CASE STUDY

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SIMPLE LINEAR MODELLING OF RIVER FLOW

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ABSTRACT

The application of the simple linear model to present the process of total rainfall and runoff has widely been used in the literature. Most of the simple linear model in modelling rainfall and runoff process has focused of the limitation of non linearity due to the fact of soil moisture and other storages. Some of the studies suggested the use of estimated runoff as an index to account for the non linearity due to the soil moisture and other storage. The arid, semi arid and drought prone regions, which receives the monsoon followed by a dry season shows a very high non linearity in first few storms. The first few storm are completely absorbed and results in no runoff. For such cases the estimated runoff can not represent the status of initial soil moisture condition and the models applied could not be appropriate.

In present contest, the rainfall is separated in to two components; one being the rainfall absorbed to meet the requirement of soil moisture in tension storage. Other being relatively less non linear, causing runoff. A correction for the separation of rainfall into two components improves the model efficiency of the simple linear model.

1.0: INTRODUCTION

One of the most important problem in applied hydrology is determining the river flows from the meteorological data such as rainfall and evapotranspiration. Simple linear models are widely used to model rainfall runoff process. A number of simple linear rainfall-runoff models have been suggested and applied in literature. The model is simplest possible representation of the relationship between input and output. It says that the effect of a particular input component is the same irrespective of its time of occurrence. However, the process of rainfall-runoff is highly non linear specially in arid, semi-arid and drought prone regions. In such areas, the major cause of non linearity in the process is due to the combined effect of interception storage, depression storage and soil moisture in tension storage and to some extent on inter flow and base flow. The application of simple linear models to such areas is possible by splitting the total rainfall into highly nonlinear and relatively linear components. The nonlinear component of rainfall is absorbed by the soil and is released back to atmosphere in the form of evaporation and evapotranspiration and the relatively linear component causes the total runoff including the direct runoff and runoff by inter flow and base flow.

2.0: REVIEW OF SIMPLE LINEAR MODELS

The methods like, unit hydrograph or the instantaneous unit hydrograph methodology is limited by the separation of hydrograph into two components of runoff and base flow and there by the non linearly of the processes is accounted by replacing the rainfall by effective rainfall. The methods not only accounts for the nonlinearity due to the tension water storage but also considers the nonlinearity due to free water storage with percolates and joins the river as inter flow and base flow.

Literature indicates that the catchments in arid and semi arid regions influenced by monsoon and in fast responding catchments, major cause of nonlinearity is due to the tension water storage, in which a significant part of the precipitation is used to satisfy tension water requirement of the soil and does not appear as river flow. The second non linear component which is relatively less dominant in fast responding catchments is the free water absorbed in the soil. A little portion of this free water meets the evaporative demand and major portion of free water emerges as inter flow and base flow and later joins the river flow introducing non linearity. The components of rainfall like tension water storage and free water including inter flow and base flow is shown in Fig. 1.

Wang (1986) used a simple linear input-output model and suggested the method for the estimation of model parameters. The Box and Jenkins (1976) discrete linear transfer function is applied to excess rainfall runoff process on storm basis.

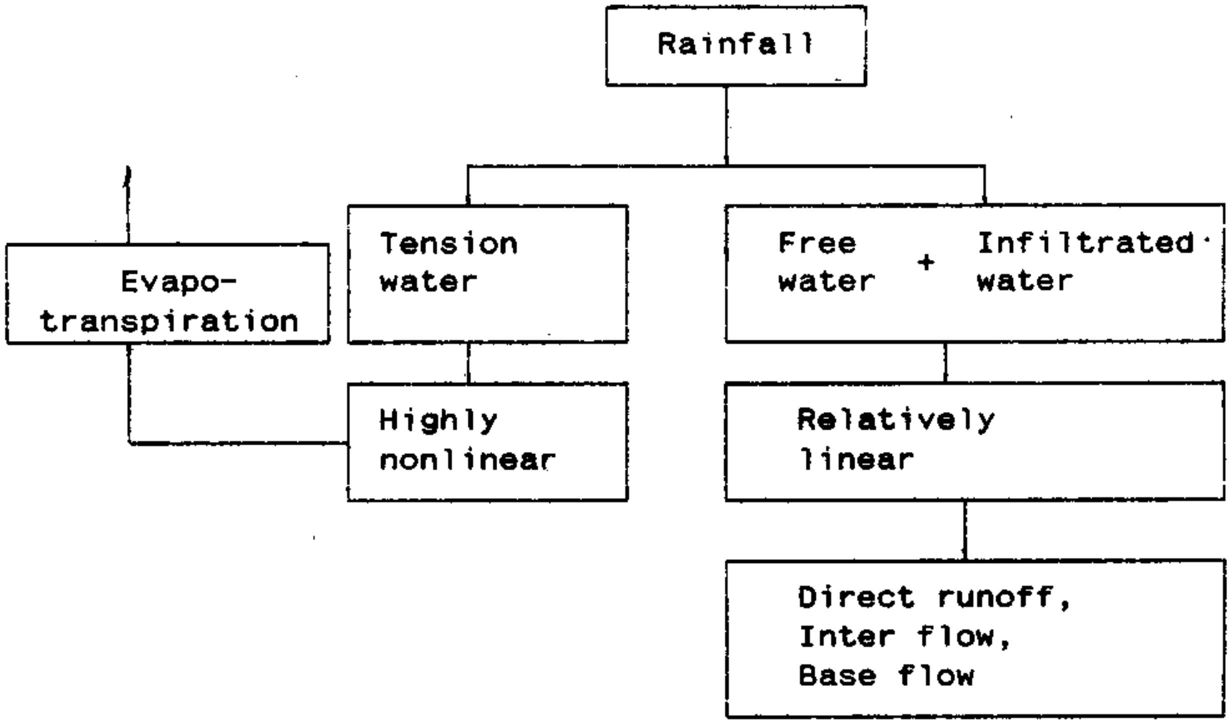

Fig. 1: Components of rainfall causing runoff.

Kachroo (1986) used the simple linear model to fifteen catchments of different country for estimation of flow using total rainfall. A poor model efficiency in all cases indicates that the assumption of linearity and time invariance were the reasons for poor efficiency. The soil moisture deficit and variation in evaporation are the significant factors influencing rainfall runoff process. It is suggested that the improvement in the results can only be done by adding a component of water balance to account for soil moisture deficit and evaporation.

Kachroo (1992) proposed a simple linear rainfall-runoff model and observed the evidence of nonlinearity by observing a variation in gain factor for the low, medium and high flow regions. The cause of the variation is suggested as the soil moisture variation with time. It is also observed that the simple linear model generally over estimates the flow, of the low flow region and under estimates the flow, in the high flow region because of the varying soil moisture conditions of the catchment. There after tried to relate the soil moisture conditions with the estimated river flow in order to improve the model efficiency.

Ahsan Mainul (1994) a simple linear rainfall runoff model with variable gain factor is applied to the same five catchment considered by Kachroo (1992). The estimated outflow is rescaled to represent catchment wetness index and the gain factor is varied in accordance with estimated wetness index based on the estimated flow. The optimum gain factor is observed varying from 0.29 to 0.66 and the efficiency of the model is observed as 51.0 to 80.0 percent.

Liang (1994) multi input single output simple linear model is applied to runoff modeling with variable gain factor model. The input to model is the runoff at two sites and output is the combined estimated runoff at third point.

The non linearity of process by which the soil absorbs water and percolates same to the groundwater and rejects a surplus to form runoff according to the intensity of rainfall and the current soil moisture status, suggests that the simple linear model could not adequately represent the rainfall-runoff relationship. The effect of evapotranspiration on the soil moisture storage and its building up in temperate regions creates high non linearly and cannot be avoided. Even the linear perturbation model (LPM) on highly seasonal catchments will not be able to remove the most of the nonlinear effect in the system.

It can be seen that the simple linear models applied to rainfall runoff process faces the problem of non linearity either due to soil moisture in tension storage or free water which percolates and reappears as inter flow or base flow. The simple linear models which utilizes, the estimated flow to represent for the initial soil moisture condition (to account for a nonlinear effect) may be applicable to the catchments like humid, moderately humid influenced by monsoon. It may be applicable only because, the variation of soil moisture is not very high during the monsoon months.

In arid, semi arid and tropical regions, which are influenced by monsoon, utilizes the significant portion of rain to satisfy the initial soil moisture requirements. In such catchments, the estimated runoff can not be treated as representative of soil moisture. The direct application of simple linear models to such an areas may be not suitable.

Keeping in view, the simple linear model is applied to represent the process of rainfall-runoff by making a separation of daily rainfall into rainfall utilized to meet the soil moisture tension storage and rainfall causing runoff including percolation. The separation for soil moisture tension storage is based on initial soil moisture and potential evaporative demand. An algebraic cumulation of separated portion of rainfall to meet the tension water storage and its loss due to evaporative demand, result in current state of available soil moisture in tension. Therefore, the study is carried out with following objective;

1. To develop a simple linear model for the simulation of runoff by iteration for soil moisture in tension storage.
2. To estimate average available soil moisture in tension storage.

3.0: STUDY AREA AND DATA

The Narmada river rises in the Amarkantak plateau of Maikala range in the Shahdol district of Madhya pradesh at an elevation of 1057 m. above mean sea level. The river travels a distance of 1312 km. before it falls into Gulf of Cambay in the Arabian sea near Bharuch in Gujarat. The Banjar and Burhner sub-basins rises in the Satpura range in the Durg district of Madhya Pradesh at an elevation of around 600 m. at north latitude 21° 42' and flows in Northwest direction for a total length of around 184 km. to join the Narmada from the left near Mandla at around 287th km. of its run. The Banjar and Burhner sub-basins drains a total area of 3370.0 and 4661.0 sq. km. The river is shown in Fig. 2.

To develop a simple linear model between rainfall and runoff, the daily rainfall and runoff data (gauge discharge at 8.00 hours) is utilized in addition to the daily pan evaporation and the soil type of the area under consideration. The data availability of Banjar and Burhner basins is listed in Table 1.

4.0: METHODOLOGY

The application of simple linear model to the catchment of Banjar upto Hridaynagar and Burhner upto Mohagaon is a combined procedure of separation of soil moisture in tension storage and fitting of simple linear model. For this, an approximation for the maximum possible soil moisture in tension storage is made on the basis of average soil type and average soil depth in the catchment. From the estimated average tension storage, a separation of rainfall is done. The first component of the separated rainfall is used to build up the soil moisture and the other results into runoff.

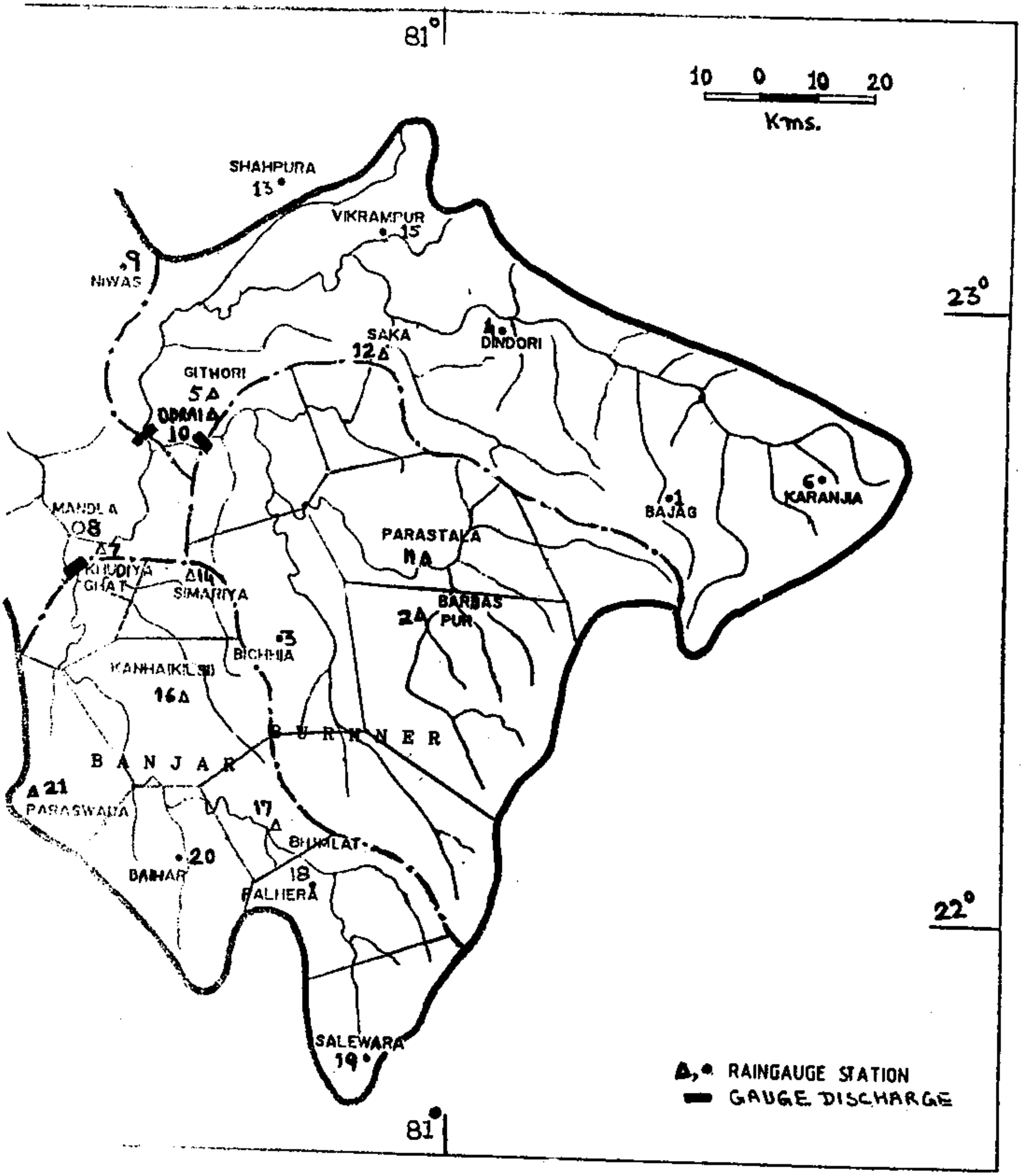

Fig. 2 : Banjar and Burhner sub-basins in upper Narmada.

Table 1: Data availability of Banjar and Burhner sub-basins of Narmada.

Type of data	Period
1. Daily gauge discharge at 8.00 A.M. except 1987-88.	
(a) Hridaynagar	1981-82 to 1986-87
(b) Mohagaon	1981-82 to 1989-90
2. Daily gauge at 8.00 A.M. except 1987-88.	
(a) Hridaynagar	1988-89 to 1989-90
3. Daily rainfall	
(A) Rain gauge stations for Banjar sub-basin.	
(a) Khudyaghat	1981 to 1990
(b) Simariya	1981 to 1990
(c) Kanha (kalsi)	1983 to 1990
(d) Bhimlat	1985 to 1990
(e) Palhera	1983 to 1990
(f) Saleware	1984 to 1990
(g) Baihar	1982 to 1990
(h) Paraswada	1981 to 1990
(B) Rain gauge stations for Burhner sub-basin.	
(a) Bajaj	1985 to 1990
(b) Barbaspur	1981 to 1990
(c) Bichhia	1983 to 1990
(d) Odrai	1981 to 1990
(e) Parastola	1981 to 1990
(f) Saka	1981 to 1990
(g) Bhimlat	1982 to 1990
4. Daily pan evaporation	
(a) Jabalpur	1981-82 to 1989-90
5. Average soil type	
(a) Banjar and Burhner	Deep, Medium and shallow black soil, Mixed red and black soil

4.1: Separation of Soil Moisture in Tension Storage

The modelling of total response simple linear rainfall runoff process considering the absolute rainfall and is a complex process by virtue of its non linearly due to soil moisture storage, release and due to the percolation of free water and its reappearance. The moisture storage in the system is in the form of tension water and free water, which are dependent on the incident moisture condition. The tension water storage is released back to atmosphere through evapotranspiration and is highly nonlinear component to rainfall runoff process, while the second component, the free water percolates and joins the runoff to appear as river flow and is relatively less nonlinear. A simple technique as suggested by Kohler and Linsely (1951) is used to filter the total rainfall into the components of soil moisture in tension storage and into the rainfall other than building the soil moisture.

Kohler and Linsely (1951) proposed an antecedent precipitation index (API) for daily value of index as follows;

$$API_t = API_{t-1} \ K + I_{t-1} \qquad \ldots\ldots\ldots (1)$$

Where; API_{t-1} value of API at previous time step, API_t is the current value of t^{th} day and I_{t-1} is the rainfall of previous time step. The value of 'K' normally ranges between 0.85 to 0.98. The equation is used to estimate daily soil moisture loss.

Using the index suggested by Kohler and Linsely (1951), a methodology was used to split the total rainfall into two components. The first being the soil moisture in tension storage, which creates nonlinearity in the process and the second is the rainfall other than building the soil moisture, which is relatively less nonlinear to the model. The portion of rainfall utilized for soil moisture in tension storage is estimated by using the index proposed by Kohler and Linsely (1951). The use of this model is done with the following assumptions;

1. Initially at the beginning (June 1), there is no rain and the soil is assumed as completely dry. Therefore, the available soil moisture in tension storage is zero till the first rain is received.

2. Any loss of soil moisture from the tension storage occurs in the form of evaporation/ evapotranspiration. On a day, when rainfall is equal or greater than the maximum soil water tension storage the moisture is lost at potential rate (0.8 of pan evaporation).

3. The soil moisture loss back to atmosphere in the form of evaporation/ evapotranspiration on the days followed by the rainy day is given by the equation of Kohler and Linsely (1951), limited to a maximum of potential evapotranspiration.

4. The soils of the region are silt loam, clay loam and clay and may have on an average the tension water storage capacity (available water) per meter depth varying from 60.0 mm to 180.0 mm (Michael,1978). Also, it is assumed that the maximum variation in soil water in tension storage takes place in top 100.0 cm. of soil. Thus, the average depth of soil water in tension storage comes to around 120.0 mm and is used as the maximum capacity of tension water storage for the separation of rainfall in to two components.

4.2: The Simple Linear Transfer Function Model

The simple linear models applied to rainfall-runoff comes from the discrete linear transfer function model described by Box and Jenkins (1976) in linear difference form as;

$$(1-a_1B - a_2B^2 - \ldots - a_pB^p)\ Q_t = (b_0 + b_1B + b_2B^2 + \ldots + b_qB^q)\ I_t \qquad \ldots\ldots\ldots(2)$$

$$Q_t = (\theta\ B\ /\ \phi\ B)\ I_t \qquad \ldots\ldots\ldots(3)$$

Where;

$\theta\ B = 1 - a\ B_1 - a\ B_2^2 - \ldots\ldots - a_p\ B^p$

$\phi\ B = b_0 + b_1B + b_2B^2 + \ldots\ldots + b_qB^q$

$\theta\ B/\ \phi\ B$ = transfer function

B = is the back shift operator as $B(Q_t)=(Q_{t-1})$

a'^s = pulse response functions or autoregressive parameters

b'^s = pulse response functions or moving average parameters

Q_t = output

I_t = input

For a single input and a single output, the simple linear transfer function could thus be defined as;

$$Q_t = \sum_{J=1}^{p} a_J\ Q_{t-J} + \sum_{J=1}^{q} b_J\ I_{t-J+1} + e_t \qquad \ldots\ldots\ldots(4)$$

Where; t = 1 to n, and 'n' is the total length of input and output data for the model calibration; e_t is the error component or model residuals. When the model is applied to rainfall and runoff, it yields following sets of equation which could be solved for operators a'^s and b'^s.

$$
\begin{vmatrix} Q_1 \\ Q_2 \\ Q_3 \\ . \\ . \\ . \\ . \\ . \\ Q_n \end{vmatrix}
=
\begin{vmatrix}
0 & 0 & 0 & 0 & I_1 & 0 & 0 & 0 \\
Q_1 & 0 & 0 & 0 & I_2 & I_1 & 0 & 0 \\
Q_2 & 0 & 0 & 0 & I_3 & I_2 & I_1 & 0 \\
. & . & . & \ldots\ldots & . & . & . & . \\
. & . & . & \ldots\ldots & . & . & . & . \\
. & . & . & \ldots\ldots & . & . & . & . \\
. & . & . & \ldots\ldots & . & . & . & . \\
. & . & . & \ldots\ldots & . & . & . & . \\
Q_n & Q_{n-1} & Q_{n-2} & ..Q_{n-p} & I_n & I_{n-1} & I_{n-2} & ..I_{n-p+1}
\end{vmatrix}
\begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ a_p \\ . \\ b_1 \\ b_2 \\ b_q \end{vmatrix}
+
\begin{vmatrix} e_1 \\ e_2 \\ e_3 \\ . \\ . \\ . \\ . \\ . \\ e_n \end{vmatrix}
\qquad \ldots\ldots\ldots (5)
$$

By using matrix notion the equation (5) could be written as;

$$[Q] = [A] \, . \, [H] + [E] \qquad \ldots\ldots\ldots (6)$$

The solution of equation (6) for the value of model parameters could be done by one of the method such as least square, correlation function, linear programming or by quadratic programming. In least square sòlution, the sum of square of error ($E^T.E$) is minimized. The lest square solution of the matrix [Q] = [A] . [H] + [E] could be find in any of the standard book in the following form;

$$[H] = \{[A]^T \, . \, [A]\}^{-1} \, .[A]^T \, .[Q] \qquad \ldots\ldots\ldots (7)$$

The variance and standard error of parameters is given by Johnsten (1972) as;

$$\text{Standard deviation} = \sqrt{\text{Var (H)}} \qquad \ldots\ldots\ldots (8)$$

$$\text{Var(H)} = ([A]^T \; [A])^{-1} \sigma^2 \qquad \ldots\ldots\ldots (9)$$

$$\sigma^2 = \frac{1}{(n+1)} \sum_{t=1}^{m} e^2_{(t)} \qquad \ldots\ldots\ldots (10)$$

The gain factor (GF) of the simple linear model is described as;

$$GF = \Sigma_{J=1}^{q} b_J \ / \ \Sigma_{J=1}^{p} a_J \qquad \ldots\ldots\ldots (11)$$

4.2.1: Model evaluation criteria

The commonly known criteria for the efficiency of the model is mean square error (MSE) i.e. sum of square of differences between the observed and estimated (residual variance; F) divide by number of values as;

$$MSE = \Sigma_{1}^{n} (Q_o - Q_e) \ / \ n \qquad \ldots\ldots\ldots (12)$$

Where; Q_o is the observed runoff, Q_e is the estimated runoff, $(Q_o - Q_e)$ is the residual variance. Since, this criteria is a dimensioned quantity a criteria for undiamentioned quantity has been suggested by Nash and Sutcliffe (1970) by comparing the residual variance (F) by initial variance (F_o) as;

$$R^2 = 1 - \frac{F}{F_o} = 1 - \frac{\sum_{t=1}^{n} (Q_o - Q_e)^2}{\sum_{t=1}^{n} (Q_o - \overline{Q})^2} \qquad \ldots\ldots\ldots (13)$$

The R^2 expresses the efficiency of model and is identical to the coefficient of determination of the linear regression analysis. Another efficiency criteria applied to the present model is the index of volumetric fit (IVF), which is the ratio of observed to estimated values as follow;

$$IVF = \sum_{t=1}^{n} (Q_o) \;/\; \sum_{t=1}^{n} (Q_e) \qquad \ldots\ldots (14)$$

A value of index of volumetric fit (IVF) equal to unity represents a perfect volumetric fit between the observed and estimated flows. A value of IVF less than or greater than unity implies, respectively an over or under estimation of the total volume of flow in the period 'n'.

4.3: Proposed Model

The inherent linearity in equation 4 is the short coming of the model when applied to represent a nonlinear rainfall runoff process. To cope with the nonlinearity in the basin response is through the use of soil moisture deficiency limited by maximum soil moisture availability (AMMAX). The maximum available soil moisture is estimated by knowing the average soil type and its average field capacity and wilting point. The difference of the field capacity and the wilting point results in the value of maximum available soil moisture.

If AM is measure of available soil moisture than the deficiency in available soil moisture (AMD) will be AMD=AMMAX-AM. The following equation is used to estimate daily deficiency in soil moisture

$$AMD_t = API_{t-1} - API_t \qquad \ldots\ldots (15)$$

$$AMD_t = API_{t-1} - API_{t-1}.K - I_{t-1} \qquad \ldots\ldots (16)$$

The cumulative deficiency in available soil moisture (AMDC) till next rain is estimated using the equation given below;

$$AMDC = \sum_{t=1}^{n} API_{t-1} - API_{t-1}.K - I_{t-1} \quad \ldots\ldots (17)$$

where; n is the day on which the rain is received. To start for the estimation of cumulative deficiency in available soil moisture, the initial value of antecedent precipitation index (API_{t-1}) is considered as zero.

The cumulative deficiency in available soil moisture (AMDC) is than compared with the rainfall input (I) to yield to separate rainfall input series in to I_l and I_{nl} to account for linear and nonlinear responses.

If:

$$I > AMDC \text{ than } I_{nl} = AMDC \text{ and } I_l = I - AMDC \quad \ldots.(18)$$

$$I \leq AMDC \text{ than } I_{nl} = I \text{ and } I_l = 0 \quad \ldots.(19)$$

By replacing the rainfall (I) in equation 4 by rainfall series (I_l) will result in the final model as below;

$$Q_t = \sum_{J=1}^{p} a_J \ Q_{t-J} + \sum_{J=1}^{q} b_J \ I_{l(t-J+1)} + e_t \quad \ldots\ldots.(20)$$

5.0: MODELLING AND RESULTS

The modelling of stream flow by simple linear transfer function required the following steps as listed below;

1. Scrutiny of observed data.
2. Soil moisture in tension storage and its separation.
3. Fitting of simple linear model for model order and parameters.
4. Model evaluation and effect of soil moisture separation on the model efficiency.

The step to step procedure adopted for model fitting is reported in the following sections.

5.1: Scrutiny of Observed Data

The weighted rainfall of the Banjar and Burhner sub-basins is estimated using the daily rainfall records as listed in Table 1. The weighted rainfall for the case of missing rainfall record is filled up by normal ratio method. In this method, the amount of rainfall are weighted by the ratio of the average annual precipitation values. In order to check the consistency of runoff-rainfall record, the average monthly rainfall (mm) and runoff (mm) for all five years is plotted (Fig. 3 and Fig. 4). The runoff-rainfall ratio for monsoon months and for annual is reported in Table 2.

Table 2: Runoff-rainfall ratio for monsoon months and for annual, for Banjar and Burhner sub-basins of Narmada.

	Runoff-rainfall ratio				
Years	1981-82	1982-83	1983-84	1984-85	1985-86
(A) Banjar sub-basin.					
June	0.01	0.02	0.01	0.00	0.00
July	0.14	0.02	0.04	0.04	0.16
August	0.28	0.19	0.13	0.26	0.26
Sept.	0.15	0.22	0.23	0.35	0.30
Monsoon Av.	0.14	0.11	0.10	0.16	0.18
Annual	0.14	0.15	0.14	0.17	0.18
(B) Burhner sub-basin.					
June	0.07	0.03	0.05	0.03	0.06
July	0.19	0.09	0.23	0.16	0.41
August	0.52	0.33	0.33	0.45	0.57
Sept.	0.30	0.58	0.36	0.87	0.64
Monsoon Av.	0.27	0.25	0.24	0.37	0.42
Annual	0.25	0.28	0.30	0.38	0.45

Monthly rainfall and runoff reported in Fig. 3 and Fig. 4 indicates a corresponding runoff to rainfall in monsoon months. In non-monsoon months, the runoff is very low or nil corresponding to a rainfall. It suggest a very high nonlinearity in the rainfall-runoff relation with time of the year and suggest for the removal of this nonlinearity when applying a simple linear model to represent the rainfall-runoff model.

The runoff-rainfall ratios of months July and August are in general higher than observed in June and September. It indicates that the months (June and September) receiving low rainfall does not results a proportionate runoff as received in high rainfall months (July and August) and suggests for a nonlinearity even with in the monsoon months. On an average a similarity is observed in the runoff-rainfall ratios on the average monsoon basis and on annual basis. The runoff-rainfall ratio is found varying from 0.14 to 0.18 for Banjar and 0.25 to 0.45 for Burhner sub-basins. It indicates that both the basins are not behaving similarly in yielding the runoff.

5.2: Soil Moisture in Tension Storage and its Separation

The average soil moisture in tension storage is estimated by assuming the soil to be silty clay loam and that the top one meter of soil is active in storage of soil moisture and its relies back to the atmosphere by the process of evaporation and evapotranspiration. Since, the available water in silty clay loam soils varies from 60.0 to 180.0 mm per meter depth and the depth of active soil zone is assumed as 100.0 cm, the average value of soil moisture in tension storage becomes 120.0 mm.

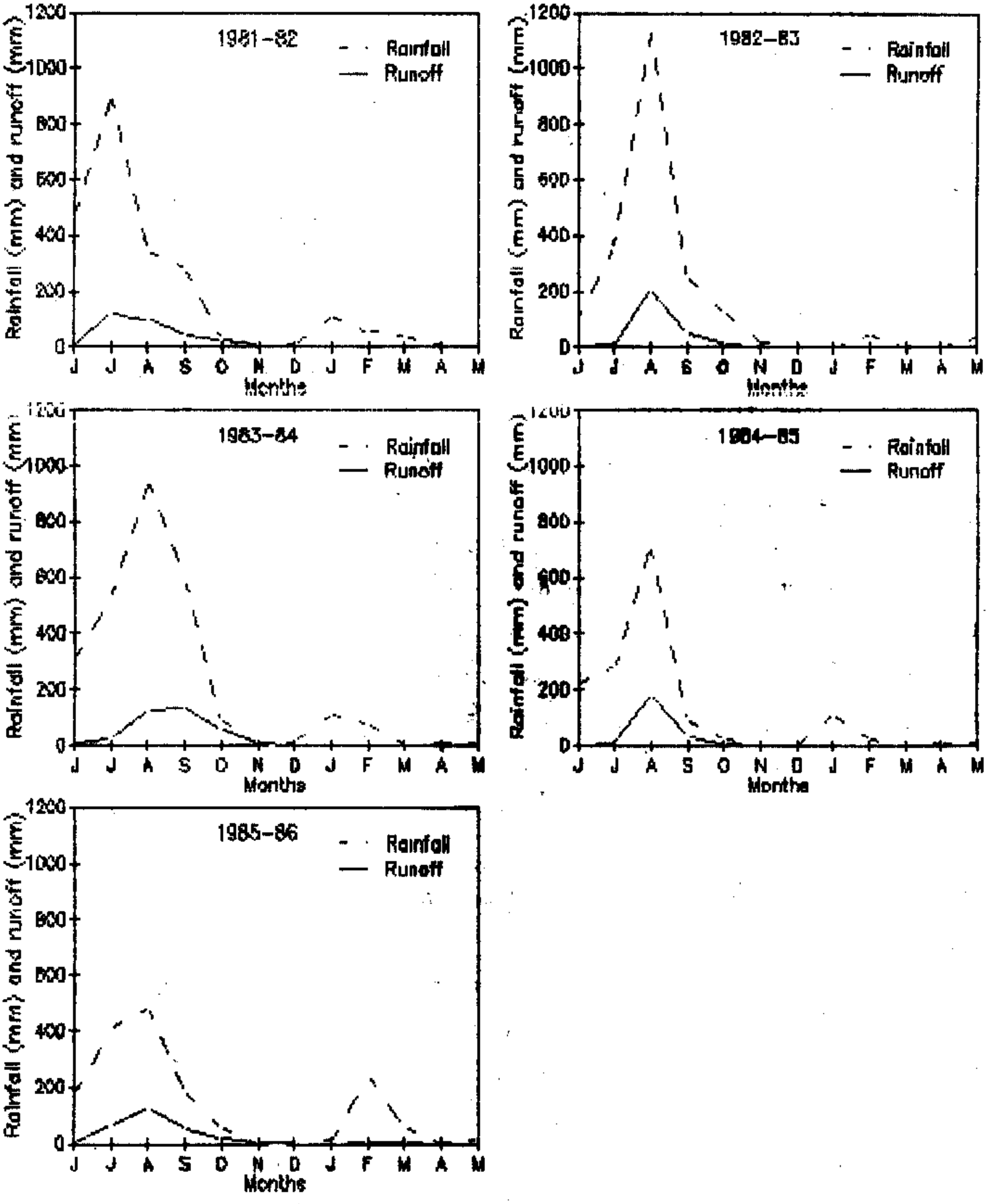

Fig. 3 : Observed monthly runoff and rainfall for Banjar sub-basin of Naramada.

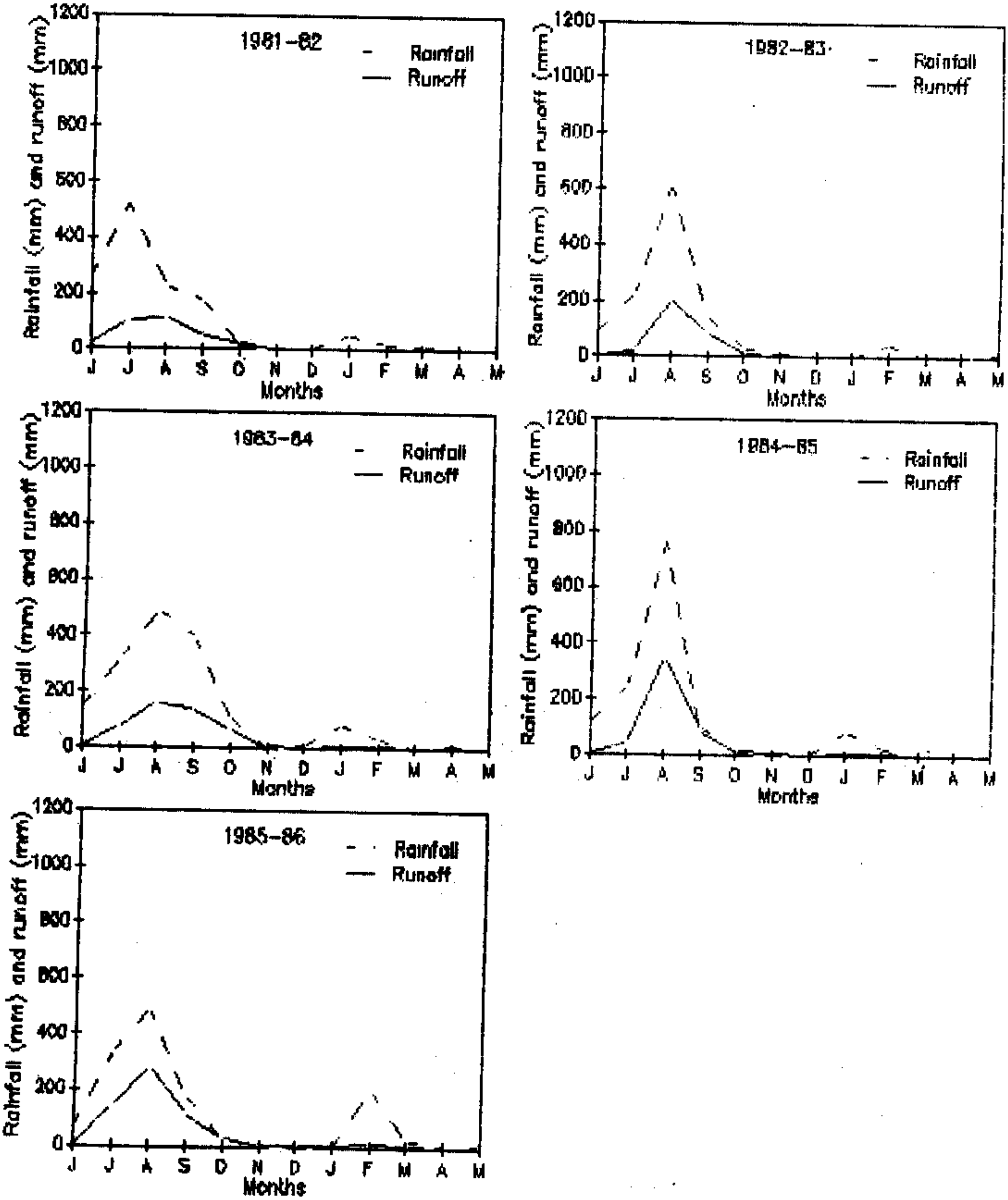

Fig. 4: Observed monthly runoff and rainfall for Burhner subbasin of Narmada.

For simple linear rainfall-runoff model for Banjar and Burhner sub-basins of Narmada, the total rainfall is separated into two components as discussed earlier. The programme used to separate the amount of soil moisture in tension storage from the daily rainfall is listed in Appendix I. The input to this programme is the daily rainfall (mm) and the average daily pan evaporation. The output is daily, ten daily average, monthly average and annual soil moisture in tension storage and the amount of rainfall other than utilized for meeting the soil moisture in tension storage. The output of this programme is used as input to simple linear model reported in Appendix II.

5.3: Fitting of Simple Linear Model for Model Order and Parameters.

The simple linear models have been used successfully in hydrology and the model ordered and constants of the modes are estimated. The decision of model order is based on the judgement and not on any physical basis. One method for the selection of the order of model is to compare the parameters with its standard error and if the parameter is greater than the standard error the order of model is selected. However, it is always not true and needs personal judgement keeping the fitness of model in the background. It has been seen that the parameters sometimes exhibit physically unrealistic behaviour, such as multipeaks or oscillation around some value. It happens due to numerical instability of the model and is normally visualized when the order of the model is high. In the case of simple linear models, where, the order of the model is normally not more than two to three and, the numerical instability is normally not reflected when applied to simulate the rainfall runoff process. During the process of the identification of the order, the model parameters are also estimated.

In the present model fitting, the order of the model is started with a 3,3 model, for daily, ten daily data and monthly data. The coefficients and standard error for different orders are reported in Table 3.

In case of Banjar sub-basin, the parameter b_3 (0.002) of a 3,3 model, fitted to daily data is found lower than its standard error (0.005). It suggests that the order of b'^{s}be reduced. Finally a 3,2 model is found suitable for the daily data. When a 3,3 model is applied to ten daily data, the parameter a_2 (-0.015) is found negative, indicating an appearance of oscillation and suggests for numerical instability. Therefore, the order of the model for a'^{s} is reduced. With a 2,3 model, the parameter a_2 (0.018) is lower than its standard error (0.057). Finally a 1,3 model is found suitable to fit with ten daily data. A 3,3 model applied to monthly data results in a negative values for a_2 (-0.053) and b_2 (-0.020) indicating a possible appearance of oscillation. Finally a 1,1 model is found suitable for monthly data. Similarly the orders of the model for Burhner sub-basin are selected for daily, ten daily and monthly models as (3,2), (2,2) and (1,1).

5.4 Model Evaluation and Effect of Separation of Soil Moisture in Tension Storage.

Suitably selected model for daily ten daily and monthly is applied to the total rainfall and separated rainfall (rainfall minus soil moisture in tension storage). The results of the model are reported in Table 4.

Table 3: Estimated parameters of the simple linear models with soil moisture in tension storage as 120 mm.

Sl. No.	Order of Model a's	b's		Auto regressive parameters associated with runoff a1	a2	a3	Moving average parameters associated with rainfall b1	b2	b3	Gain factor of model
(A)	Banjar sub-basin;									
	(a) Daily model									
1.	3	3	Coeff.	.366	.028	.092	.029	.067	.002	.193
			Std.error	.026	.026	.022	.004	.005	.005	
2.	3	2	Coeff.	.371	.031	.090	.030	.068	-	.192
			Std.error	.024	.025	.022	.004	.004	-	
	(b) Ten daily model.									
1.	3	3	Coeff.	.108	-.015	.040	.079	.065	.044	.216
			Std.error	.069	.065	.046	.010	.013	.014	
2.	2	3	Coeff.	.116	.018	-	.079	.065	.041	.213
			Std.error	.073	.057	-	.010	.014	.015	
3.	1	3	Coeff.	.124	-	-	.079	.064	.044	.212
			Std.error	.070	-	-	.010	.014	.013	
	(c) Monthly model									
1.	3	3	Coeff.	.307	-.053	.024	.184	-.020	.009	.240
			Std.error	.151	.153	.012	.035	.035	.033	
2.	1	1	Coeff.	.236	-	-	.179	-	-	.234
			Std.error	.042	-	-	.009	-	-	
(B)	Burhner sub-basin;									
	(a) Daily model									
1.	3	3	Coeff.	.025	.147	.081	.320	.093	-.046	.467
			Std.error	.024	.023	.017	.010	.015	.014	
2.	3	2	Coeff.	.016	.096	.079	.305	.076	-	.471
			Std.error	.024	.018	.017	.010	.014	-	
	(b) Ten daily model									
1.	3	3	Coeff.	.155	-.006	.119	.316	.068	.015	.545
			Std.error	.068	.069	.041	.017	.029	.029	
2.	2	2	Coeff.	.186	.098	-	.319	.056	-	.524
			Std.error	.074	.044	-	.018	.031	-	
	(c) Monthly model									
1.	3	3	Coeff.	.460	-.042	.011	.430	-.104	-.012	.551
			Std.error	.123	.132	.045	.017	.055	.055	
2.	2	2	Coeff.	.464	-.057	-	.430	.107	-	.544
			Std.error	.118	.044	-	.017	.053	-	
3.	1	1	Coeff.	.234	-	-	.428	-	-	.559
			Std.error	.039	-	-	.020	-	-	

Table 4: Results of the simple linear model for Banjar and Burhner sub-basins.

Model	Order	With total rainfall			With rainfall other than the soil moisture in tension storage		
		GF	R^2	IVF	GF	R^2	IVF
Banjar sub-basin							
Daily	(3,2)	.152	.39	1.02	.192	.46	.85
Ten daily	(1,3)	.170	.72	1.10	.212	.75	.92
Monthly	(1,1)	.182	.82	1.18	.234	.87	1.00
Burhner sub-basin							
Daily	(3,2)	.368	.47	1.10	.471	.52	.81
Ten daily	(2,2)	.383	.75	1.13	.524	.80	.89
Monthly	(1,1)	.405	.85	1.18	.554	.90	.95

It can be seen that the efficiency of the model increases with the use of separated portion of rainfall in the model. The observed and estimated runoff for ten daily and monthly models for both the sub-basins are shown in Figures 5 to 8. The estimates of available soil moisture in tension storage for ten daily and monthly are reported in Figures 9 to 12. It can be seen that the available soil moisture in tension storage is found highest in monsoon months and drops to around 50 percent level in the month of October. In winter months, the available soil moisture in tension storage remains in between nearly zero or to around 25 percent.

The total annual rainfall, the portion of rainfall utilized for meeting the soil moisture tension storage demands, and the portion of rainfall resulting in total runoff and observed runoff is reported in Table 5.

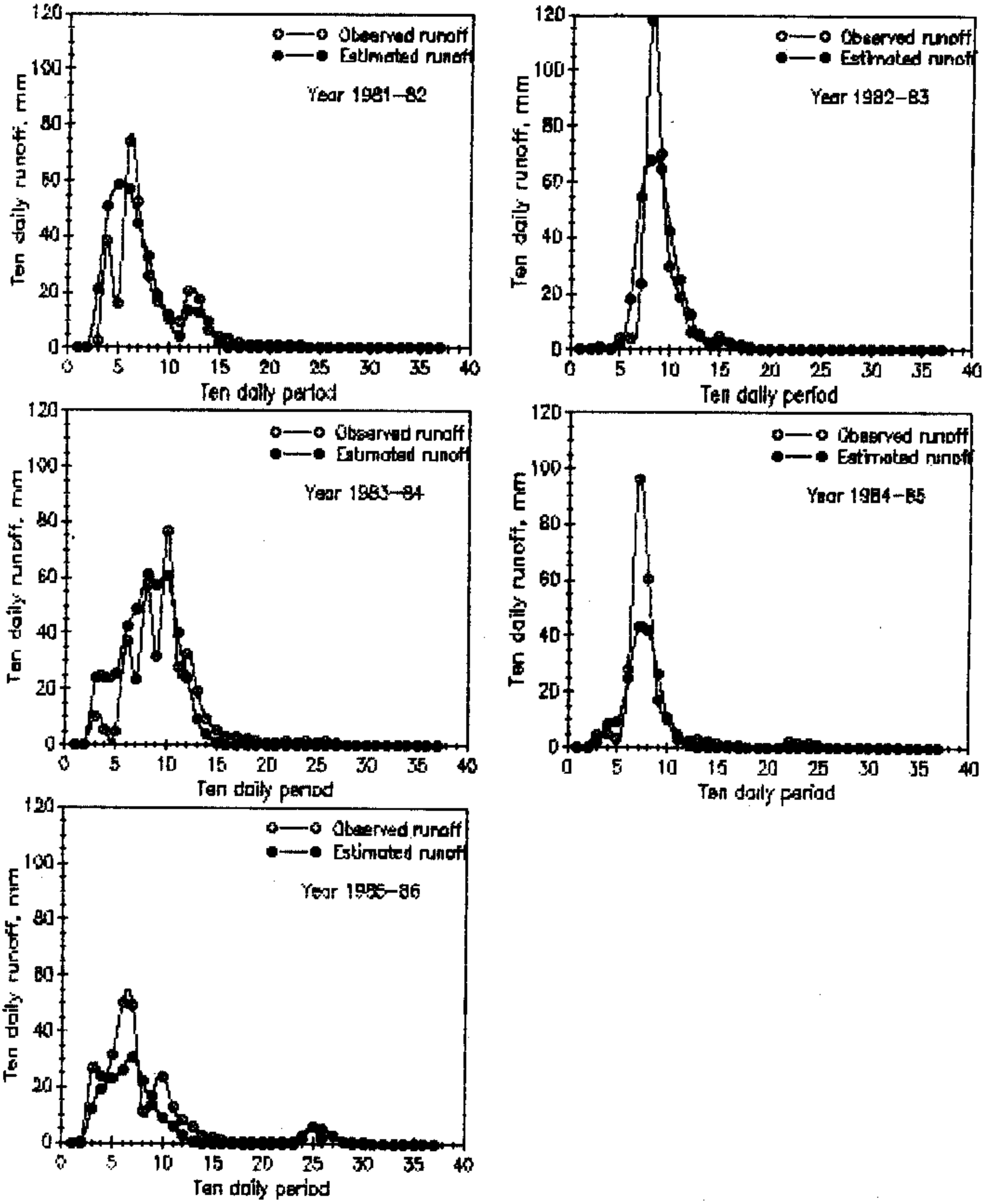

Fig. 5 : Ten daily observed and estimated runoff from June 1 at site Hridaynagar of Naramada during simulation.

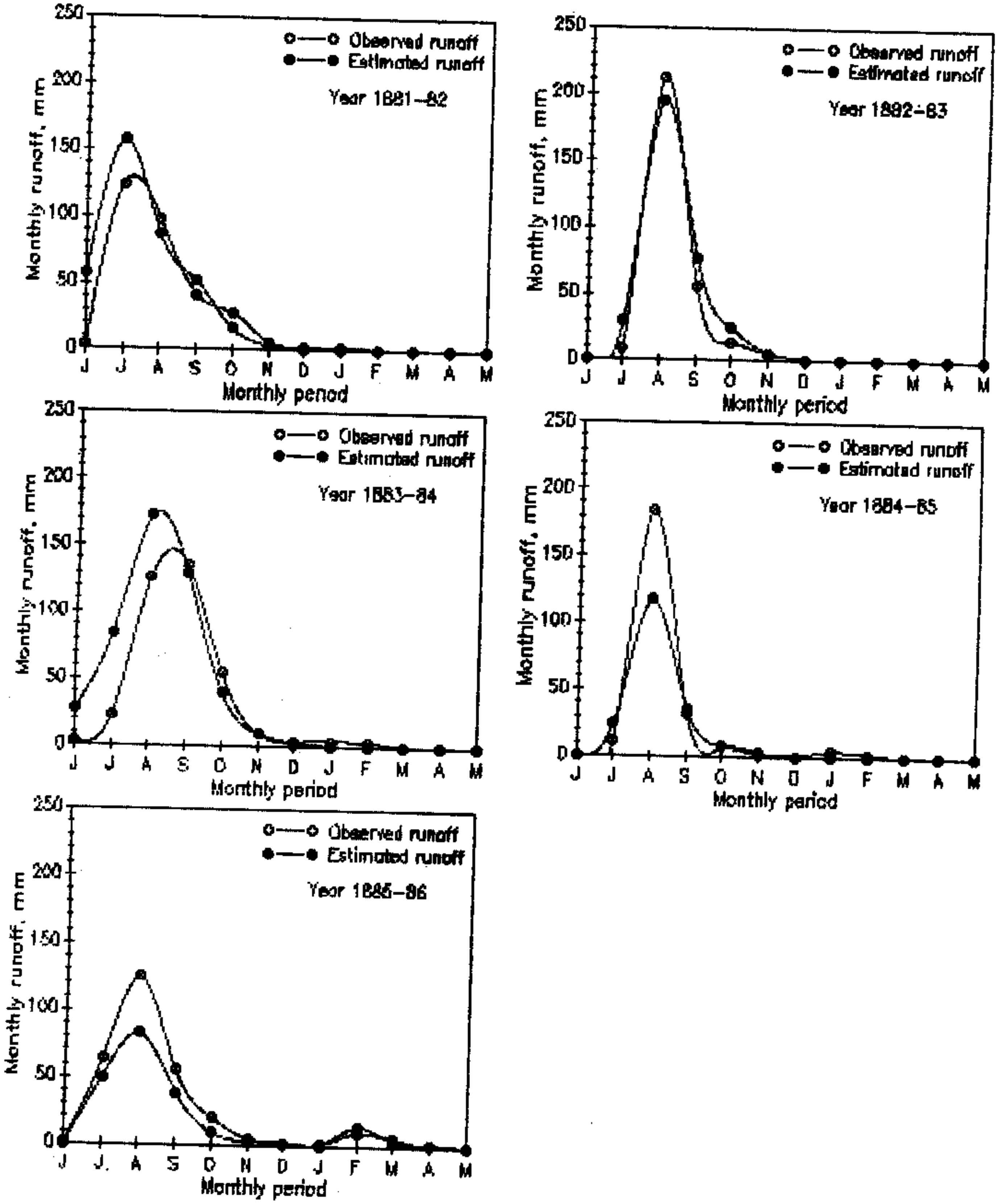

Fig. 6 : Monthly observed and estimated runoff from June 1 at site Hridaynagar of Naramada during simulation.

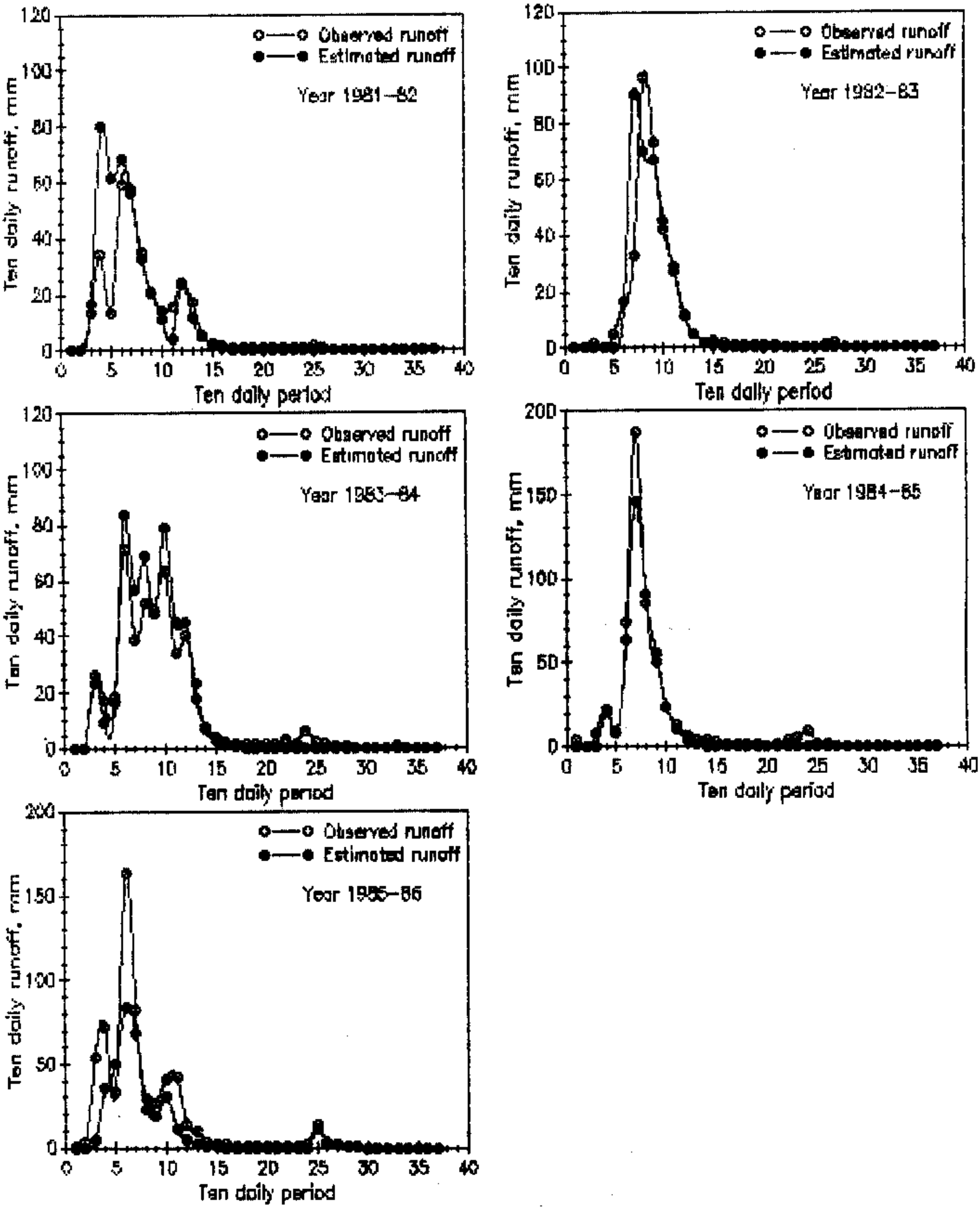

Fig. 7 : Ten daily observed and estimated runoff from June 1 at site Mohagaon of Naramada during simulation.

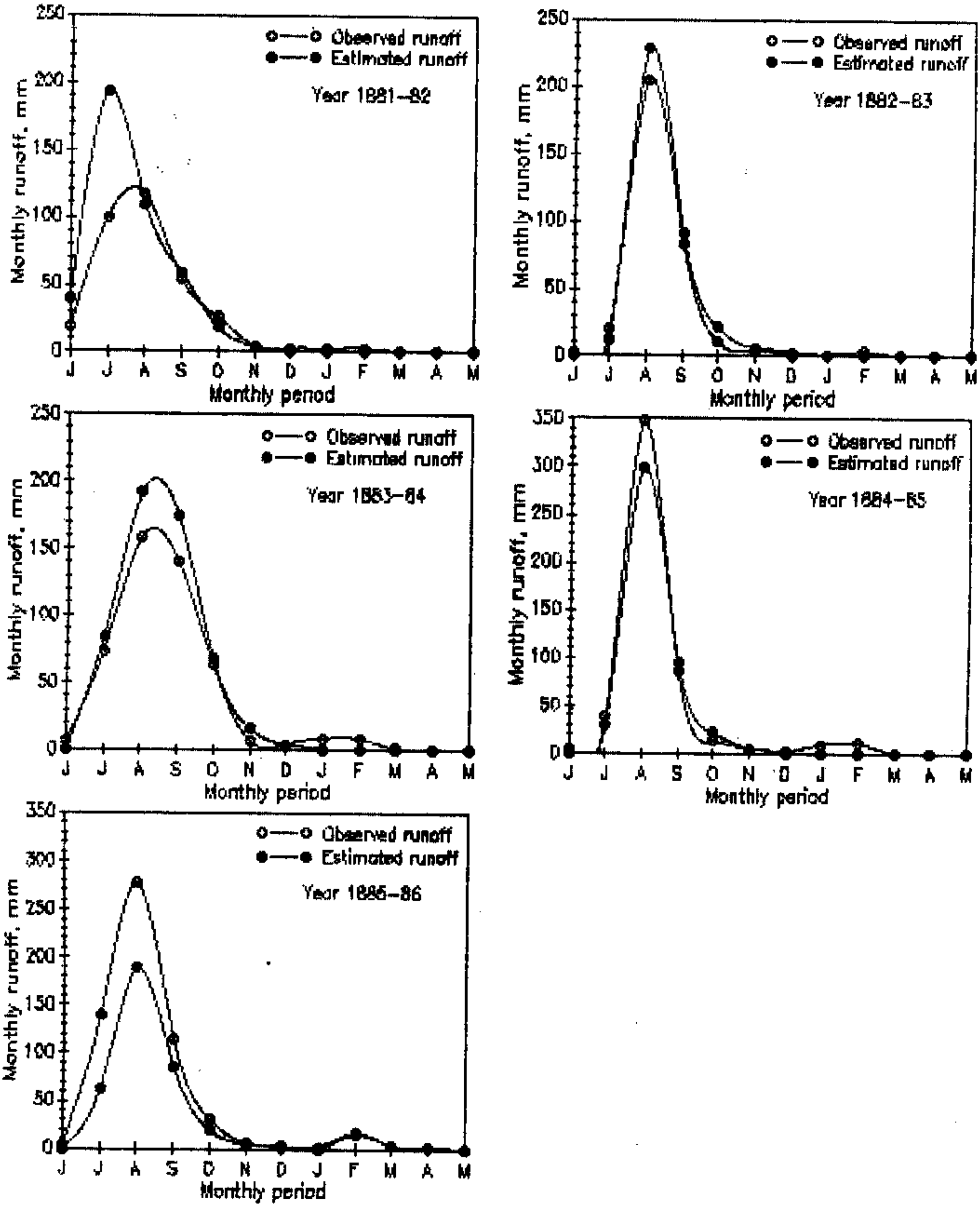

Fig. 6: Monthly observed and estimated runoff from June 1 at site Mohagaon of Naramada during simulation

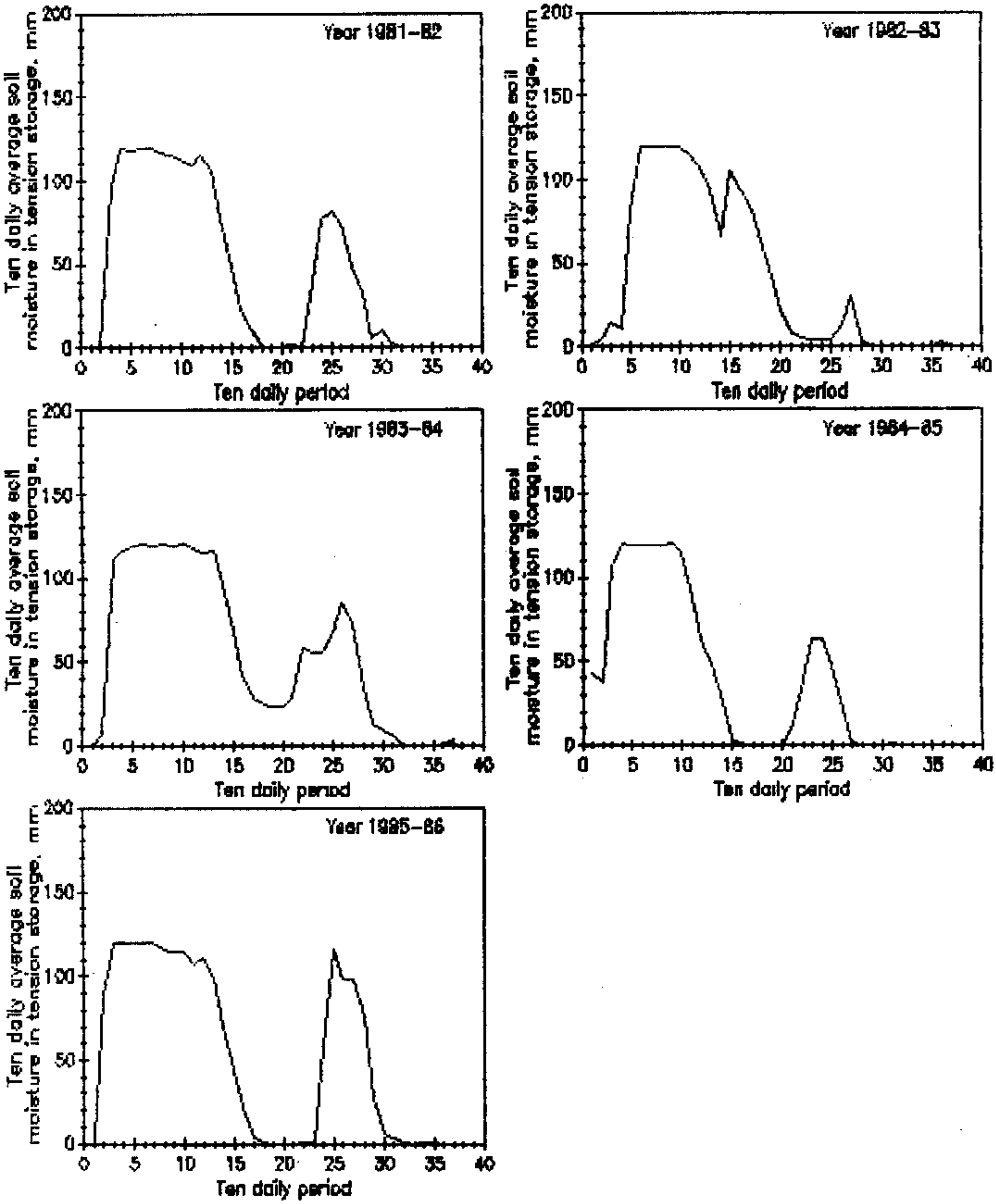

Fig. 9. Ten daily average soil moisture in tension storage from June 1 at Banjar sub-basin of Narmada during simulation.

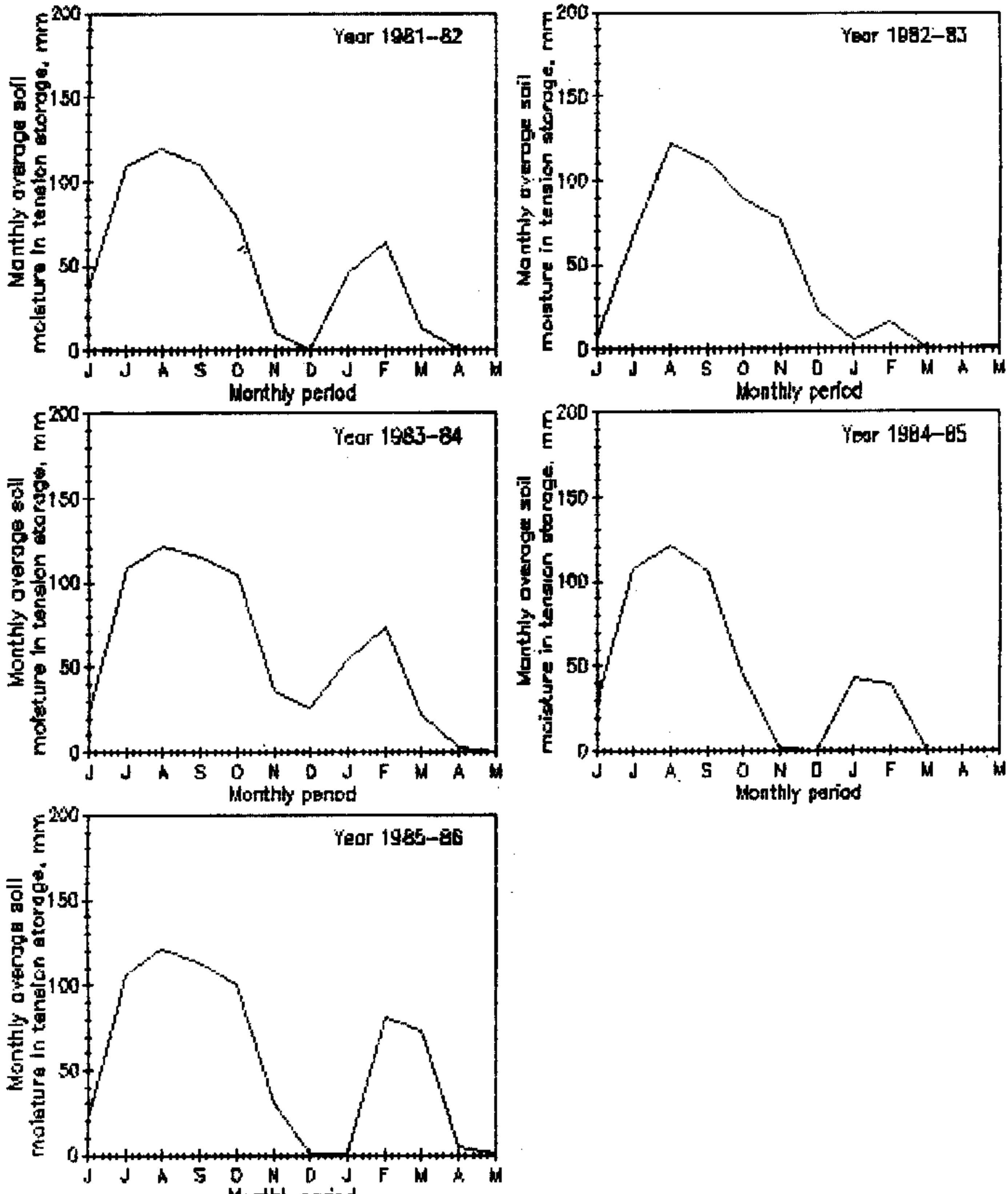

Fig.10. Monthly average soil moisture in tension storage from June 1 at Banjar sub–basin of Naramada during simulation.

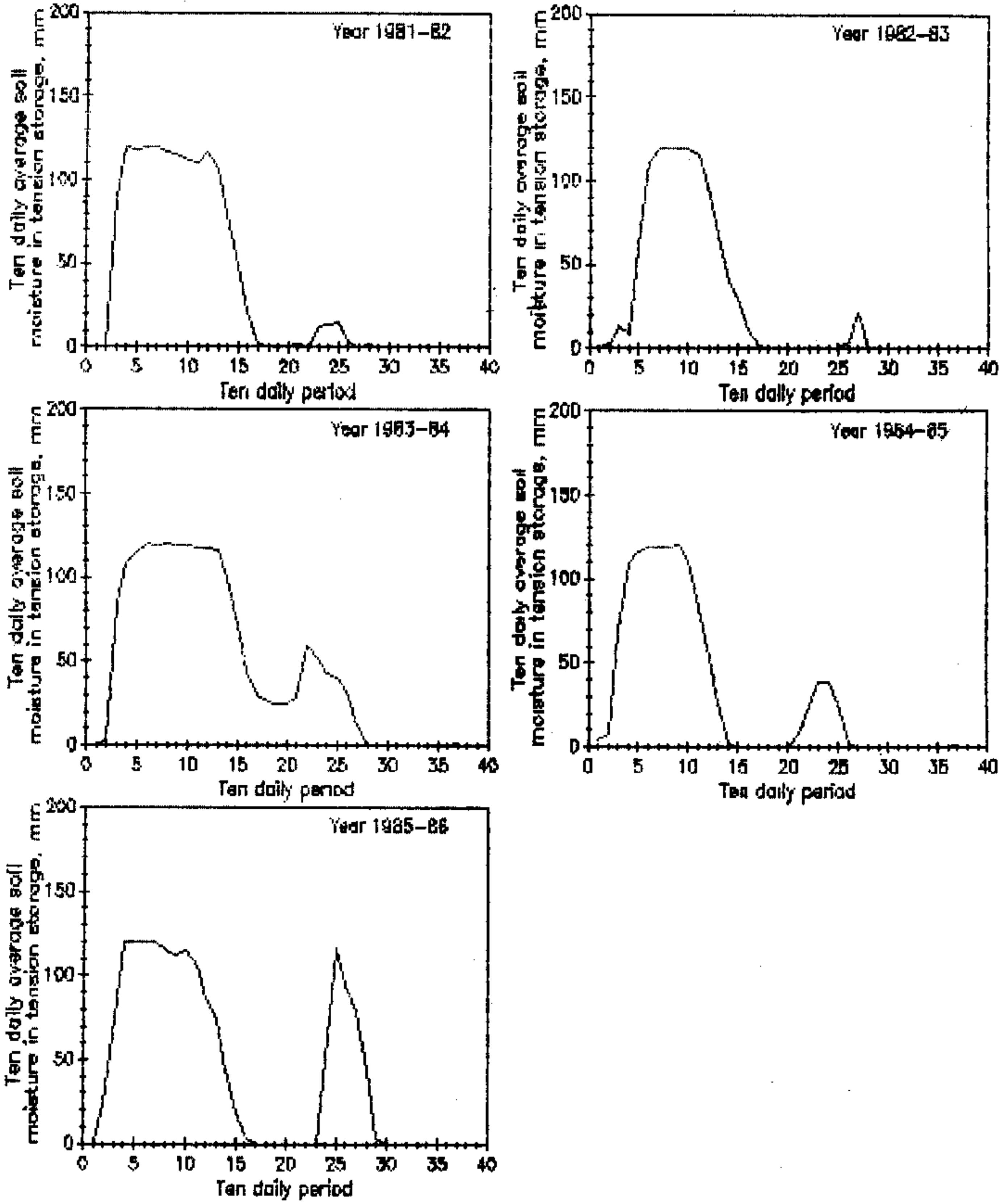

Fig. 11. Ten daily average soil moisture in tension storage from June 1 at Burhner subbasin. of Naramada during simulation.

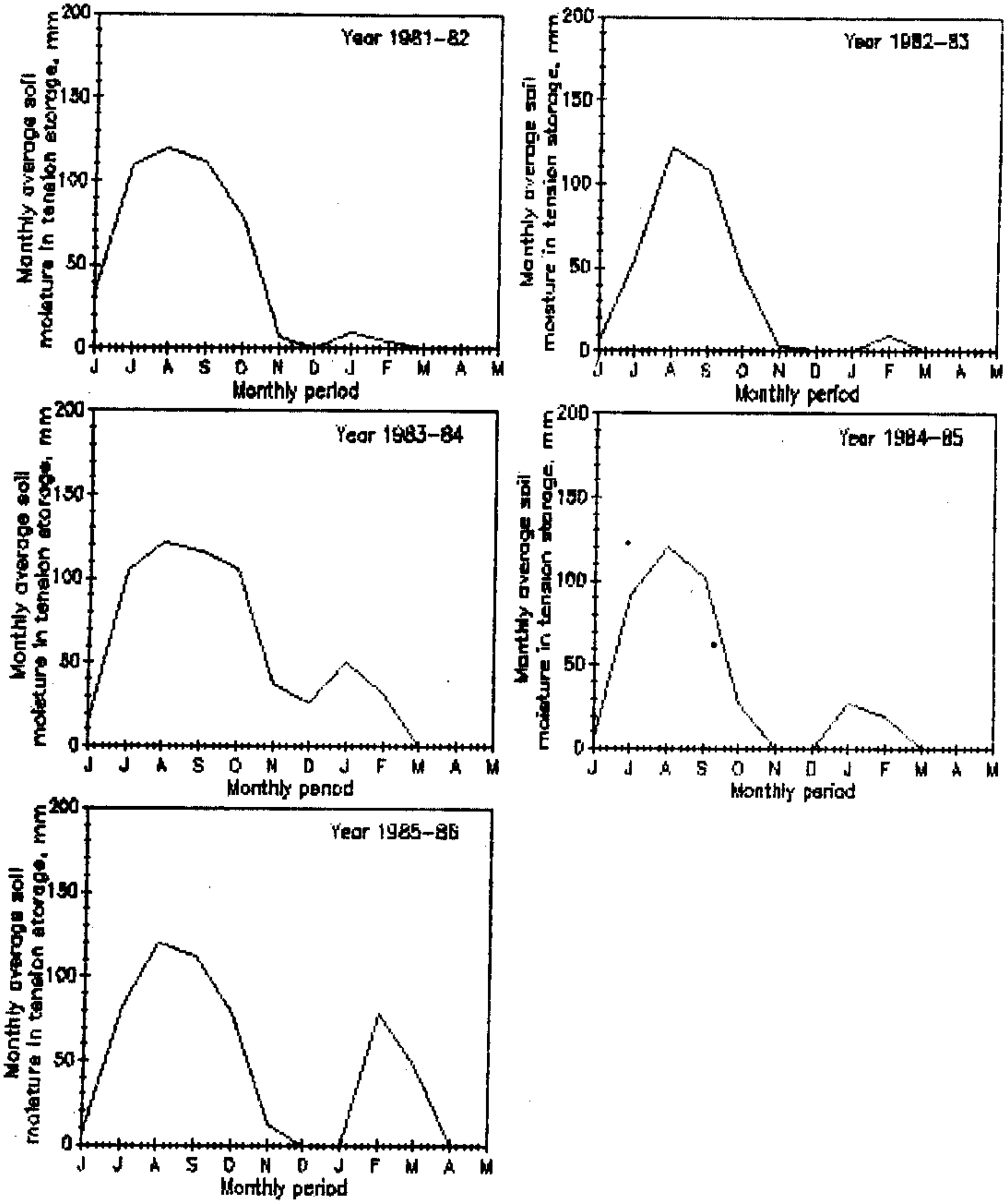

Fig.12. Monthly average soil moisture in tension storage from June 1 at Burhner subbasin of Naramada during simulation.

Table 5: Total annual rainfall (mm), portion of rainfall used in soil moisture (mm), rainfall resulting runoff (mm) and runoff (mm).

Year	Total annual rainfall (mm)	Portion of rainfall used for soil moisture storage. (mm)	Portion of rainfall resulting runoff. (mm)	Observed runoff (mm)
Banjar sub-basin				
1981-82	2257.40	663.94	1593.46	309.45
1982-83	2076.20	648.81	1427.39	301.47
1983-84	2678.90	686.07	1992.83	362.57
1984-85	1490.80	682.50	808.30	248.54
1985-86	1633.20	772.59	860.61	287.15
Burhner sub-basin				
1981-82	1311.50	550.56	760.94	329.63
1982-83	1172.50	528.35	644.15	333.66
1983-84	1590.50	622.77	967.73	474.15
1984-85	1358.20	544.68	813.52	517.98
1985-86	1334.40	649.98	684.42	600.57

5.5 Verification of Model

For the verification of the model, the data of years 1986-87 and 1988-89 to 1989-90 is considered. In case of Banjar sub-basin, the daily discharge data is estimated from the daily gauge values using gauge discharge curve of the year 1985-86. The efficiencies of the model during verification are reported in Table 6.

The observed efficiencies and the reported figures 13 and 14, indicates a good fit between observed and estimated runoff during the verification of the model. An increase in model efficiency and a decrease in index of volumetric fit is observed as compared to the simulation efficiencies. It might be happening because, lesser numbers of data length is verified as compared to data length used for the process of simulation of the model.

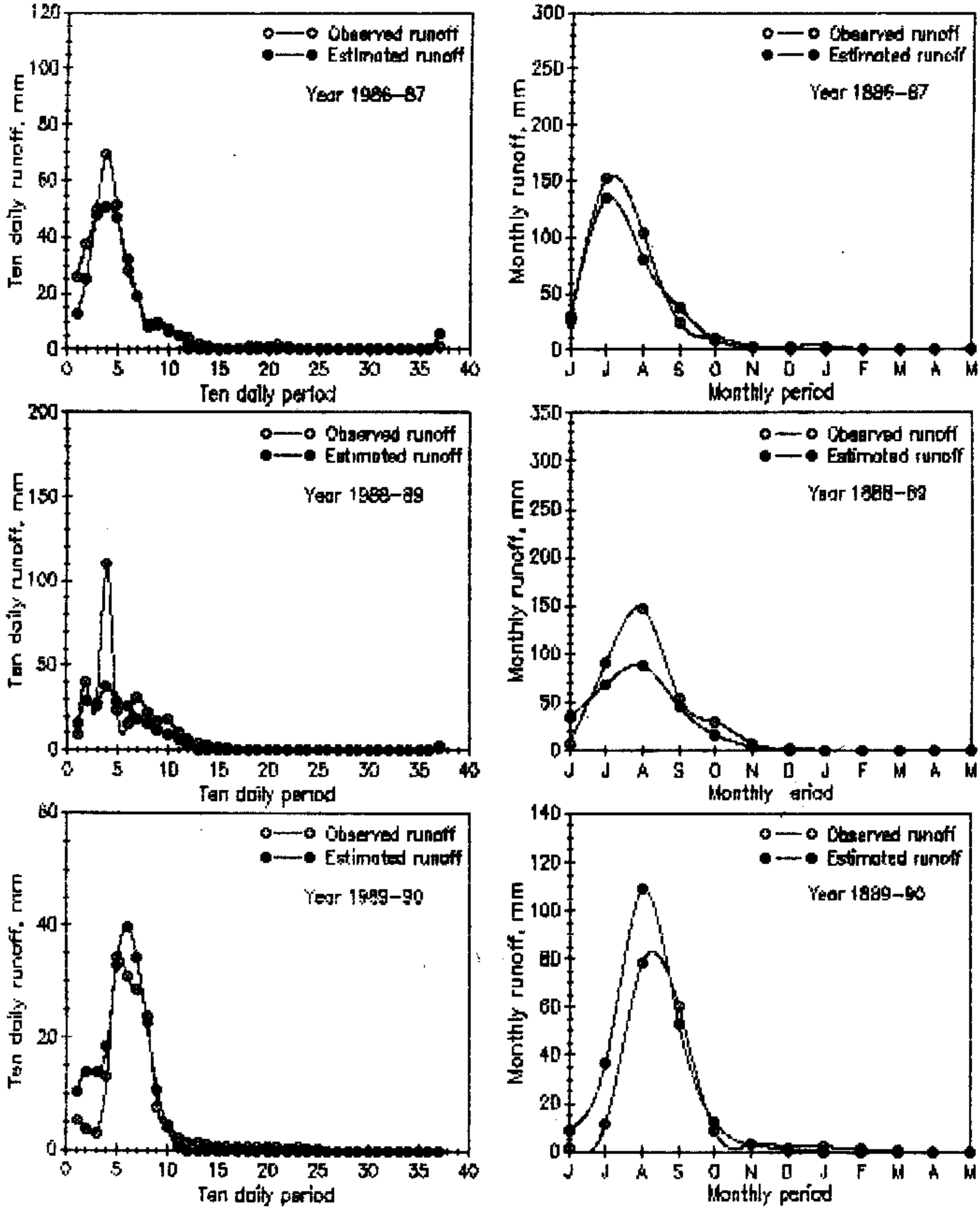

Fig. 13. Ten daily and monthly observed and estimated runoff from June 1 at site Hridaynagar of Narmada during verification.

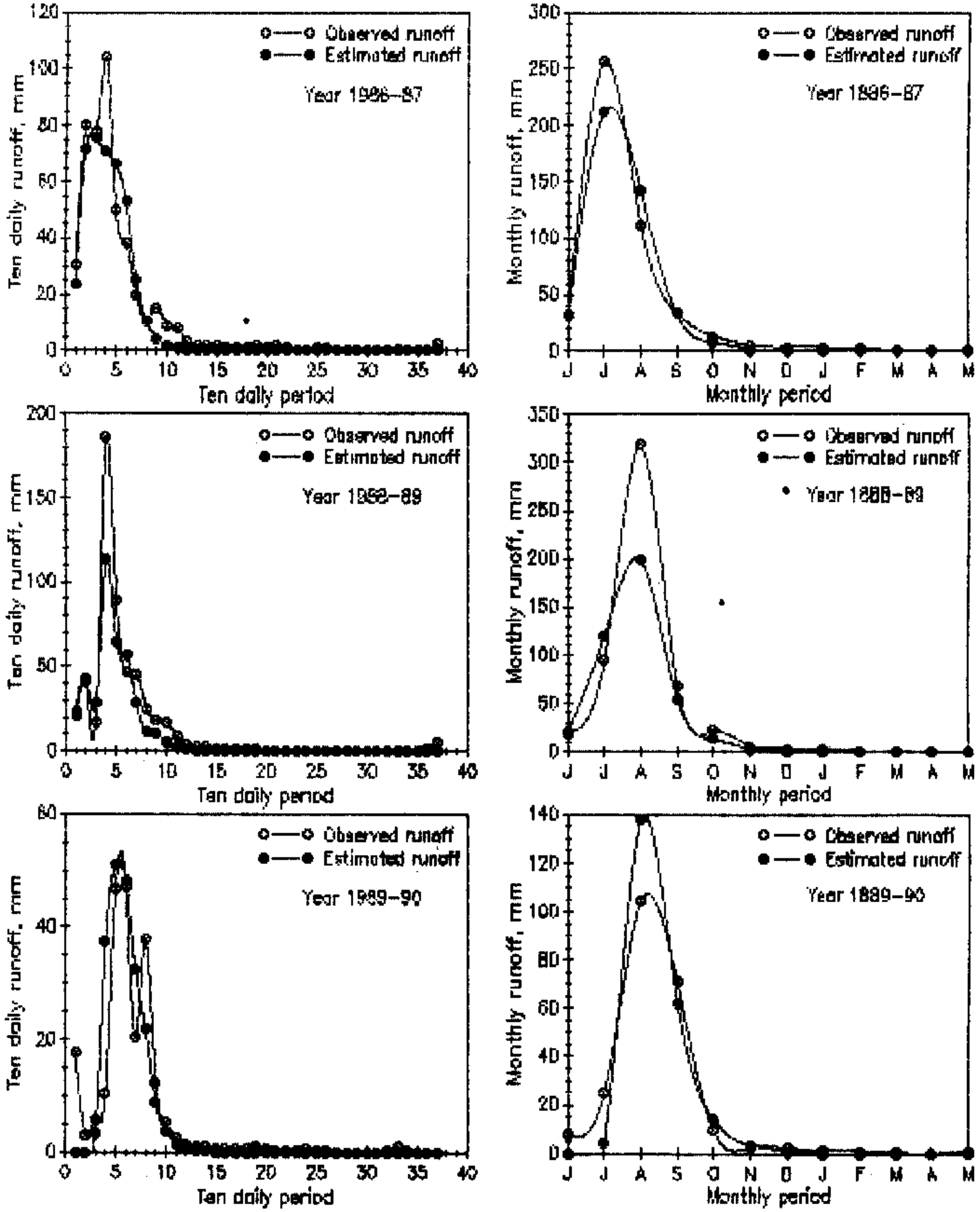

Fig. 14. Ten daily and monthly observed and estimated runoff from June 1 at site Mohagaon of Naramada during verification.

Table 6: Results of the verification of simple linear model for Banjar and Burhner sub-basins.

Model	Order	Efficiencies of the model R^2	IVF
Banjar sub-basin			
Daily	(3,2)	.55	.75
Ten daily	(1,3)	.73	.85
Monthly	(1,1)	.87	.92
Burhner sub-basin			
Daily	(3,2)	.59	.73
Ten daily	(2,2)	.84	.75
Monthly	(1,1)	.88	.85

6.0: RESULTS AND DISCUSSION

The daily rainfall and runoff data of the period from 1981-82 to 1985-86 is used for the simulation of the runoff. It can be seen from Table 3 That the autoregressive order of the model for Banjar sub-basin is found 3 for daily, one for ten daily and one for monthly model. It indicates that the runoff is dependent on more than one previous values of rainfall in daily model and on one previous value in ten daily and monthly model. The moving average parameter are 2, 3 and 1 respectively for daily, ten daily and monthly model. It indicates that the runoff at current time is dependent on two previous values in daily, three previous values in ten daily and one previous value in monthly model.

In Burhner basin the autoregressive orders are (3,2,1) and moving average orders are (2,2,1). The order of the model decreases with change of model form daily to ten daily to monthly model. The similar trend is not observed with the banjar basin in case of the ten daily model and suggest for a modification in selection of the model order based on the judgement to have a better efficiency during the process of simulation and verification of the model.

The efficiencies (Table 4) of model with total rainfall and with the rainfall separation for soil moisture in tension storage is found increasing in both the test catchments. On an average a five percent increase in the model efficiency is observed by providing a separation for soil moisture in tension storage. The efficiency of the model is also found increasing with averaging the time period from daily to ten daily to monthly. In case of daily model a higher value of the index of volumetric fit and lower model efficiency is possibly because, the values of the daily runoff record are measured at 8.00 A.M. and does not represent as an average daily flow of the day. However, the averaging process in ten daily and monthly model reduces the effect of a single value taken as an average of the day and, therefor, results in higher model efficiency with a fairly good index of volumetric fit.

7.0: CONCLUSION

The simple linear model could be applied to total rainfall to simulate total runoff in arid and semi arid regions in which the major cause of the nonlinearity in the process is due to the combined effect of interception, depression storage and soil moisture in tension storage. For the application of simple linear model, it is necessary to split the total rainfall into a nonlinear and relatively linear component. The nonlinear component of the rainfall represents the amount of soil moisture which is released back to atmosphere and thus could represent the average soil moisture condition in the basin. The modelling with the linear component of rainfall results an increase in the efficiency of the model without loosing index of volumetric fit.

8.0: REFERENCES

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```
$debug
$large
C       PROGRAMME CAN HANDLE DAILY DATA OF MAXIMUM TEN YEARS.
C       STARTING DAY SHOULD BE THE MONTH OF JUNE.
C       CUM  =Maximum available tension water storage, mm.
C       AREA =Catchment area of sub-catchment.
C       R    =Weighted rainfall of Mandla, mm.
C       Q    =Observed runoff at Hridaynagar, m3/sec.
C       PAN  =Average Daily pan evaporation, mm.
C       AMD  =Available tension water in soil, mm.
C       ER   =Excess rainfall, mm.
C       IQQ  =Runoff operator (Optional).
C       IRA  =Rainfall operator (Optional).
        DIMENSION R(3650),PAN(3650),AMD(3650),CU(3650),
     1ER(3650),QQ(3650),Q(3650),ERT(370),QT(370),AMDT(370),
     1ERM(120),QM(120),AMDM(120),QRM(120),ERA(10),QA(10),
     1AMDA(10),RT(370),RM(120),RA(10),QRA(12)
        OPEN(UNIT=1,FILE='RAIN.OUT',STATUS='OLD')
        OPEN(UNIT=2,FILE='DIS.DAT',STATUS='OLD')
        OPEN(UNIT=3,FILE='D',STATUS='UNKNOWN')
        OPEN(UNIT=4,FILE='T',STATUS='UNKNOWN')
        OPEN(UNIT=5,FILE='M',STATUS='UNKNOWN')
        OPEN(UNIT=6,FILE='A',STATUS='UNKNOWN')
   79   FORMAT(5F10.2)
   80   FORMAT('Daily observed and estimated runoff')
   81   FORMAT('Time in days')
   82   FORMAT('Ten daily observed and estimate runoff')
   83   FORMAT('Time in ten daily')
   84   FORMAT('Monthly observed and estimated runoff')
   85   FORMAT('Time in months')
   86   FORMAT('Discharge')
   87   FORMAT('6 2 5 2')
   88   FORMAT('13 4 5 2')
   89   FORMAT('6 2 4 2')
   95   FORMAT(4F10.2)
   67   FORMAT(6F10.2)
c   96  FORMAT(8X,F8.1)
c   76  FORMAT(8X,F8.1,16X,F8.1)
C       For Mohegaon use the formats given below.
   96   FORMAT(16X,F8.1)
   76   FORMAT(16X,F8.1,8X,F8.1)
   97   FORMAT(6I5)
   98   FORMAT(7F10.2)
   99   FORMAT(9X,'R',7X,'PAN',8X,'PA',7X,'AMD',8X,'CU',8X,'ER',9X,'Q')
        READ(2,*)CUM
```

```
      READ(2,97)IRR,ID,IW,IMO,IQQ,IRA
      READ(2,76)AREA
      READ(2,76)(QQ(IR),PAN(IR),IR=1,IRR)
      write(6,76)AREA
C     CONVERTING M3/SEC TO MM/DAY.
      DO 101 IR=1,IRR
  101 Q(IR)=60.0*60.0*24.0*1000*QQ(IR)/(AREA*1000.0*1000.0)
      READ(1,96)(R(IR),IR=1,IRR)
C     If CUM=0.0;  ER=R
      IF(CUM-1)303,302,302
  303 CUM=CUM
      DO 304 IR=1,IRR
      ER(IR)=R(IR)
  304 AMD(IR)=0.0
  302 IF(CUM-1)305,306,306
  306 CUM=CUM
C     CALCULATION FOR RAINFALL MINUS SOIL MOISTURE.
      DO 102 IR=1,IRR
  102 PAN(IR)=0.8*PAN(IR)
      ER(1)=0.
      AMD(1)=0.
      CU(1)=CUM
      NSS=1
      DO 103 IR=2,IRR
      NSP=IR-NSS
      IF(CU(IR-1)-CUM)104,104,105
  104 AMD(IR)=((0.9)**NSP)*AMD(IR-1)
      IF(AMD(IR)-PAN(IR))106,107,107
  107 AMD(IR)=PAN(IR)
  106 AMD(IR)=AMD(IR)
      CU(IR)=CU(IR-1)+AMD(IR)
  105 IF(CU(IR)-CUM)108,108,109
  109 CU(IR)=CUM
  108 AMD(IR)=CUM-CU(IR)
      C=R(IR)
      IF(C)110,110,111
  111 NSS=IR
      A=CU(IR)
      B=R(IR)
      IF(A-B)112,113,113
  113 ER(IR)=0
      CU(IR)=CU(IR)-R(IR)
      AMD(IR)=CUM-CU(IR)
  112 IF(A-B)114,110,110
  114 ER(IR)=R(IR)-CU(IR)
      CU(IR)=0.
      AMD(IR)=CUM
  110 IF(C)115,115,103
```

```
  115 ER(IR)=0.
  103 CONTINUE
  305 CUM=CUM
      WRITE(3,97)IQQ,IRR,ID,IQQ,IRA
      WRITE(3,67)(R(IR),ER(IR),Q(IR),QQ(IR),AMD(IR),PAN(IR),IR=1,IRR)
      WRITE(3,80)
      WRITE(3,81)
      WRITE(3,86)
      WRITE(3,87)
C     CONVERTING DAILY DATA TO TEN DAILY DATA.
      SR=0.
      SER=0.
      SQ=0.
      SAMD=0.
      NNN=0
      I=1
      IT=1
      ILD=0
      DO 121 IR=1,IRR
      ITEN=10
      ILD=ILD+1
      IF(ILD-365)116,116,117
  116 SR=SR+R(IR)
      SER=SER+ER(IR)
      SQ=SQ+Q(IR)
      SAMD=SAMD+AMD(IR)
      NNN=NNN+1
      RT(I)=SR
      ERT(I)=SER
      QT(I)=SQ
      AMDT(I)=SAMD
      IF(IT-37)118,119,119
  119 ITEN=5
  118 ITEN=ITEN
      IF(NNN-ITEN)117,120,120
  120 NNN=0
      RT(I)=RT(I)
      ERT(I)=ERT(I)
      QT(I)=QT(I)
      AMDT(I)=AMDT(I)/ITEN
      IT=IT+1
      I=I+1
      SR=0.
      SER=0.
      SQ=0.
      SAMD=0.
  117 IF(ILD-365)121,122,122
  122 ILD=0
```

```
      IT=0
  121 CONTINUE
      II=(IRR/365)*37
      WRITE(4,97)IQQ,II,IW,IQQ,IRA
      WRITE(4,95)(RT(I),ERT(I),QT(I),AMDT(I),I=1,II)
      WRITE(4,82)
      WRITE(4,83)
      WRITE(4,86)
      WRITE(4,88)
C     CONVERTING DAILY DATA TO MONTHLY DATA.
      IMM=IRR*12/365
      DO 221 IM=1,IMM
      RM(IM)=0.
      ERM(IM)=0.
      QM(IM)=0.
  221 AMDM(IM)=0.
      IP=0
      IM=1
      DO 222 IR=1,IRR
      RM(IM)=RM(IM)+R(IR)
      ERM(IM)=ERM(IM)+ER(IR)
      QM(IM)=QM(IM)+Q(IR)
      AMDM(IM)=AMDM(IM)+AMD(IR)
      IPP=IR-IP
      IF(IPP-31)222,223,224
  223 IM=IM+1
  224 IF(IPP-59)222,225,226
  225 IM=IM+1
  226 IF(IPP-90)222,227,228
  227 IM=IM+1
  228 IF(IPP-120)222,229,230
  229 IM=IM+1
  230 IF(IPP-151)222,231,232
  231 IM=IM+1
  232 IF(IPP-181)222,233,234
  233 IM=IM+1
  234 IF(IPP-212)222,235,236
  235 IM=IM+1
  236 IF(IPP-243)222,237,238
  237 IM=IM+1
  238 IF(IPP-273)222,239,240
  239 IM=IM+1
  240 IF(IPP-304)222,241,242
  241 IM=IM+1
  242 IF(IPP-334)222,243,244
  243 IM=IM+1
  244 IF(IPP-365)222,245,245
  245 IM=IM+1
```

```
      IP=IP+365
  222 CONTINUE
      WRITE(5,97)IQQ,IMM,IMO,IQQ,IRA
      DO 301 IM=1,IMM
      RM(IM)=RM(IM)
      ERM(IM)=ERM(IM)
      QM(IM)=QM(IM)
  301 AMDM(IM)=AMDM(IM)/30.5
      DO 132 IM=1,IMM
      IF (RM(IM))130,130,131
  130 QRM(IM)=0.0
  131 IF(RM(IM))132,132,134
  134 QRM(IM)=QM(IM)/RM(IM)
  132 CONTINUE
      WRITE(5,79)(RM(IM),ERM(IM),QM(IM),AMDM(IM),QRM(IM),IM=1,IMM)
      WRITE(5,84)
      WRITE(5,85)
      WRITE(5,86)
      WRITE(5,89)
      CONVERTING MONTHLY DATA TO ANNUAL DATA.
      IAA=IRR/ID
      IIA=1
      RA(IIA)=0.
      ERA(IIA)=0.
      QA(IIA)=0.
      AMDA(IIA)=0.
      NS=0
      DO 124 IR=1,IRR
      ISP=IR-NS
      IF(ISP-365)125,125,126
  126 NS=NS+365
      IIA=IIA+1
      RA(IIA)=0.
      ERA(IIA)=0.
      QA(IIA)=0.
      AMDA(IIA)=0.
  125 RA(IIA)=RA(IIA)+R(IR)
      ERA(IIA)=ERA(IIA)+ER(IR)
      QA(IIA)=QA(IIA)+Q(IR)
      AMDA(IIA)=AMDA(IIA)+AMD(IR)
  124 CONTINUE
      DO 127 IIA=1,IAA
      RA(IIA)=RA(IIA)
      ERA(IIA)=ERA(IIA)
      QA(IIA)=QA(IIA)
  127 AMDA(IIA)=AMDA(IIA)/365
      DO 133 IIA=1,IAA
  133 QRA(IIA)=QA(IIA)/RA(IIA)
```

```
WRITE(6,79)(RA(IIA),ERA(IIA),QA(IIA),AMDA(IIA),QRA(IIA),IIA=1,IAA)
STOP
END
```

```
$large
C      THIS PROGRAMME USES THE OUT PUT OF SOIL.FOR
C      LTF: THE PROGRAMME IS FOR LINEAR TRANSFER FUNCTION MODELLING
C      PROGRAMME CAN HANDLE DAILY DATA OF MAXIMUM FIVE YEARS
C      CAN HANDLE MAXIMUM TEN MEMORY LENGTH
       DIMENSION R(1825),ER(1825),Q(1825),AMD(1825),RMQ(1825,5),
      1RMP(1825,5),RM(1825,10),CON(10),CONQ(5),CONP(5),QE(1825),
      1RMTRMI(10,10),VAR(10),SE(10),Q1(365),QE1(365),TIME1(365)
       COMMON CON,RMTRMI
       CHARACTER*12 INFIL,OUFIL,ibns*1
       WRITE(*,22)
    22 FORMAT(5X,'INPUT FILE NAME?')
       READ(*,32)INFIL
    32 FORMAT(A)
       WRITE(*,21)
    21 FORMAT(5X,'OUTPUT FILE NAME?')
       READ(*,32)OUFIL
       OPEN(UNIT=1,FILE=INFIL,STATUS='OLD')
       OPEN(UNIT=2,FILE=OUFIL,STATUS='UNKNOWN')
    83 FORMAT(12X,'Observed',1X,'Estimated',2X,'Rainfall',1X,
      1'Rain excess',1X,'Moisture')
    85 FORMAT(I10,5F10.2)
    86 FORMAT('Runoff coefficients')
    87 FORMAT('Rainfall coefficients')
    88 FORMAT(5X,4I5)
    89 FORMAT('Gain factor')
    90 FORMAT('Ro square')
    91 FORMAT('Variance of coefficients of LTF')
    92 FORMAT('Standard error of coefficients of LTF')
    93 FORMAT('Operators of linear function model')
    94 FORMAT(4F15.5)
    95 FORMAT(10F8.2)
    97 FORMAT(/)
    98 FORMAT(4F10.2)
    99 FORMAT(10F8.3)
       READ(1,88)IRR,IG,IQQ,IPP
C      IQQ : Autoregessive operators associated with runoff
C      IRR : Moving average operators associated with rainfall
       ICC=IQQ+IPP
       READ(1,98)(R(IR),ER(IR),Q(IR),AMD(IR),IR=1,IRR)
C      FORMULATION OF THE MATRIX
       DO 101 IR=1,IRR
       DO 102 IQ=1,IQQ
       IF(IR-IQ)103,103,104
   103 RMQ(IR,IQ)=0.0
```

```
  104 IF(IR-IQ)102,102,105
  105 RMQ(IR,IQ)=Q(IR-IQ)
  102 CONTINUE
  101 CONTINUE
      DO 106 IR=1,IRR
      DO 107 IP=1,IPP
      IF(IR-IP)108,109,109
  108 RMP(IR,IP)=0.0
  109 IF(IR-IP)107,110,110
  110 RMP(IR,IP)=ER(IR-IP+1)
  107 CONTINUE
  106 CONTINUE
      DO 111 IR=1,IRR
      DO 112 IC=1,ICC
      IF(IQQ-IC)113,114,114
  114 RM(IR,IC)=RMQ(IR,IC)
  113 IF(IQQ-IC)131,112,112
  131 RM(IR,IC)=RMP(IR,IC-IQQ)
  112 CONTINUE
  111 CONTINUE
      CALL LSE(RM,Q,ICC,IRR)
      WRITE(2,93)
      WRITE(2,99)(CON(IC),IC=1,ICC)
      DO 115 IC=1,ICC
      IF(IQQ-IC)117,116,116
  116 CONQ(IC)=CON(IC)
  117 IF(IQQ-IC)135,115,115
  135 CONP(IC-IQQ)=CON(IC)
  115 CONTINUE
      WRITE(2,86)
      WRITE(2,99)(CONQ(IQ),IQ=1,IQQ)
      WRITE(2,87)
      WRITE(2,99)(CONP(IP),IP=1,IPP)
C     CALCULATION OF GAIN FACTOR
      XQ=0.
      DO 118 IQ=1,IQQ
  118 XQ=XQ+CONQ(IQ)
      XR=0.
      DO 119 IP=1,IPP
  119 XR=XR+CONP(IP)
      GF=XR/(1-XQ)
      WRITE(2,89)
      WRITE(2,99)GF
C     ESTIMATION OF DISCHARGE WITH RAINFALL
      CALL EOF(IRR,IQQ,IPP,CONQ,CONP,ER,QE)
C     CHECKING OF MODEL
      RO=0.0
      DO 126 IR=ICC,IRR
```

```
  126 RO=RO+((Q(IR)-QE(IR))**2)
      ROS=RO/(IRR-(2*(IPP-1))+1)
      WRITE(2,90)
      WRITE(2,*)ROS
C     ESTIMATION OF VARI. AND S.E. TO DECIDE MODEL ORDER
      DO 127 IC=1,ICC
      VAR(IC)=RMTRMI(IC,IC)*ROS
  127 SE(IC)=SQRT(VAR(IC))
      WRITE(2,91)
      WRITE(2,99)(VAR(IC),IC=1,ICC)
      WRITE(2,92)
      WRITE(2,99)(SE(IC),IC=1,ICC)
      WRITE(2,97)
C     TESTING OF THE MODEL ( EVALUATION CRITERIA OF NASH )
      CALL TTM(ICC,IRR,Q,QE)
      WRITE(2,97)
      WRITE(2,83)
      WRITE(2,85)(IR,Q(IR),QE(IR),R(IR),ER(IR),AMD(IR),IR=1,IRR)
C     VERIFICATION OF THE MODEL
C     IRR = DATA LENGTH FOR VERIFICATION
      READ(1,*)IRR
      READ(1,98)(R(IR),ER(IR),Q(IR),AMD(IR),IR=1,IRR)
      CALL EOF(IRR,IQQ,IPP,CONQ,CONP,ER,QE)
C     TESTING OF THE MODEL ( EVALUATION CRITERIA OF NASH )
      CALL TTM(ICC,IRR,Q,QE)
      WRITE(2,97)
      WRITE(2,83)
      WRITE(2,85)(IR,Q(IR),QE(IR),R(IR),ER(IR),AMD(IR),IR=1,IRR)
      STOP
      END
C
C
C     SUBROUTINE FOR LEAST SQUARE ESTIMATES
      SUBROUTINE LSE(RM,Q,ICC,IRR)
      DIMENSION RM(1825,10),RMV(18250),RMTV(18250),RMTRM(10,10),
     1RMTRMV(100),RMTRMI(10,10),Q(1825),CON(10)
      COMMON CON,RMTRMI
   98 FORMAT('Determinant of the matrix,RMTRM')
   99 FORMAT(10F8.2)
      NUM=0
      DO 101 IC=1,ICC
      DO 102 IR=1,IRR
      NUM=NUM+1
  102 RMV(NUM)=RM(IR,IC)
  101 CONTINUE
C     TRANSPOSE OF A GENERAL MATRIX
      CALL GMTRA(RMV,RMTV,IRR,ICC)
C     MULTIPLICATION OF RMT AND RM MATRIXES
```

```
      CALL GMPRD(RMTV,RMV,RMTRMV,ICC,IRR,ICC)
      NUM=0
      DO 103 IJ=1,ICC
      DO 104 IK=1,ICC
      NUM=NUM+1
  104 RMTRM(IJ,IK)=RMTRMV(NUM)
  103 CONTINUE
C     INVERSION OF THE MATRIX,'RMTRM'TO FORM RMTRMI
      CALL MINV(RMTRMV,ICC,DDD)
      WRITE(2,98)
      WRITE(2,*)DDD
      NUM=0
      DO 105 IJ=1,ICC
      DO 106 IK=1,ICC
      NUM=NUM+1
  106 RMTRMI(IJ,IK)=RMTRMV(NUM)
  105 CONTINUE
C     MULTIPLICATION OF RMTRMI AND RMT TO FORM AAA
      NUM=0
      DO 107 IR=1,IRR
      DO 108 IC=1,ICC
      NUM=NUM+1
  108 RMTV(NUM)=RM(IR,IC)
  107 CONTINUE
C     RMV IS REUSED TO REDUCE MEMORY
      CALL GMPRD(RMTRMV,RMTV,RMV,ICC,ICC,IRR)
C     MULTIPLICATION OF RMV AND Q TO FORM RESULTS
      IAB=1
      NUM=0
      CALL GMPRD(RMV,Q,CON,ICC,IRR,IAB)
      RETURN
      END
C     TRANSPOSE OF A GENERAL MATRIX
      SUBROUTINE GMTRA(A,R,N,M)
      DIMENSION A(1),R(1)
      IAR=0
      DO 100 I=1,N
      IJ=I-N
      DO 100 J=1,M
      IJ=IJ+N
      IAR=IAR+1
  100 R(IAR)=A(IJ)
      RETURN
      END
C     INVERSION OF THE MATRIX
      SUBROUTINE MINV(A,N,D)
      DIMENSION A(100),L(100),M(100)
C     SEARCH FOR LARGEST ELEMENT
```

```
      D=1.0
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
   10 IF(ABS(BIGA)-ABS(A(IJ))) 15,20,20
   15 BIGA=A(IJ)
      L(K)=I
      M(K)=J
   20 CONTINUE
C     INTERCHANGE ROWS
      J=L(K)
      IF(J-K) 35,35,25
   25 KI=K-N
      DO 30 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
   30 A(JI)=HOLD
C     INTERCHANGE COLUMNS
   35 I=M(K)
      IF(I-K)45,45,38
   38 JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   40 A(JI)=HOLD
C     DIVIDE COLUMNS BY MINUS PIVOT
   45 IF(BIGA)48,46,48
   46 D=0.0
      RETURN
   48 DO 55 I=1,N
      IF(I-K)50,55,50
   50 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
   55 CONTINUE
C     REDUCE MATRIX
      DO 65 I=1,N
```

```
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 65 J=1,N
      IJ=IJ+N
      IF(I-K)60,65,60
   60 IF(J-K)62,65,62
   62 KJ=IJ-I+K
      A(IJ)=HOLD*A(KJ)+A(IJ)
   65 CONTINUE
C     DIVIDE ROW BY PIVOT
      KJ=K-N
      DO 75 J=1,N
      KJ=KJ+N
      IF(J-K)70,75,70
   70 A(KJ)=A(KJ)/BIGA
   75 CONTINUE
C     PRODUCT OF PIVOTS
      D=D*BIGA
C     REPLACE PIVOT BY RECIPROCAL
      A(KK)=1.0/BIGA
   80 CONTINUE
C     FINAL ROW AND COLUMN INTERCHANGE
      K=N
  100 K=(K-1)
      IF(K)150,150,105
  105 I=L(K)
      IF(I-K)120,120,108
  108 JQ=N*(K-1)
      JR=N*(I-1)
      DO 110 J=1,N
      JK=JQ+J
      HOLD=A(JK)
      JI=JR+J
      A(JK)=-A(JI)
  110 A(JI)=HOLD
  120 J=M(K)
      IF(J-K)100,100,125
  125 KI=K-N
      DO 130 I=1,N
      KI=KI+N
      HOLD=A(KI)
      JI=KI-K+J
      A(KI)=-A(JI)
  130 A(JI)=HOLD
      GO TO 100
  150 RETURN
      END
```

```
C     MULTIPLICATION OF THE MATRIX
      SUBROUTINE GMPRD(A,B,R,N,M,L)
      DIMENSION A(1),B(1),R(1)
   97 FORMAT(/)
   99 FORMAT(10F7.2)
      IR=0
      IK=-M
      DO 100 K=1,L
      IK=IK+M
      DO 100 J=1,N
      IR=IR+1
      JI=J-N
      IB=IK
      R(IR)=0
      DO 100 I=1,M
      JI=JI+N
      IB=IB+1
  100 R(IR)=R(IR)+(A(JI)*B(IB))
      NM=N*M
      ML=M*L
      NL=N*L
      RETURN
      END
C     SUBROUTINE FOR ESTIMATION OF DISCHARGE WITH RAINFALL
      SUBROUTINE EOF(IRR,IQQ,IPP,CONQ,CONP,ER,QE)
      DIMENSION CONQ(5),CONP(5),ER(1825),QE(1825)
      DO 120 IR=1,IRR
      SUQ=0.
      SUR=0.
      DO 121 IQ=1,IQQ
      IF(IR-IQ)121,121,123
  123 SUQ=SUQ+QE(IR-IQ)*CONQ(IQ)
  121 CONTINUE
      DO 124 IP=1,IPP
      IF(IR-IP)124,125,125
  125 SUR=SUR+ER(IR-IP+1)*CONP(IP)
  124 CONTINUE
      QE(IR)=SUQ+SUR
  120 CONTINUE
      RETURN
      END
C     SUBROUTINE FOR THE TESTING OF MODEL
      SUBROUTINE TTM(ICC,IRR,Q,QE)
      DIMENSION Q(1825),QE(1825)
   80 FORMAT('Index of volumetric fit')
   81 FORMAT('MSE (Residual variance); Initial variance; Efficiency')
   82 FORMAT(4F15.5)
      BMSE=0.0
```

```
      DO 128 IR=ICC,IRR
  128 BMSE=BMSE+((Q(IR)-QE(IR))**2)
      BMSE=BMSE/(IRR-ICC)
      SUMO=0.0
      DO 129 IR=ICC,IRR
  129 SUMO=SUMO+Q(IR)
      SUME=0.0
      DO 130 IR=ICC,IRR
  130 SUME=SUME+QE(IR)
      AIVF=SUME/SUMO
      AMEAN=SUMO/(IRR-ICC)
      FO=0.0
      DO 132 IR=ICC,IRR
  132 FO=FO+((Q(IR)-AMEAN)**2)
      FO=FO/(IRR-ICC)
      RSQ=1-(BMSE/FO)
      WRITE(2,81)
      WRITE(2,82)BMSE,FO,RSQ
      WRITE(2,80)
      WRITE(2,82)SUME,SUMO,AIVF
      RETURN
      END
```

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