annual rainfall during the period 1951-1975 as compared to 1950 normals. This is particularly true in respect of coastal districts of Chingleput, South Arcot, Tanjore, Ramanathapuram and Tirunelveli and also in the districts of Madurai, Tiruchy and Coimbatore. Only in Salem and North Arcot districts increases have been noticed during 1951-1975 as compared to 1950 normals.

Table 1 shows the number of raingauge stations in different districts of Tamil Nadu where the departure of mean annual rainfall during 1951-1975 from 1950 normals exceeds 50 mm and also gives the frequencies under different ranges of departure. It is seen that the departure is mostly negative except in North Arcot and Salem districts (including Dharmapuri) where comparable positive departures are also noticed. It is interesting to note that these districts receive fairly good amount of rainfall from southwest monsoon also.

TABLE 2

Number of raingauge stations in four dry districts of Tamil Nadu showing decrease of rainfall during northeast monsoon and southwest monsoon in 1951-1975 as compared to 1950 normals

Station	Southwest monsoon	Northeast monsoon	Total No. of stations
Coimbatore	10	19	22
Madurai	9	12	17
Ramanathapuram	9	11	18
Tirunelveli	7	19	20

It is considered that the negative departures noticed are mostly decrease in quantum of northeast monsoon rainfall received.

So, this requires careful analysis of trends in the three seasonal rainfall regimes that occur in the State. Hence this study was taken up at the outset in the four districts of Coimbatore, Madurai, Ramanathapuram and Tirunelveli. Analysis of 1950 normals and means for the period 1951-1975 for each of the season, *viz.*, hot weather period, southwest monsoon and northeast monsoon in respect of these four districts indicates that the major portion of the decrease of rainfall during 1951-1975 can be attributed to decrease in northeast monsoon rainfall (Table 2).

Thus it is clear that decreases of rainfall during northeast monsoon during 1951-1975 have been more widespread. This has been found to be so in coastal districts also.

5. Time series analysis of rainfall by stochastic processes

In order to study the above mentioned aspect in greater detail, the recently developed analysis of rainfall by stochastic processes holds a lot of promise. We have to determine auto-correlations in respect of rainfall of various stations with different time lags. The time series analysis by this approach presumes that the series to be forecasted has been generated by a stochastic (or random) process with a structure that can be characterised and described. Our objective is to relate observation y_t to its past values and lagged random disturbances. Generally a linear specification is used so that we can make quantitative statements about the stochastic properties of the models and forecast generated by the model (*e.g.*, we can calculate confidence intervals around the forecasts). These models apply to stationary processes as well as to non-stationary processes (which can be differenced a few times to yield stationary processes). Models are written generally with fixed estimated coefficients representing a stochastic structure that does not change over time. The time varying coefficients have also been developed recently for non-stationary processes.

In a simple moving average model, the process y_t is described completely by a weighted sum of the current and lagged random disturbances. In a simple autoregressive model y_t depends on a weighted sum of its past values and a random disturbance term.

For instance, in the moving average process of order q[*i.e.*, MA(q)] each observation y_t is generated by a weighted average of random disturbances going back to q periods as indicated below :

$$y_t = \mu + \epsilon_t - \theta_1 \epsilon_{t-1} - \theta_2 \epsilon_{t-2} - \ldots - \theta_q \epsilon_{t-q} \quad (1)$$

where the parameters $\theta_1, \ldots\ldots, \theta_q$ may be positive or negative and each disturbance term ϵ_t is assumed to be a random variable with mean 0, variance σ_ϵ^2 and covariance $\gamma_k = 0$. In the autoregressive process of order p [*i.e.*, AR(p)], the current observation y_t is generated by a weighted average of past observations going back to p periods together with a random disturbance in the current period, *viz.*,

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + \delta + \epsilon_t \quad (2)$$

where δ is a constant term which relates to the mean of the stochastic process.

If the process is stationary, μ must be invariant with respect to time. One of the necessary condition for this is $\phi_1 + \phi_2 + \ldots + \phi_p < 1$

Many stationary random processes cannot be modelled as purely moving average or purely autoregressive, since they have the qualities of both the type of processes. So we have to use the mixed autoregressive moving average process of the order (p, q). We denote this process as ARMA (p, q) which is denoted by the following equation:

$$y_t = \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} + \delta + \epsilon_t - \theta_1 \epsilon_{t-1} \ldots - \theta_q \epsilon_{t-q} \quad (3)$$

A necessary condition for the stationarity of this process is

$$\phi_1 + \phi_2 + \cdots \phi_p < 1 \quad (4)$$

In practice, many of the time series are non-stationary so that the characteristics of the underlying stochastic process change over time. These non-stationary series can be transformed into stationary series by differencing a few times. For instance y_t is non-stationary of order d if $W_t = \triangle^d y_t$ is a stationary series. If we can model this W_t as an ARMA process, then we say that y_t is an integrated autoregressive moving average process of the order (p, d, q), *i.e.*, ARIMA (p, d, q) using the backward shift operator B which imposes a one period time lag each time it is applied to a variable

$$[viz., B\epsilon_t = \epsilon_{t-1}, B^2\epsilon_t = \epsilon_{t-2} \ldots \quad B^n\epsilon_t = \epsilon_{t-n}] \quad (5)$$

Various models can be written as follows :

MA(q)

$$y_t = \mu + (1 - \theta_1 B - \theta_2 B^2 \ldots - \theta_q B^q)\,\epsilon_t \quad (6)$$

AR(p)

$$(1 - \phi_1 B - \phi_2 B^2 \ldots - \phi_p B^p) y_t = \delta + \epsilon_t \quad (7)$$

ARMA(p, q)

$$(1 - \phi_1 B - \phi_2 B^2 \ldots - \phi_p B^p) y_t = \delta + (1 - \theta_1 B - \theta_2 B^2 \ldots - \theta_p B^p)\epsilon_t \quad (8)$$

ARIMA (p, q, d)

$$\phi(B)\, \triangle^d y_t = \delta + \theta(B)\,\epsilon_t \quad (9)$$

where, $\phi(B) = 1 - \phi_1 B - \phi_2 B^2 \ldots\ldots - \phi_p B^p$

and $\theta(B) = 1 - \theta_1 B - \theta_2 B^2 \ldots\ldots - \theta_q B^q \quad (10)$

Thus $\phi(B)$ and $\theta(B)$ can be called as auto-regressive operator and moving average operators respectively.

The mean of W_t is given by $\dfrac{\delta}{1 - \phi_1 - \phi_2 \ldots - \phi_p}$

Thus if δ is not equal to zero, the integrated series will have a built in deterministic trend. ARIMA with $d=2$ and $\delta > 0$, $W_t = \triangle^2 y_t$ will have no time trend and $\Sigma W_t = \triangle y_t$ will have a linear time trend and so on.

The parameters of an ARIMA model can be estimated by the methods of non-linear estimation. A diagnostic checking of time series model is also important. For the series y_t to be modelled, the first problem is to determine the degree of homogeniety d, *i.e.*, number of times that the series must be differenced to produce a stationary series. To determine the appropriate value of d, we can make use of the principle that ρ_k (auto-correlation for lag k) must approach zero as k becomes large, for the particular differenced series. In this connection, the auto-correlation functions drawn for annual rainfall of Bangalore for lags upto 10 years for the period 1951-1980 and 1901-1980 have been presented in Fig. 6. It is seen that non-stationarity is reduced when we take a longer series of rainfall. Thus, taking of data for large number of years in such analysis is important. Further, since the fluctuations of auto-correlation increase after 5 years lag, d value also appears to be quite critical.

After d is determined, we can work with stationary series $W_t = \triangle^d y_t$ and its autocorrelation function itself can be used to determine the proper specifications of p and q of ARIMA model. For low order processes, this procedure is relatively simple. But if the series is not of low order, a tentative guess of p and q should be made and parameters of ARMA (p, q) should be estimated. As a first step in diagnostic checking, the auto-correlation function of the estimated ARMA (p, q) model should be compared with the auto-correlation function of the original series to see how they agree with each other. If they do not match, a new specification has to be tried. With lot of experience one should be able to recognise auto-correlation function and link it with appropriate values of p and q. With appropriate specification, diagnostic checking becomes easier.

Time series analysis by the above approach for rainfall of different stations by southwest monsoon and northeast monsoon systems would not only throw light on the trends, if any that occur there but also would help in a seasonal forecasting of monsoon rainfall within the accuracy limitations imposed by the method.

References

Bharucha, F. R. and Shanbhag, G. Y., 1957, Precipitation effectiveness in relation to vegetation of India, Pakistan and Burma, Botanical Memoirs No. 3, University of Bombay.

Carter, D.B., 1954, Climates of Africa and India according to Thornthwaite's 1948 classification. Final Report Climatology 7(4). Drexel Inst. Tech., Laboratory of Climatology, Centerton, N.J., U.S.A.

Krishnan, A., 1968, Distribution of arid areas in India, Proc. Symp. of the Arid Zone, 21st International Geographical Congress, November 1968, Jodhpur, India.

Krishnan, A., 1969, Some aspects of water management for crop production in arid and semi-arid zones of India, *Annals of Arid Zone*, **8**, 1-16.

Krishnan, A. and Mukhtar Singh, 1968, Soil climatic zones in relation to cropping patterns, Proc. Symp. on cropping patterns, New Delhi, ICAR, 172-185.

Penman, H.L., 1948, Natural evaporation from open water, bare soil and grass, *Proc. Roy. Soc. Series, A* **193**, 120-145.

Rao, K.N., George, C.J. and Ramasastri, K.S., 1972, Agro-climatic classification of India, India Met. Dep. Monogr. Agric. Met. No. 4.

Shanbhag, G.Y., 1956, The climates of India and its vicinity according to a new method of classification. *Indian Geogr. J.*, **31**, 20-25.

Subrahmanyam, V.P., 1956, Climatic types of India according to rational classification of Thornthwaite, *Indian J. Met. Geophys.*, **7**, 3, p. 253.

Subrahmanyam, V.P., Subba Rao, B. and Subrahmanyam, A.R., 1965, Koppen and Thornthwaite climatic classification as applied to India, *Annals of Arid Zone*, **4**, 46-55.

Thornthwaite, C.W., 1948, An approach towards a rational classification of climate, *Geogr. Rev.*, **38**, 55-94.

Thornthwaite, C.W. and Mather, J.R., 1955, *The water balance*, Publications in Climatology, Vol. **8**, No. **1**, Drexel Inst. Tech., Lab. of Climatology, Centerton, N.J., U.S.A., 104.